2022 8th International Conference of the Immersive Learning Research Network (iLRN)

May 30 – June 4, 2022
Vienna, Austria and Online

Conference Proceedings

DISRUPTION, INNOVATION & RESILIENCY: becoming an inclusive & robust global community for immersive learning

Educational Technology • Pedagogy x Computer Science • Serious Games • 3D Collaboration • Digital Twins • Embodied Pedagogical Agents • Medical & Healthcare Education • Workforce & Industry • Cultural Heritage • Language Learning • K-12 STEM • Museums & Libraries • Informal Learning • Community & Civic Engagement • Special Education • Geosciences • Data Visualization and Analytics • Assessment & Evaluation

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Proceedings of
2022 8th International Conference of the Immersive Learning Research Network (iLRN)

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Date and Venue
Vienna, Austria and Online.

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iLRN 2022 Preface

The 8th annual International Conference of the Immersive Learning Research Network (iLRN2022) was the first iLRN event to offer a hybrid experience, with two days of presentations and activities on the iLRN Virtual Campus (powered by ©Virbela), followed by three days on location at the FH University of Applied Sciences BFI in Vienna, Austria.

Following two years of innovative fully online and in-VR conferences at the 2021 and 2020 editions, this year's conference offered scholars and professionals working from informal and formal education settings, as well as those representing diverse industry sectors, the opportunity to share their research findings, experiences, and insights; to network and establish partnerships to envision and shape the future of XR and immersive technologies for learning; and to contribute to the emerging scholarly knowledge base on how these technologies can be used to create experiences that educate, engage, and excite learners.

To achieve this, iLRN invited scientists, practitioners, organizations, and innovators across disciplines to report on their research at the iLRN2022 international conference. This year's theme, DISRUPTION, INNOVATION & RESILIENCY: becoming an inclusive & robust global community for immersive learning, fostered a flourishing global network of researchers and practitioners collaborating to develop the scientific, technical, and applied potential of immersive learning. Moreover, the IEEE Education Society served as our technical co-sponsor for the third consecutive year, and we are grateful for their support. Therefore, all accepted and registered papers in the Academic Stream presented at iLRN2022 and included in this volume will be submitted to the IEEE Xplore® Digital Library.

Our online meeting hosted the Metaverse Adventures series for the first time, inviting prominent speakers that explored different aspects of the metaverse: from representations of poverty in videogames to gamification, intelligent NFTs and human knowledge visualization. For our in-person meeting in Vienna, amongst other events, we hosted the first public meeting of the IEEE Technical Committee on Immersive Learning Environments (TC-ILE), part of the IEEE Education Society (EdSoc). The City of Vienna government presented a session on technology and innovation being currently developed and implemented, including Immersive Training, Digital GeoTwins and AR/VR for infrastructure visualization. We hosted the third edition of the Special Track on Self and Co-Regulated Learning (SCRL) with Immersive Learning Environments (SCILE). Finally, we presented six featured talks and four keynote talks, including contributions from representatives of the Austrian government, best-seller authors and leading researchers. The complete list is available in this book's Keynote and Featured Speakers section.
One hundred and twenty-six submissions were received for the Academic track. These include full and short papers, work-in-progress (poster) papers and submissions to the Doctoral Colloquium. Two to four reviewers independently assessed all submissions. All contributions were evaluated in a double-blind review process and checked for plagiarism to ensure authors submitted original work. All authors were given meaningful feedback on their submissions. Authors were invited to resubmit in a different category when reviewers agreed that papers needed substantial work, i.e. full papers as short papers and short papers as posters.

After a rigorous review, ninety-four papers were accepted for inclusion in the final Academic proceedings (77.77% acceptance rate). From those, twenty-six out of thirty-two full papers were accepted (81.25% acceptance rate), twenty-two out of thirty-one short papers were accepted (70.97% acceptance rate), thirty-nine out of fifty-two work-in-progress papers were accepted (75% acceptance rate) and seven out of eleven doctoral colloquium papers were accepted (63.63% acceptance rate).

In addition, this year, we have our inaugural Practitioner Proceedings volume, which includes twenty-nine submissions. These submissions were peer-reviewed and presented at the conference and included twenty oral presentations, two posters, two workshops, two panel sessions and three special sessions. Authors were required to submit an abstract with well-articulated perspectives on applications of Immersive Learning. This allows practitioners to share their work with our community if they do not qualify for the rigorous requirements of an academic publication. This volume is published separately by iLRN, and it is not indexed by the IEEE Xplore® Digital Library.

Four hundred thirty-seven authors from one hundred fifty different academic institutions, research centres and companies in thirty-one countries submitted publications to the Academic and Practitioner tracks. Countries included Australia, Austria, Belgium, Brazil, Canada, China, Colombia, Cyprus, Denmark, Ecuador, Germany, Greece, India, Ireland, Italy, Japan, Latvia, New Zealand, Norway, Portugal, Russia, Singapore, South Africa, South Korea, Spain, Switzerland, Thailand, Tunisia, UK, USA and Uzbekistan.

We celebrated outstanding contributions through our Best Academic Paper awards (with awards for each category, including student papers) and our Best Practitioner award. The Program Chairs chose final nominees from those that received the best reviews and have been nominated for awards by reviewers. The winning papers were selected by an independent jury panel, which was asked to review the nominated papers based on contribution, methodology, and clarity.

Reviewers provided feedback on submitted papers, suggested improvements, and recommended to the Program Chairs whether to accept, reject or request changes to the papers. Reviewing is a volunteer activity and a time-intensive process, and we are grateful to all our reviewers for contributing to our community. We implemented the Best Academic Reviewer award as a small way to recognize them for their service. An independent jury panel chose the winning reviews. The panel did a meta-review of the nominated reviews based on the rigour of the review, contribution to improving a paper, and developing the conference. The list of winners is available in the Awards section of this volume.

We sincerely thank those involved who volunteered their time to make this such a great event and to attendees for joining us and sharing their excellent work with the iLRN community.
If you are not already involved, we invite you to read these proceedings and join us in our subsequent events and ongoing initiatives.

Anasol Peña-Rios and Daphne Economou
iLRN 2022 General Chairs
About iLRN Conference Series

iLRN's annual conference is the premier scholarly event focusing on advances in the use of virtual reality (VR), augmented reality (AR), mixed reality (MR), and other extended reality (XR) technologies to support learners across the entire span of learning—from K-12 through higher education to work-based, informal, and lifelong learning contexts.

iLRN's annual conference is indexed with CORE ranking C (http://portal.core.edu.au/conf-ranks/2266/), being the most relevant conference in Immersive Learning, devoting the entire conference to this topic.

iLRN has hosted entirely online and in-VR conferences in 2021 and 2020, and in-person editions in London, UK (2019), Missoula, Montana, USA (2018), Coimbra, Portugal (2017), Santa Barbara, California, USA (2016), and Prague, Czech Republic (2015).

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- Inquiries regarding these proceedings should be sent to publications@immersivelrn.org
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#iLRN
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“Adaptive Intelligence for XR Learning: Building Resilience and Creative Capacity at Global Scale” (Opening Keynote)

Caitlin Krause takes leaders and impact-makers to their next level of wellbeing and innovation with her unique approach to wonder, awe, and creative flow-hacking, called MindWise FlowCamp. Her practices helping people optimize flow performance, metaverse fluency, and tech relationships will be an ideal way for iLRN2022 to frame together our common goals and challenges.

- priming ourselves as resilient, adaptive, curiosity driven educators and learners
- meeting global needs in a personal way that involves agency and inclusion
- how to foster connection capacity
“Innovative Mindsets in a Meaningful Metaverse” (Closing Keynote)

Caitlin Krause, MindWise XR Studio

Caitlin Krause focuses on the intersection of technology, innovation, and well-being, and founded the XR design studio and consultancy MindWise in 2015 with the mission "to empower meaningful human connection." 2022 marks the launch of FlowCamp, an interactive metaverse space for creative flow practices, collaboration, team-building and reflection centered on wonder and awe.

She teaches about XR and Digital Well-being at Stanford University and is a creative producer for ScienceVR. Author of the books “Designing Wonder: Leading Transformative Experiences in VR” (2021) and “Mindful by Design” (2019), Krause has built numerous collaborative experiences in social XR, fusing presence, storytelling and emotional intelligence. She is dedicated to helping individuals and teams navigate complexity and change, prioritizing wonder, awe and imagination.

- Video available at: https://youtu.be/P1SH-N9FOsQ

“Educational VR Games: Lessons Learned“

Virtual Reality and Augmented Reality are two related technologies that are poised to become revolutionary educational platforms. This talk will address the many questions that surround this idea. Questions like…

- When will VR and AR be ready to use in education
- What form will VR and AR platforms take?
- What students and topics will VR and AR serve most effectively?
- How can educators make the best use of these technologies?

Using examples from successful VR education products, Jesse will present concrete tips about how to make XR experiences as effective as possible. Expect to come away with a clear picture of the present state and future promise of XR for Education.

Jesse Shell, CEO of Schell Games

Jesse Schell is the CEO of Schell Games, a team of more than one hundred thirty people who strive to make truly great games, both for the purposes of entertainment and education, including award-winning VR games such as “I Expect You to Die”, “HoloLAB Champions”, and “Until You Fall”. Jesse serves as Distinguished Professor of the Practice of Entertainment Technology at Carnegie Mellon University and is the author of the award-winning book The Art of Game Design: A Book of Lenses.

- Video available at: https://youtu.be/xS81gmQFMVQ
“Multimodal data as a means to augment the learning experience“

Enhancing learning in a meaningful, attractive, and accessible manner is critical for the 21st century. Learners need easy-to-use but also powerful technologies, offering fine-grained control of time and progress. Contemporary learning systems need to translate learners' data into a sequence of useful and actionable information; this allows systems to employ different information representation and intelligence augmentation techniques. Collecting learning analytics coming from multi-modal streams can power AI and ML algorithms with the goal to improve the learning experience. In this talk, I will present methods and studies, and our initial results on how multi-modal analytics can support the learning experience.

Michail Giannakos, Norwegian University of Science and Technology, Norway

Michail (Michalis) Giannakos is a professor of interaction design and learning technologies at the Department of Computer Science of NTNU, and Head of the Learner-Computer Interaction lab. His research focuses on the design and study of emerging technologies in online and hybrid education settings, and their connections to student and instructor experiences and practices. Giannakos has co-authored more than 150 manuscripts published in peer-reviewed journals and conferences (including Computers & Education, Computers in Human Behavior, IEEE TLT, Behaviour & Information Technology, BJET, ACM TOCE, CSCL, Interact, C&C, IDC to mention few) and has served as an evaluator for the EC and the US-NSF. He has served/serves in various organization committees (e.g., general chair, associate chair), program committees as well as editor and guest editor on highly recognized journals (e.g., BJET, Computers in Human Behavior, IEEE TOE, IEEE TLT, ACM TOCE). He has worked at several research projects funded by diverse sources like the EC, Microsoft Research, The Research Council of Norway (RCN), US-NSF, the German agency for international academic cooperation (DAAD) and Cheng Endowment; Giannakos is also a recipient of a Marie Curie/ERCIM fellowship, the Norwegian Young Research Talent award and he is one of the outstanding academic fellows of NTNU (2017-2021).

“Digital Basic Education and Digital Action Plan in Austria”

With a digital eight action plan Austria implements its digital strategy in education. A new subject Digital Basic Education will start in September 2022 for 1.500 lower secondary schools to force computational thinking and media literacy. A brief insight.
Stephan Waba, Federal Ministry of Education, Science and Research, Austria

Stephan Waba is Deputy Head of the Department for IT Didactics in the Federal Ministry of Education, Science and Research in Austria. His main areas of work are pedagogical concepts for the development of digital and IT skills by pupils and the qualification of pedagogues. Prior to that, he was a teacher of English and German at a general secondary school, teacher trainer and head of the Virtual PH.
“Developing disinformation resilience competence using the Provenance tool”

Disinformation and fake news have become a virulent problem in our times. Though this is not a new phenomenon, it has become particularly problematic through the emergence of digital media. One reason for the pervasiveness of online media with disinformation can be found in the sharing behaviour of people with low competence in evaluating online media. This talk presents a learning concept and study how such media literacy competence can be developed, in order to make people more resilient against disinformation. The key component of this concept is a tool that has recently been created by the EC-funded Provenance research project. The learning concept is built upon the seven indicators provided by the tool, which the identification of problematic aspects of online news. A study demonstrates the positive learning effect of the concept and the repeatedly applied tool in the context of a training course.
Alexander Nussbaumer, Sylvia Ebner, Christian Gütl, Graz University of Technology, Austria

Alexander Nussbaumer received a master's degree in Telematics (Information and Computer Engineering) and a doctoral degree in Computer Science from Graz University of Technology (TUGraz), Austria. After working in the industry as a software developer, he joined the Cognitive Science Section of the Department of Psychology at the University of Graz in 2006. Since 2009, he has been working at the Cognitive Science Section at the Knowledge Technologies Institute at Graz University of Technology. In 2019 he joined the Cognitive and Digital Science Lab (CoDiS Lab) of the Interactive Systems and Data Science (ISDS) at TUGraz. He has been participating in several EU-funded and Austrian research projects on digital learning, medical training, cultural heritage, secure societies, and smart cities. His research focus currently lies on digital literacy, disinformation, decision support, and evaluation analytics.

Sylvia Ebner graduated from the University of Graz, Austria, in psychology and educational science. Now she works in the Cognitive and Digital Science Lab (CoDiS) of the Institute of Interactive Systems and Data Science (ISDS) at the Graz University of Technology, Austria. The focus of her research interest includes the evaluation of learning and research environments, self-regulated learning, digital learning as well as development of motivation and interest in the STEM field.

Christian Gütl holds a Ph.D. in Computer Science from Graz University of Technology (TUG) and has received the “venia legendi” for applied computer science in 2009. He is at the Institute of Interactive Systems and Data Science at TUG in Graz, Austria, where he leads the Cognitive and Digital Science (CoDiS) Lab. Christian is involved in e-learning and e-assessment for more than 20 years and he has authored and coauthored in more than 220 peer-reviewed book chapters, journals, and conference proceedings publications. He is involved in numerous organizational and editorial boards as well as program committees. He is founding member of the global Immersive Learning Research Network (iLRN), chair of the technical committee of immersive learning (ILE-TC) of IEEE Education Society, managing editor of J.UCS, coeditor of the International Journal of Knowledge and Learning (IJKL). His research interests include information search and retrieval, e-education, e-assessment, adaptive media technologies, and virtual and augmented reality for learning and knowledge transfer.

“Immersive learning technologies for evidence-based practices”

The Technological Pedagogical Content Knowledge model seems to work well when immersive technologies are integrated in education research and teaching. But how are immersive technologies introduced in pedagogical reasoning and action? Technological Content knowledge guides us to choose the pertinent immersive technology to study a specific discipline. Technological Pedagogical Knowledge shows the instructional design to follow for the chosen technology and discipline. What are the features of immersive
technologies that add pedagogical added value? Are there certain research designs that result in evidence base of effectiveness at cognitive, emotional, and psychomotor levels? Technological and their consequent learning affordances of immersive technologies are the core elements for the design of effective immersive learning environments. Psychophysiological measures such as electroencephalography assess learners’ cognitive and affective states and indicate how technological affordances affect the design of immersive learning environments. Rigorous research designs show how learning affordances affect interventions in immersive environments.

Anastasios Mikropoulos, University of Ioannina, Greece
Currently Professor in ICT and virtual reality in education at the Department of Primary Education, School of Education, University of Ioannina, Greece. Dr. Anastasios Tassos Mikropoulos holds a B.Sc. in Physics from the University of Ioannina and a Ph.D. in optical signal processing from the University of Athens. He is the director of the “Educational Approaches to Virtual Reality Technologies laboratory – earthlab”. Anastasios is the elected chair of the Hellenic Association of ICT in Education. His research interests are on learning technologies in general and special education, and especially on virtual and augmented reality in education, and educational neuroscience. Mikropoulos’ work has been published in numerous refereed journals, conferences, and volumes with more than 2900 citations. He is a member of the editorial board and reviewer for many international journals and foundations and chair on special tracks of international conferences. He has been project director, principal investigator, and consultant in many research and development and educational projects. He also serves as a consultant for the Greek Ministry of Education in topics such as digital school and in-service teachers’ further training.

“The Virtual Reality of the Pandemic”
The pandemic has changed not only our real lives, but also our virtual lives. The establishment of remote working, WHO's suggestions to play video games, virtual sporting events, and digital funerals have found their way into our everyday lives. And it especially changed the way how we work and collaborate. In this talk, Johanna Pirker discusses the impact of the pandemic and especially how games have changed everything.

Johanna Pirker, Graz University of Technology, Austria
Dr. Johanna Pirker is Assistant Professor at TU Graz in Austria, leading the research group Game Lab Graz, and research games with a focus on AI, HCI, data analysis, and VR technologies. She has lengthy experience in designing, developing, and evaluating games and VR experiences and believes in them as tools to support learning, collaboration, and solving real problems.
“Virtual Reality for European Young Job Seekers”

Youth unemployment is a serious challenge in today’s European labour market, especially in a post-COVID context. XR/immersive technologies have extensive possibilities to inform about jobs, professions and career paths and provide basic workplace compared to traditional media. These technologies are being deployed by several industries and have proven effectiveness in workplace training, mostly targeting established professionals. Little has been done to prepare job seekers for entering the labor market and to help the unemployed (especially young unemployed) by using immersive technologies. In order to fill the gap in the current research and practice, we suggest establishing collaboration between academia with expertise on immersive technologies for learning and training, public sector bodies and related European industries to investigate how VR can inform and motivate young job seekers, increase their interest in and understanding of workplace processes and prepare them for future work as a part of Erasmus+ VR4VET project.

Ekaterina Prasolova-Førland, Norwegian University of Science and Technology, Norway

Ekaterina Prasolova-Førland is full Professor at the Department of Education and Lifelong Learning at the Norwegian University of Science and Technology (NTNU). Ekaterina has been working with educational virtual worlds and immersive technologies since 2002, with over 100 publications in the field. She has been involved in developing educational virtual reality simulations for a wide range of stakeholders, from aquaculture industry to the Norwegian Labour and Welfare Administration. Ekaterina has founded and is leading Innovative Immersive Technologies for Learning (IMTEL) research group and VR lab at NTNU. She is Ambassador for Women in Immersive Tech and a member of several international expert panels. Prof. Prasolova-Førland frequently gives public speeches and interviews on immersive technologies for learning and training. She is currently working on a number of projects on applications of immersive technologies in STEM education, climate change awareness, professional training, medicine and therapy, career guidance, collaborative learning and other areas.

“Challenges in Educating Digitally Literate Doctors of Tomorrow”

Contemporary challenges of educating and training doctors and health professionals of tomorrow are undoubtedly shaped by digital technologies as well as modern pedagogical approaches. Immersive technologies, although set the excitement pace by the caused disruption, should be going hand-in-hand with (innovative) experiential learning episodes as well as evidence-based evaluation practices. The whole environment is also driven by the urgent need to create digital solutions allowing for a wider notion of a
"topical resiliency" in the sense that any health workforce training should be topically allowing for "One-Health" ideas, as well as affording up-skilling. In this talk, numerous examples from running a handful of projects will be provided.

Panagiotis Bamidis, Aristotle University of Thessaloniki, Greece
Panagiotis Bamidis is a Professor of Medical Physics, Informatics and Medical Education and Director of the Lab of Medical Physics and Digital Innovation in the School of Medicine at the Aristotle University of Thessaloniki, Greece. He designs, implements, and evaluates IT and Assistive Technologies systems that improve everyday activities of elderly or other vulnerable groups and improves their health or life quality or improves the education and training of health professionals. He conducts research that attempts to understand how the brain reacts to different stimuli, technological or educational interventions, as well as, the development and evolution of human emotions and sleep transitions. He is the co-ordinator of ten large European projects, and the principal investigator for many national and international funded projects. He is the President of the Hellenic Biomedical Technology Society (ELEBIT), HL7 Hellas, the international Society of Applied Neuroscience (SAN), a member of the Administration Boards of other societies and patient associations. He is/has been the Chairman/Organiser of some 20 international conferences and several national Biomedical Technology conferences. In 2017, he became a visiting Professor of Medical Education Technology, Innovation and Change for the Leeds Institute of Medical Education (LIME) of the University of Leeds, UK. Since 2020, he leads the Medical Education Innovation & Research Unit (MEIRU) of the Special Unit for Biomedical Research and Education (SUBRE) of the School of Medicine.

“Green Immersive Education for All”
Media is ubiquitous in education and its impact on the environment is unavoidable. The British Academy of Film and Television Arts (BAFTA) estimates that the annual emissions from UK film production totals in excess of 149,000 tonnes of CO2 (the equivalent CO2 output of a small village), while figures from Greenpeace suggest that Information and Communications Technologies (ICT) generate up to 3% of global carbon emissions (on par with air travel) (Jones 2018). It is estimated that by 2030, ICT electricity usage could contribute up to 23% of global greenhouse gas emissions (Andrae and Edler 2015). Storing pictures, uploading videos and attending online meetings all emit carbon. The presentation proposes some small steps to curve media pollution and present the EU Green Education framework where immersive media plays a central role both in green education and in immersive and accessible learning.

Pilar Orero, Universitat Autònoma de Barcelona, Spain
PhD (UMIST, UK) is a Professor at Universitat Autònoma de Barcelona (Spain) in the TransMedia Catalonia Lab. She has written and edited many books, near 100 academic papers and almost the same number of book chapters --all on Media Accessibility. Leader and participant on numerous EU funded research projects focusing on media accessibility. She works in standardisation and participates in the UN ITU IRG-AVA - Intersector Rapporteur Group Audiovisual Media Accessibility, ISO and ANEC. She has been working on
Immersive Accessibility for the past 4 years first in a project called ImAc, which results are now further developed in TRACTION, MEDIAVERSE, MILE, and has just started to work on green accessibility in GREENSCENT. She leads the EU network LEADME on Media Accessibility.
Metaverse Adventures

“Representations of Poverty in Videogames”
This conversation concerns the new monograph Representations of Poverty in Videogames, which is forthcoming from Palgrave Macmillan in late June 2022. In that text, Crowley argues that the videogame form has become a meaningful vehicle for representing contemporary, middle-class anxieties about poverty. In this presentation, these anxieties are explored with gameplay examples relevant to select supply-chain and inflation-related concerns that manifested in the United States during the third year of the Covid-19 pandemic.

Adam Crowley, Husson University, USA
Adam Crowley is a Professor of English at Husson University in Bangor, Maine. His books include The Wealth of Virtual Nations: Videogame Currencies (2017) and Representations of Poverty in Videogames (2022). He was a featured speaker at the 2022 Popular Culture Association conference. Crowley was also invited to lead a "Meet the Experts" talk on game studies and education hosted by Thomas University this past spring. His commentary has appeared in Wired magazine and other publications. He can be followed on Twitter at @AdamMCrowley.

- Video available at: https://youtu.be/ui6tXPO8PQk
“Gamification & the Metaverse”

The most important educational purpose of gamification is to create a fun and engaging experience that promotes task or concept mastery. Games are often talked about as if they were a relief from serious work. But in the make-believe world of games, we are in charge, making decisions, as we assess risk to master a range of challenges. Play helps create new connections between neurons and between different parts of the brain. Do we in fact have a neurological imperative to allow our learners to play? Employee disengagement and high turnover rates are real challenges that employers face as they navigate the post-pandemic landscape. Based on what we know of the highly interactive, responsive, and personalized nature of Internet of Things (IoT) products and services, gamification promises to be one of the most-effective concepts to apply to employee engagement, retention, and upskilling.

Monica Cornetti, Sententia Inc.

Monica Cornetti works with individuals and organizations who want to learn how to think playfully to achieve uncommon results. A gamification speaker and designer, Monica was repeatedly rated #1 among the “Gamification Gurus Power 100” by RISE from 2015-2020, and in 2021 was recognized as #1 in the Most Influential Women in Gamification who have created a legitimate impact in the gamification industry. Monica is the President of Sententia, Inc. and leads the company’s education and design projects at Sententia Gamification. She is also the Gamemaster of GamiCon (annual international conferences for the gamification of learning) and Head of Faculty at the Gamification Academy. She is the author of the books Lipstick Lessons, What Were You Thinking?, Totally Awesome Training Activities Guide: Put Gamification to Work for You, and co-author of Deliberate Fun: A Purposeful Application of Game Mechanics to Learning Experiences.

She is a graduate of Seton Hill with a BA in psychology, and The University of Houston-Victoria where she earned a Masters Degree in Economic Development and Entrepreneurship.

Monica is hired for her skill as a gamification speaker and strategist and is considered at the top of her field in gamification design for corporate training and adult education.

“Illintelligent NFTs”

Arif Khan is the CEO and co-founder of Alethea AI, a decentralised protocol to create an Intelligent Metaverse inhabited by interactive and intelligent NFTs (iNFTs). Alethea AI is a hypergrowth deep tech startup at the intersection of two exponential technologies, Artificial Intelligence and Blockchain. As its CEO and founder, Arif has been regularly invited to speak at major global events like The World Economic Forum, World Web Forum, and has guest lectured at the Singapore Management University’s MBA program. He is a top writer for Artificial Intelligence on Medium.com and his work has been featured in Fast Company, Forbes, The Wall Street Journal & The New York Times. Alethea’s protocol is backed by a roster of Tier-1 Investors like Binance, Gemini, Dapper Labs, Multicoin, Metapurse, Alameda Ventures, BITKRAFT, Galaxy Interactive, Sfermion and more.
Arif Khan, Alethea AI
How Artificial Intelligence technologies can be leveraged to encompass a learning experience, in the context of our products. From passing on oral history, to preserving cultural heritage and language, our Metaverse, “Noah's Ark,” can empower users and communities to engage each other, via AI-powered characters that are trained to share intelligence and narrative.

“The power of human networks, especially in education”
With the evolution of the web, how have human networks changed the way different industries operate? This session will explore the change between web1, web2, and web3, along with the onset of the metaverse. We will explore a metaverse space called the Eduverse and how teacher networks can bring education into the future.

Vriti Saraf, Ed3 DAO
Vriti Saraf (@vritisaraf), the founder of k20 Educators (@k20educators), is building the Eduverse on web3, a free metaverse space for educators to connect, collaborate, learn, and earn. k20 has been recognized as the world's top 200 most innovative edtech companies by Global Silicon Valley. She is also the co-founder of Ed3DAO (@Ed3DAO), a web3 digital co-op (Decentralized Autonomous Organization) for educators by educators, aiming to catalyze innovation at scale. Vriti's goal is to break down silos among educators through web3. Her free newsletter, Metaverse for Education, contextualizes web3 for educators. Vriti has served as a teacher, dean, & director in public, private, & charter schools both locally & internationally across k12 & higher education.

“Visualise Human Knowledge”
Jackie Lee, Science VR
Jackie Lee, Ph.D. is a cross-disciplinary inventor in VR/AR, learning, and Affective Computing. He worked on Intel's RealSense 3D cameras and Project Alloy (the first all-in-one VR headset). He did biosensing and behavioral research at the Affective Computing Group at MIT Media Lab. He did his master thesis focusing on Spatial User Interface and Augmented Reality. Jackie is the recipient of the Virtual World Society's Nextant Rising Star Prize at AWE 2020. He is part of the Oculus Launch Pad 2020 program and a two-time recipient of Epic Games’ MegaGrants.
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Awards

Academic Paper Awards

All nominated papers have gone through blind peer-review. Final nominees were chosen by the Academic Program Chairs from those that received best reviews and have been nominated for awards by reviewers.

The winning papers were chosen by an independent jury panel, which was asked to review the nominated papers based on: contribution, methodology and clarity.

Independent jury panel members voting for the Best Academic Papers (Full/Short)

- Leonel Morgado, *iLRN Vice President for Scientific Quality, Universidade Aberta, and INESC TEC, Portugal*
- Dennis Beck, *University of Arkansas, USA - iLRN Board Member*
- Teresa Oliveira, *Universidade Aberta (UAb), Portugal*
- Daithí Ó Murchú, *Dublin West Education Centre, Ireland*

Independent jury panel members voting for the Best Academic Papers (WIP/DC)

- Alexander Klippel, *The Pennsylvania State University, USA*
- Patrick O'Shea, *Appalachian State University, USA - iLRN Board member*
- Tassos Mikropoulos, *University of Ioannina, Greece*

We thank the independent jury panel members for your time, effort, and recommendations.

Best Academic Full Paper

Winner

- "Investigating the Mobile Augmented Reality Acceptance Model with Pre-Service Teachers"
  Tassos A. Mikropoulos (1), Michail Delimitros (1) & George Koutromanos (2); 1: University of Ioannina, Greece; 2: National and Kapodistrian University of Athens, Greece
  https://www.youtube.com/watch?v=SKT5sNiWQa4

Runners-up

- "Reflecting on Research: A Virtual GLAM Proposal", Michael Vallance; Future University Hakodate, Japan
  https://www.youtube.com/watch?v=wUoA9wRhyaQ

- "Undergraduate Nursing Students' Experiences and Perceptions of Self-Efficacy in Virtual Reality Simulations" Mamta Shah, Christine Gouveia & Ben Babcock; Elsevier, United States of America
  https://www.youtube.com/watch?v=d9Fkk4u1RL4
Best Academic Short Paper

Winner

- "Framework For Scalable Content Development In Hands-on Virtual And Mixed Reality Science Labs"
  Hamadani Kambiz, Jiang Yuanyuan, Ahmadinia Ali, Hadaegh Ahmad, Moraleja-Garcia Juan, Mendez Alan & Shaikh Arshia; California State University San Marcos, United States of America
  https://www.youtube.com/watch?v=5ocOT99XTOA

Runner-up

- "Game-based virtual reality for language culture learning: An example of The Forbidden City"
  Junjie Gavin Wu (1), Danyang Zhang (2) & Minjuan Wang (3); 1: Shenzhen Technology University; 2: Shenzhen University; 3: San Diego State University
  https://www.youtube.com/watch?v=1WTrPJjZriY

Best Academic Work-in-Progress Paper

Winner

- "Measuring Learners' Subjective Experience in Augmented Reality: First Evaluation of the ARcis Questionnaire"
  Jule M. Kruger & Daniel Bodemer; University of Duisburg-Essen, Germany
  https://www.youtube.com/watch?v=miFfSFUpUU

Runners-up

- "Using Virtual Reality in Museums to Assist Historical Learning"
  Adam Morsman, Ben Newman, Stephanie Bally, Jack Johns, Hannah Cook, Daniel McHugh & Grace Williams; BT Plc, United Kingdom
  https://www.youtube.com/watch?v=Z2C2TwnsuGI

- "Avatar vs Teams: Co-presence and Visual Behavior in a Videoconference Cooperative Task"
  Cesar Daniel Rojas Ferrer, Takayuki Fujiwara; Hitachi, Ltd. Research & Development Group, Japan
  https://www.youtube.com/watch?v=QgwObGgTCvk

- "Blower VR: A Virtual Reality Experience to Support the Training of Forest Firefighters"
  Federico De Lorenzis, Filippo Gabriele Pratico, Fabrizio Lamberti; Politecnico di Torino, Italy
  https://www.youtube.com/watch?v=qwq_i7zbRZE&t=6s
Best Doctoral Colloquium Paper

Winner

- "Artmaking: From a Hands-on Process to a VR Translation"
  Maritina Keleri, Daphne Economou & Jeffrey Ferguson; University of Westminster, United Kingdom
  https://www.youtube.com/watch?v=zIn223bb9Bw

Runners-up

- "Building Intertextual Connections with Secondary Students in Minecraft"
  Tracey Cole & Jim Shifflett; Old Dominion University, United States of America
  https://www.youtube.com/watch?v=EKa4eKoapM4

- "The Potential Of Mixed-Reality Technology For Motivating Dentistry Students In Higher Education"
  Areej Reda Banjar & Abraham G.Campbell; University College Dublin, Ireland
  https://www.youtube.com/watch?v=ESFj9SZcLlw

Best Student Full Paper

Winner

- "Immersive Haptic Interface Simulating Skin Biopsy for Dermatological Skill Training"
  Jin Woo Kim (1), Hyunjae Jeong (1), Dustin P Demeo (2), Bryan T Carroll (2,3) & Kwangtaek Kim (1); 1: Kent State University, United States of America; 2: Case Western Reserve University School of Medicine; 3: University Hospitals Cleveland Medical Center
  https://www.youtube.com/watch?v=GCTICE8X18g

Runners-up

- "Exploring Constraints on Dialogic Interaction in Immersive Environments Arising From COVID-19 Protocols"
  Chenwei Hu (1) & Kenneth Y T Lim (2); 1: Hwa Chong Institution, Singapore; 2: National Institute of Education, Singapore, Singapore
  https://www.youtube.com/watch?v=er5JJiUiZhk

- "Research Based on Affective Filter Theory Is Social VR an Effective Tool for Learning a Second Language"
  Yeonhee Cho (1), Hao Ning Hsu (1), Zhewen Zheng (1), Emily Elizabeth Trinh (1), HyunYoung Jang (1) & Yusi Cheng (2); 1: University of Washington, United States of America; 2: Northeastern University, United States of America
  https://www.youtube.com/watch?v=D8MEP4TaKKQ
Best Student Short Paper

Winner

- "Which Types Of Learners Are Suitable For The Virtual Reality Environment: A FsQCA Approach"
  Liu Jiaxu, Liu Qingtang, Yu Shufan, Ma Jingjing, Liu Mengfan & Wu Linjing; Central China Normal University, People's Republic of China
  https://www.youtube.com/watch?v=YlQoMfwplEE

Runners-up

- "SAVR - Design and Evaluation of an Immersive Virtual Reality Serious Game on Hazard Perception in Technical and Vocational Education"
  Carl Boel (1,2), Tijs Rotsaert (2), Niels Vleeschouwer (2) & Tammy Schellens (2); 1: Thomas More University of Applied Sciences, Belgium; 2: Ghent University, Belgium
  https://www.youtube.com/watch?v=eWj4iwpn8FQ

- "An Interactive Chess-Puzzle-Simulation for Computer Science Education"
  Michael Holly, Jan-Heliodor Tscherko & Johanna Pirker; Graz University of Technology, Austria
  https://www.youtube.com/watch?v=mUVjKSUsKPU

Best Student Work-in-Progress Paper

Winner

- "Flood Adventures: A Flood Preparedness Simulation Game"
  Alec Bodzin (1), Robson Araujo-Junior (1), Kenneth Straw (1), Surui Huang (1), Benjamin Zalatan (1), Kathryn Semmens (2), David Anastasio (1) & Thomas Hammond (1); 1: Lehigh University, United States of America; 2: Nurture Nature Center, United States of America
  https://www.youtube.com/watch?v=n1OnX46Llnw
Academic Reviewer Awards

Reviewers provide feedback on submitted papers, suggest improvements, and make a recommendation to the Program Chairs about whether to accept, reject or request changes to the papers.

Reviewing is a volunteer activity. It is a time-intensive process, and we are grateful to all our reviewers for contributing to our community. As a small way to recognise them we have implemented this award.

The nomination is based on careful consideration of all the reviews based on the following criteria:

- rigor of review, contribution to improve the paper, contribution to developing the conference.
- rejection reviews count, if they are grounded, detailing the research weaknesses for rejecting and helping the authors to improve their work.
- scathing rejection eliminates a nominee.
- glanced-over acceptances eliminate a nominee.
- emphasis on form (style, organization) rather than substance (research quality) is not a desirable reviewing focus.

The winning reviews were chosen by an independent jury panel, which was asked to do a meta-review of the nominated reviews based on the criteria above.

Independent jury panel members voting for the Best Reviewer

- Nigel Newbutt, UWE Bristol, UK
- Vasileios Argyriou, Kingston University London, UK
- Ioannis Doumanis, University of Central Lancashire, UK

Best Academic Reviewer Awards

Winners

- Dr. Ludovic Hamon; Le Mans University, Laval IUT, France
- Thayna Bertholini; Universidade Federal do Espirito Santo (UFES/Brazil), Brazil

Runners-up

- Tone Lise Dahl; SINTEF AS, Norway
- Salah Ahmed; Shaanxi Normal University, People's Republic of China
- Jule M. Kruger; University of Duisburg-Essen, Germany
- Robson Martins de Araujo Junior; Lehigh University, USA
Practitioner Awards

Eligibility: All presenters who submitted through the iLRN 2022 Practitioner Stream, including oral presentations, panels, posters, workshops, and special sessions.

Independent jury panel members

- Dr. Dongjin Kwon, Texas A&M University, USA
- Dr. Sungwoong Lee, University of West Georgia, USA
- Stephanie Wossner
- Meaghan Mood Stalnaker

We were grateful to receive award recommendations from scholars who reviewed all the Practitioner Stream proposals to make their decisions.

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Innovation in K-12 Education

Awarded to a Practitioner Stream presenter whose work is at the leading edge in immersive learning and likely to change the field in K-12 education.

- "Engaging Early Learners in a VUCA World"
  Nely Daher, Emma Donaldson, Georgie Ridehalgh, Penelope Dugan; Knox Grammar Preparatory School, Australia
  https://www.youtube.com/watch?v=o1WMH8emOgQ
- "Aurora Simulator: A Software Application for Exploring the Aurora in Upper Elementary Science Classrooms"
  Anisa Bora; Columbia University, USA

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Innovation in Higher Education

Awarded to a Practitioner Stream presenter whose work is at the leading edge in immersive learning and likely to change the field in higher education.

- "The Mystery of Lehigh Gap: Game-based VR for Informal Learning"
  Alec Bodzin, Araujo Junior Robson, Josie Koelsch, Mayra Arnoat Perez, Udita Agarwal, Marcos Escobar, Chad Schwartz, David Anastasio, Thomas Hammond, Brian Birchak, Junchen Bao, Yiting Chen, Tarah Cicero, Xiangyu Hu, E.J. Rovella, Laura Sary, Matthew Silverman & Hayley Whitney; Lehigh University, Lehigh Gap Nature Center, USA
  https://www.youtube.com/watch?v=Ox5PIL52j4M
- "Pedagogical Approaches to Graduate Education in Learning Experience Design Using Immersive Technologies Online"
  Douglas A. Wilson; George Mason University
  https://www.youtube.com/watch?v=f8cwT89safQ
Immersive Learning Pedagogy
Awarded to a Practitioner Stream presenter whose work represents impactful pedagogy or innovative practice in immersive learning.

- "Augmented Reality Affording Immersive Learning Experiences in Museum Education"
  Quincy Wang & Kristiina Kumpulainen; Simon Fraser University, Canada
  https://www.youtube.com/watch?v=vetENBpAOFo
- "ALIVE: Avatar Learning Impact assessment for Virtual Environments"
  Sarune Savickaite, Elliot Millington, Chris Freeman, Robert McMillan & Mohamed Khamis; University of Glasgow, UK, Edify.ac
  https://www.youtube.com/watch?v=Dh1spNbYzus

Outstanding Contribution to Research
Awarded to a Practitioner Stream presenter whose work represents ground-breaking research or theoretical innovation in immersive learning.

- "Designing Effective Immersive VR Learning Experiences"
  Jan Plass; New York University, USA
  https://www.youtube.com/watch?v=oM5KMWiIU9E

Outstanding Contribution to Workplace & Industry Training
Awarded to a Practitioner Stream presenter whose leadership and vision will positively impact workplace and industry training.

- "Between Skills and Success: Developing Workers' Dispositions for Applying Skills in an Uncertain, Disruptive World"
  Chris Dede & Ashley Etemadi; Harvard Graduate School of Education, USA
  https://www.youtube.com/watch?v=h0uVKeOOjSg
Special Awards

Outstanding Contribution to the Conference Development

Our conference runs entirely on the volunteering work of exceptional individuals committed to the iLRN’s vision.

Every conference committee member has made invaluable contributions to the event, and we are grateful to all of them. However, we would like to publicly recognise the work of colleagues who have gone above and beyond in their roles.

- Genevieve Smith-Nunes, University of Cambridge, UK
- Jule M. Krüger, University of Duisburg-Essen, Germany
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Assessment & Evaluation (A&E)
Teachers’ Attitudes and Technology Acceptance Towards AR Apps for Teaching and Learning

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Abstract—Teacher attitudes and technology acceptance towards Augmented Reality (AR) are important constructs because their development has an impact on the teachers’ use of AR applications in classroom practice. The present study focuses on these two constructs and analyses them from a theoretical and empirical perspective. In this context, results from a pre-test from the European H2020 project ARETE are introduced. In this study, n=129 teachers from 13 countries responded to an online survey which included questions on demographic data as well as two scales to measure teacher attitudes towards AR and teacher technology acceptance towards AR. The results show a mostly highly motivated sample and very positive attitudes towards AR among the participating teachers. An analysis of correlations and predictors was performed by calculating the Pearson Correlation coefficient and a regression analysis, which indicated that teacher attitudes and technology acceptance towards AR are highly correlated. Additionally, the teachers’ previous experience with AR and, in case of technology acceptance, the self-assessed expertise in using digital media for teaching and learning are significant predictors for the two constructs in question.

Index terms—Augmented Reality, teacher attitudes, TAM, international research, pilot study, ARETE

I. INTRODUCTION

Teacher attitudes towards any medium are relevant to the successful integration of this medium in teaching and learning processes because they help understanding the teachers’ opinion on the medium in question. Similarly, the well-researched construct of technology acceptance gives valuable insight into the teachers’ predispositions towards using the medium in class. Hence, both attitudes and technology acceptance influence the teachers’ actions in classroom practice. For this reason, it is important to carefully monitor and evaluate teachers’ attitudes and technology acceptance as well as their development when implementing a new medium.

Within the ARETE H2020 project, three different Augmented Reality (AR) apps are piloted in Elementary school classes across Europe. Affirmative teacher attitudes and technology acceptance towards AR are considered a key condition for the successful integration of the AR apps into teaching and learning processes and are therefore monitored closely by means of pre and post online surveys (n=129), along with demographic data and preconditions.

In the following paper, the ARETE research on teacher attitudes and technology acceptance will be contextualized, the scales applied to measure both constructs will be introduced and exploratory pre-test results regarding teacher attitudes and technology acceptance towards AR will be presented. The data allow for conclusions on factors that influence the teachers’ attitudes and technology acceptance.

Overall, the procedure described in the following will provide an important basis for further analysis of pre-test and post-test data and at the same time introduce a methodology for a thorough evaluation of teacher attitudes and technology acceptance within related contexts of AR in teaching and learning or further innovative media offers. The focus is on the methodology of attitude and technology acceptance measurement and on an exploratory analysis of correlations and predictors impacting the results.

Against this background, the following two research questions will be addressed in the following paper:

1) How can teachers’ attitudes and teachers’ technology acceptance towards AR be defined and measured?

2) Which predictors have an impact on teachers’ attitudes and technology acceptance towards AR?

II. STATE OF RESEARCH

A. Teacher Attitudes Towards Augmented Reality

According to related research, AR has the potential to stimulate student motivation and to support learning processes with various benefits [1]–[4]. However, as with any medium, there is a complex network of factors influencing whether its integration into teaching and learning processes will be successful. Among these factors, teacher attitudes play a key role.

There is a long tradition of researching the role of teacher attitudes in educational research. According to Allport [5], they are defined as “a mental and neural state of readiness, organized through experience, exerting directive or dynamic
influence upon the individual’s response to all objects and situations with which it is related”. Richardson [6] summarizes this as “predispositions that consistently affect actions”. There is empirical evidence that these attitudes towards a medium indeed influence the teachers’ technology integration in class as they are a strong predictor for ICT use [7]–[9]. Consequently, it is helpful to understand these predispositions when discussing the integration of a new medium into classroom practice. Yet, most studies concerning attitudes and AR tend to focus on the learners’ perspective, i.e. students and preservice teachers in particular [10].

A well-researched instrument in this context is the Augmented Reality Applications Attitude Scale (ARAAS), developed by Küçük et al. [11]. It was confirmed in further studies [12] and also adopted to other national contexts [13], [14]. The scale addresses the attitudes of preservice teachers towards the use of AR apps in initial teacher education and differentiates between three dimensions which are “Relevance”, “Satisfaction” and “Reliability”. However, due to its focus on the preservice teachers’ perspectives as learners, it is not ideal for assessing the attitudes of in-service teachers as facilitators and organizers of learning processes; for example, Diaz Noguerà et al. [13] list the following items that illustrate the focus on the learners’ perspective: “AR applications make my learning difficult because they confuse my mind” or “AR has changed my attitude as a student, not only in this module, but generally in all subjects”.

Yet, teacher attitudes towards AR have also been assessed repeatedly in related literature. Different foci and methods have been applied: for example, Tzima et al. [3] ask in a qualitative study with a small sample of teachers whether teachers would use a specific AR application as teaching tools, whether students would be interested, and whether they would come up against practical issues, and summarize the results on these opinions as “attitudes”. Parsons and MacCallum [10] assessed in-service teachers’ attitudes towards free AR and VR tools, also applying a non-standardized, self-developed scale without further specifying the scale metrics. Lham et al. [15] applied a self-developed scale, reporting its high internal consistency but not elaborating on the scale development or its theoretical foundations. Similarly, Yakubova et al. [9] used a non-standardized survey to collect information on the attitudes towards AR and VR of special education teachers.

As these studies show, teacher attitudes towards AR have been measured in current literature but there is a lack of coherent and standardized scales with a thorough examination of scale metrics and predictors. Hence, all the sources examined offer evidence of the perceptions of teachers in specific contexts but are questionable in their theoretical foundation and transferability. This status implies the research desideratum to examine more closely how teacher attitudes towards AR can be defined and measured with a valid approach.

B. Teacher Technology Acceptance Towards AR

The Technology Acceptance Model (TAM) is a well-established model for user acceptance of information systems [16]. Rooted in social psychology, it is considered a valid measure to explain and predict user behaviour for respective technologies [17], [18]. The TAM postulates that a person’s attitude toward using a technology depends on the perceived usefulness of the technology and on the perceived ease of use. The resulting attitude leads to a behavioural intention to use the technology, and this intention influences the actual technology use [16].

There are different updates and extended versions of the original TAM and various TAM-based standardized scales to measure the technology acceptance of persons in different contexts. An overview of respective developments, studies and publications in educational contexts can be found in [19], [20].

Against the background of the varieties of contexts for TAM measurement scales, it is noteworthy that instruments for measuring teachers’ TAM towards AR are rather scarce. However, the scale developed by Ibili et al. [21] measures the technology acceptance of teachers in relation to an AR tutoring system. Based on a broad literature review and a thorough statistical analysis, the resulting scale adds the factors of “Satisfaction”, “Anxiety” and “Social Norms” to the original dimensions to capture the construct of technology acceptance in a valid way.

As the literature review reveals, the constructs of teacher attitudes towards AR and technology acceptance towards AR are linked closely. The difference between the two refers to their focus: the construct of teacher attitudes is focussed on the predispositions within a teacher and the teacher's general perceptions about the medium. The survey applied in the following study asks, e.g., whether teachers find AR apps motivating or whether they believe such apps are helpful to support personalized learning. The TAM scale used on the other hand is about the teachers’ attitudes towards using AR in educational contexts and about concrete intentions to apply the medium, for example in “I plan to use AR apps in the future” or in “Using AR apps is easy for me.”

Hence, both constructs of attitudes and technology acceptance are interrelated and complement each other by combining attitudes towards the medium itself and towards using the medium. Based on this differentiation, it appears useful to look at both constructs when evaluating teachers’ predispositions towards using the medium of AR in class even though the proximity of both constructs may cause certain overlaps.

III. METHODOLOGY

A. ARETE Study Context and Research Approach

In the ARETE project, a comprehensive research approach has been developed to draw valid conclusions on the effects of AR applications in teaching and learning processes both on students and teachers on a European level. There are four different pilot phases in the project with different apps and aims. The following paper refers to selected results from pilot phases 1 and 2. Details on the research designs of both pilots are explained in detail in [22] and [23].

ARETE Pilot 1 is an exploratory study about supporting English literacy attainment of students who underperform in reading and spelling. There are 9 teachers with 34 students from grades 4, 5 and 6 participating in this pilot, which runs
from September 2021 to March 2022. These classes are either from Ireland or English-speaking classes from Italy and Luxembourg. Seven intervention group classes, i.e., 26 students, work with an AR-enhanced literacy learning program over a school term on a daily basis. Two classes, i.e., 8 students, form the control group without access to the app between pre and post testing. An additional historical control group will be used for the analysis of pre and post test data at a later stage.

The students’ spelling and reading abilities are assessed by standardized pre and post testing. Selected teachers are interviewed pre and post intervention and all teachers fill in an online survey pre and post intervention on demographics, attitudes, technology acceptance and, in the post survey, on their experiences with the app [22].

ARETE Pilot 2 aims to support knowledge acquisition and retention in Mathematics and Science with two AR-enhanced apps. There is one app from the content area of Geometry and a second app about Geography. Students in this pilot are in grades 4 and 5 and come from 11 European countries. Within the school term from September 2021 to March 2022, teachers in Pilot 2 can integrate their app (either Geometry or Geography) into their classes as long and as often as they consider appropriate. There are 120 teachers in the pilot 2 sample who completed the pre survey, teaching approx. 2,400 students. 60 classes are in intervention group, working with the app, and 60 classes are in the control group and do not have access to the app between pre and post testing but teach in their traditional ways.

The students’ knowledge gain through the apps is evaluated through standardized knowledge tests in pre, post and retention testing in Pilot 2. The tests are based on the Trends In International Mathematics and Science Study (TIMSS) [24]. Teachers complete the same evaluation steps as in pilot 1; they respond to the same pre and post online survey on demographics, attitudes, technology acceptance and, in the post survey, on experiences with the app [23]. Furthermore, there are interviews and focus groups pre and post intervention for selected teachers from both pilots.

Within this scope of research activities in the ARETE project, the focus for the following analyses will be on the evaluation of pilot 1 and pilot 2 teachers’ input from the online survey pre-test.

B. Scale Metrics

The online survey used in the pilots includes a scale for measuring teachers’ attitudes towards AR and a second scale to measure teachers’ technology acceptance towards AR. Additionally, it includes context questions on demographic data and on relevant conditions, as there are the teachers’ previous experience with AR, their teaching experience and their self-assessed expertise in using digital media for teaching on learning.

Against the limited background of valid measurement instruments for teachers’ attitudes towards AR, a new scale was developed based on the research background of available instruments from related research. Main factors were included that reoccur in related scales, such as the impact of AR apps on student motivation, classroom engagement, learning achievements and its role in teaching and learning activities. Additionally, the game-based learning research background was considered in the scale development process as it is comparatively broad and offers useful parallels [25], [26]. The items were adapted to match the AR context. The final scale consists of 21 items for agreement with statements on a scale from 1 (strongly disagree) to 5 (strongly agree). Examples of items from this scale are “[Apps which include Augmented Reality] are fun for the students”, “They help increase content knowledge acquisition” or “They can be used as rewards when students do well in class”.

The internal consistency of the scale is very high with a Cronbach’s α of 0.93. The discrimination power of all items ranges between 0.38 and 0.77; hence, the items appropriately represent the construct of attitude to be measured.

The second scale is based on the Teacher Technology Acceptance Model (TAM) and thus has a stronger focus on the intention of using AR in class. Given the large variety of available scales to measure TAM, relevant scales were reviewed in the selection process and prioritized with regards to:

1) Validation: the selection of a scale took into account whether the validation procedure was described in the paper and whether the scales had satisfying reliabilities;
2) Target group: scales measuring the technology acceptance of teachers were prioritized;
3) AR reference: scales applying the TAM in studies focusing on AR were prioritized.

On this basis, the scale of Ibili et al. [21] was considered most appropriate for the ARETE research and selected dimensions of it were used.

The scale consists of 12 items for agreement with statements on a scale from 1 (strongly disagree) to 7 (strongly agree; 2 reverse items). Two items from each of the following constructs were included: “Perceived Usefulness”, “Perceived Ease of Use”, “Anxiety”, “Attitude”, “Behavioural Intention”, and “Social Norms”.

The original scale by Ibili et al. [21] also includes a scale for “Satisfaction”, which was not used in the ARETE scale because it refers back to the experience with the Augmented Reality app. Thus, it is not applicable for a pre-testing before respondents could actually make experiences with the apps. The internal consistency of the resulting scale is high with Cronbach’s α = 0.84. All items have a discrimination power between 0.34 and 0.73. Therefore, all items were confirmed to appropriately represent the construct of technology acceptance.

In related literature, the different constructs described by the technology acceptance model are usually kept separated and analyzed without summarizing them to one score. For the research context within the ARETE project, it was considered useful to work with one score averaged over the different constructs because the focus of the study is not on the validation of a theoretical model but on the evaluation of the teachers’ expectations for and experiences with using AR.
Hence, it is necessary to reduce the dimensions to one score of “technology acceptance”; this way, the score can be used as one out of several correlates to be applied in further analyses.

C. Sample

The sample consists of 129 participants from 13 countries. There are 95 women (73.6 %) and 34 men (26.4 %) in this group. No person ticked “other / do not want to say”. Participants are aged 44 on average (SD 7.1; range: 27–63).

There are 3 teachers (2.3 %) with less than five years of teaching experience and only 14 teachers (10.9 %) with 5 to 10 years of teaching experience. A majority of teachers (112 teachers / 86.8 %) has more than 10 years of teaching experience.

According to their self-assessment, the teachers are very competent in using digital media in teaching and learning. On a scale from 1 (very poor) to 5 (very good), teachers rated their own expertise in using digital media in teaching and learning as 4.3 on average (SD 0.7). There are no teachers estimating their own expertise as “very poor” and only one teacher assessing it as “poor”. A majority of teachers rated it as “good” (50 teachers / 38.8 %) or “very good” (61 teachers / 47.3 %).

To quantify previous experiences with AR, a sum score of three related items was calculated. The items were “Have you heard or read about AR?”, “Have you used AR in your leisure time?”, and “Have you used AR for teaching and learning?”. All three could be answered with “no” (0 points), “a little” (1 point) or “a lot” (2 points). Hence, the sum score may range from 0 (no experience with AR at all) to 6 (maximum experience with AR).

The average total AR experience on this scale from 0 to 6 across all participants was 2.3 (SD 1.5). Values achieved range from 0 to 6, showing in accordance with the comparably high standard deviation that the sample is quite heterogeneous in their previous AR experiences: 10 persons are totally inexperienced with AR (7.8 %) and 5 persons indicated maximum experience (3.9 %). However, most teachers tend to be overall less experienced with AR.

All participants are teachers teaching classes 4 to 6. They all applied for participation in the ARETE project voluntarily, hence the sample is a convenience sample. The survey was obligatory to fill in for teachers before starting the pilot.

IV. RESULTS

A. Descriptive Results

a) Teacher Attitudes: On a scale from 1 (strongly disagree) to 5 (strongly agree), teachers show most agreement with the following three statements about apps which include AR:

“They are motivating for the students” (mean 4.6; SD 0.6); “They are fun for the students” (mean 4.6; SD 0.5); “They can promote learning in STEM” (mean 4.6; SD 0.6).

Least agreement was achieved for the following three items:

“They bridge the gap between what students do at home and at school“ (mean 3.9; SD 0.8); “They can promote literacy skills” (mean 3.9; SD 0.8); “Students are attuned to learning with AR” (mean 3.6; SD 1.0).

The average agreement with the statements concerning teacher attitudes is at 4.2 (SD 0.5), showing that the teachers have overall positive attitudes towards AR. Fig. 1 illustrates this average agreement.

b) Teacher Technology Acceptance: On a scale from 1 (strongly disagree) to 7 (strongly agree), teachers showed most agreement with the following three statements about using apps which include Augmented Reality:

“It’s a good idea to use AR apps” (mean 6.3, SD 0.7); “I plan to use AR apps in the future” (mean 6.3; SD 0.8); “I predict I would use AR apps in the future” (mean 6.2; SD 0.9).

Least agreement was achieved with the following items:

“I hesitate to use AR apps for fear of making mistakes I cannot correct” (reverse: mean 5.3; SD 1.7); “I feel apprehensive about using AR apps” (reverse: mean 5.1; SD 1.7); “I find it easy to get AR apps to do what I want it to do” (mean 5.0; SD 1.3).

The average agreement with the statements on technology acceptance is at 5.7 (SD 0.7). Hence, it can be concluded that the teachers in the sample all in all have quite a high technology acceptance. Fig. 2 shows this technology acceptance.
B. Correlations

To deeper explore the sample in this study and to achieve an enhanced understanding of the constructs of teacher attitudes and teacher technology acceptance towards Augmented Reality, it is useful to analyse correlations of these constructs and certain predictors. “Gender”, “AR Experience”, “Teaching Experience” and “Expertise in using digital media in teaching and learning” were defined as potentially correlating predictors for the constructs of “Teacher attitudes towards AR” and “Teacher Technology Acceptance towards AR” based on related research findings [8], [21]. Fig. 3 illustrates the bivariate correlations identified in the data by calculating the Pearson correlation coefficient for every pair of variables after checking for significance (p < 0.05).

![Correlation Diagram](image)

Fig. 3. Correlations between relevant constructs.

As Fig. 3 shows, there is a strong correlation between the constructs of teacher attitudes towards AR and teacher technology acceptance towards AR, \( r = 0.67, p < 0.001 \). There is also a strong correlation between previous AR experience and teacher technology acceptance towards AR, \( r = 0.53, p < 0.001 \). Teacher technology acceptance further correlates with the teachers’ expertise in using digital media in teaching and learning with a medium strong effect, \( r = 0.34, p < 0.001 \). Finally, there is a weak correlation between previous AR experience and teacher attitudes towards AR, \( r = 0.25, p < 0.01 \). Gender and teaching experience do not correlate with the dependent variables nor with any other factors (p < 0.05).

C. Regression Analysis

In case of teacher technology acceptance towards AR, two correlating factors were identified, namely “Previous AR Experience” and “Expertise in using digital media in teaching and learning”. Hence, the roles of these two factors were analysed by means of a multiple linear regression after confirming by a Kolmogorov-Smirnov test that the data is normally distributed (p > 0.05).

When defining teacher technology acceptance towards AR as the dependent variable, again “Previous AR experience” and “Expertise in using digital media in teaching and learning” were confirmed to statistically significant predict teacher technology acceptance, \( F(2, 126) = 27.68, p < 0.001 \). Their standardized coefficient \( \beta \) is 0.47 in case of “Previous AR experience” and \( \beta = 0.18 \) in case of “Expertise in using digital media in teaching and learning”. It was confirmed that there is a low risk of collinearity of the predictors (all VIF values < 1.2). Also, the Durbin-Watson statistic revealed an acceptable level of 2.19, indicating that there is no autocorrelation. The \( R^2 \) of 0.31 indicates that 31 % of the teachers’ technology acceptance towards AR can be explained by the predictors analysed (p < 0.001). According to Cohen [27], the \( R^2 \) of 0.31 (adjusted \( R^2 = .29 \)) is indicative for a high goodness-of-fit for the overall model.

The coefficients confirm that the previous AR experience has a bigger impact on the teacher technology acceptance, as it is approx. 2.6 times as high as the impact of expertise in using digital media in teaching and learning. Overall, it can be concluded that the higher a teacher’s previous experience with AR and his or her self-assessed expertise in using digital media in teaching and learning is, the higher his or her technology acceptance towards AR will be.

V. DISCUSSION

With regards to the two research questions stated above, it was possible to develop or adapt and apply two scales for measuring teachers’ attitudes and teachers’ technology acceptance towards Augmented Reality and to validate their high internal consistency by the methodology introduced. In this context, “teachers’ attitudes towards AR” are understood as predispositions within a teacher and the teacher’s general perceptions about the AR medium while “teachers’ technology acceptance towards AR” is about the predispositions towards using AR in educational contexts and about concrete intentions to apply the medium.

In the analyses, it was found that a teachers’ AR experience and technology acceptance correlates with his or her attitudes towards AR and that “AR experience” and “expertise in using digital media in teaching and learning” are significant predictors for his or her technology acceptance towards AR.

Before discussing these findings, it is important to acknowledge certain limitations to the study. Centrally, the sample is a self-selecting convenience sample because teachers applied voluntarily to take part in the ARETE study on AR. Hence, the sample does not represent the overall average of teachers; instead, these teachers can be expected to have a higher interest in educational technology and Augmented Reality. Their voluntary participation in the pilots further implies a high motivation to explore new technologies and innovative practices. The very positive results for attitudes and technology acceptance in the pre-test, where teachers did not work with the AR intervention apps yet, prove that this group of participants is quite attuned to this innovative medium even though their previous experiences with it tend to be limited.

This high degree of homogeneity within the sample also shows in the low variety of teaching experience. The sample is mostly quite experienced and results, especially from the analysis of correlations, might look different in a more heterogeneous sample.

Furthermore, the survey of teacher attitudes and technology acceptance towards Augmented Reality is based on self-
assessments. For the interpretation of results, it should be kept in mind that self-assessments may be biased and prone to confounding factors such as subjectivity and social desirability. Yet, they appear most suitable to collect data efficiently and anonymously from all teachers in this pilot context.

For the interpretation of the analyses, it is also important to take into account that the data come from 13 different countries. They may not be completely independent but have a nested structure. This cannot be confirmed here with the teacher data due to the very heterogeneous group sizes of teachers per country and the overall sample size. It will be considered though in the post test analysis of student data at a later stage, where the sample size allows for respective multi level analyses.

With regards to the descriptive results outlined above, the remarkably positive attitudes can be explained by the composition of the sample as described in the limitations. Within this frame, certain results stand out. First, it is noteworthy that the characteristic “AR apps can help promote STEM skills” was one of the items with the highest agreement while “AR apps can help promote literacy skills” was one of the items with the lowest agreement. In the ARETE project, AR-apps from the fields of STEM as well as literacy acquisition will be tested in pilots. However, 120 out of 129 teachers are involved in the pilot focusing in the two STEM apps. Therefore, it is likely that the teachers in the sample are more knowledgeable about AR and STEM and show respective expectations and attitudes. Against this background, it will be particularly relevant to look at the success of AR in literacy acquisition in the ARETE pilot study and in other related studies.

With regards to technology acceptance, the three items with the highest agreement refer to the domains of attitude and behavioural intention [21]. This focus is expectable, given the point in time right before the pilot where teachers are applying Augmented Reality apps. The three items with the lowest agreement are from the domains of anxiety and social norms. This could hint at uncertainties with the teachers regarding the use of AR, especially against the background of their relatively limited previous experience with AR. However, also these values are clearly on the side of agreement and thus do not show a descrepancy from the overall positive technology acceptance measured.

The correlations investigated are insightful on different levels, and it makes sense to have a closer look both at the correlations which are not significant and at those that are. With regards to non-significant correlations, the results show that gender and teacher attitudes and gender and teacher technology acceptance do not correlate, meaning that the gender does not have a statistically relevant impact on the result of attitudes and technology acceptance. Similarly, the teaching experience of the participants does not correlate with the two constructs in question. As Pozas and Letzel [8] summarize, the impact of gender on ICT-related constructs has been described with mixed results in related research; according to the established ICILS study, there are no general differences in the attitudes towards ICT of female and male teachers [28]. Hence, the results from this study confirm respective research results that the teachers’ attitudes and technology acceptance do not depend on the teachers’ gender.

With regards to significant correlations, it is expectable that teacher attitudes and teacher technology acceptance towards AR are strongly correlated, given the close relationship between the two constructs outlined above. In the network of relationships displayed in Fig. 3, previous AR experience plays a key role. It correlates both with teacher attitudes and teacher technology acceptance. The regression analysis conducted confirms that previous AR experience functions as a predictor for technology acceptance. As explained above, the sum score of “previous AR experience” consists of three items, namely “Have you heard or read about AR?”, “Have you used AR in your leisure time?”, and “Have you used AR for teaching and learning?”.

Based on these results, it can be concluded that increasing opportunities for teachers to try out and use AR, be it in their leisure time or in professional contexts, will have a positive impact on their attitudes and technology acceptance towards AR, which in turn is expected to have a positive impact on the success of the apps use in class. This finding supports claims from related literature to enhance opportunities for teachers to engage with the innovative medium of AR [8]. Similarly, it appears useful to enhance opportunities for teachers to increase their expertise in using digital media in teaching and learning.

These conclusions are in accordance with the broad field of research on the media-related educational competencies, or digital pedagogical competencies, of teachers. Research has shown in various studies how classroom practice and teaching and learning processes benefit from enhanced respective competencies [29]–[31]. Also according to the Education and Training Monitor [32], teachers need to be equipped with the necessary skills to take advantage of the potential of digital technologies to improve teaching and learning and to prepare their students for life in a digital society. Although frameworks have been in place to address the role of teachers in the digital technology inclusion in educational systems (DigCompEdu European Digital Competence Framework for Teachers [33] and Common Framework for Teaching Digital Competence [34]), uneven ICT skills among teachers became more apparent during the COVID-19 school closures, even though from the data analysis in this paper the teachers show an acceptance for the AR technology.

Hence, the present study adds another facet to this desideratum to support teachers with enhancing their competencies in using digital media for teaching and learning by describing how these competencies can also contribute to teachers’ technology acceptance towards AR and thus facilitate the success of integrating this innovative medium into teaching and learning processes.

Against the background of these pre-test findings introduced, it will be insightful to relate the findings to those from the post-test. Given the correlations and relationships of factors identified, it will be relevant to investigate whether, for example, the role of AR experience can be replicated and thus confirmed, or whether other factors come into play in the post test. Eventually, the comparisons of pre and post-test data, based on the data analysis of pre-test results, will bring to light
the role of teacher attitudes and technology acceptance towards AR.

In the ARETE project, this knowledge will be contextualized with the results of student knowledge tests. This way, it will be possible not only to analyse the development of teacher attitudes and technology acceptance from pre-test to post-test, but also to draw conclusions on its impact on students’ results. This research will ultimately contribute to an enhanced understanding of factors that facilitate a successful integration of AR into teaching and learning processes.

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A Metaverse-based Student’s Spatiotemporal Digital Profile for Representing Learning Situation

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Abstract—In recent years, the metaverse becomes a promising method to provide an intelligent teaching platform for the teaching-learning process. Existing teaching evaluation methods rely on the exam results and the educator’s teaching experience, which is hard to reflect the detailed teaching outcomes and each student’s learning situation. Therefore, this paper proposes a four-layer metaverse architecture to build students’ virtual entities of learning situations, containing a data acquisition layer, a technology layer, a model building layer, and an application layer. Furthermore, the virtual entities are constructed on the event logs recorded in the Learning Management System (LMS) and visualized as spatiotemporal digital profiles for students. In the spatial dimension, the profile can reflect a student’s learning situation in different aspects, including the completion of an assignment, the mastery of knowledge, the practical ability, etc. In the temporal dimension, it can reflect a student’s learning situation at different learning stages. Students’ practical abilities are obtained by the Machine Learning method GBDT (Gradient Boosting Decision Tree), and other dimensions of the profile are generated by the Knowledge Graph technology. With these profiles, educators can do teaching intervention, teaching evaluation, and personalized cultivation, providing a new path for intelligent teaching. We take the CG (Course Grading) platform and Data Structure and Algorithm course as examples to validate our model strategy. The experimental results show that the spatiotemporal digital profiles can better describe students’ learning situations, providing data support for teaching evaluation.

Index Terms—metaverse, education, teaching evaluation, spatiotemporal digital profile, Graph Knowledge

I. INTRODUCTION

Nowadays, the metaverse has attracted a lot of research interests with the development of related technologies. Metaverse is an online digital space parallel to the real world, which is a virtual world that maps and interacts with the real world [1]. Although the metaverse is still in its infancy, it has been applied in many fields, including online games, social application, medical training, and education [1]–[3]. There are many applications of metaverse on curriculum resources and teaching methods. However, the learning situation analysis and teaching evaluation are also central concerns in education. Due to the ability of metaverse to describe entities, we use it to generate students’ profiles for their learning situations and do teaching evaluations according to the profiles.

Traditional teaching evaluation takes the exam results as student profiles and the evaluation is conducted based on the educator’s teaching experiences. The evaluation criterion cannot fully reflect students’ learning situations. Meanwhile, the teaching evaluation is for the cohorts, lacking the personalized analysis of each learner. Although most courses adopt the formative evaluation and take the exam results in different teaching stages as the evaluation standard, it is still hard to reflect the students’ comprehensive learning situations. Therefore, the key is how to get detailed event logs of students’ learning processes.

The use of the Learning Management System (LMS) has grown exponentially in recent years for both online learning courses and blended-learning courses [4], [5]. LMS has many advantages including freedom of learning and practicing, collecting data on all student activities at different levels of granularity [5], [6]. Besides their traditional classrooms, nowadays most universities use the LMS, and the exemplar platforms include BlackBoard [7], Moodle [8] and EDx [9]. In LMS, the learning process data is stored in the event logs, revealing the students’ learning situations. These data contributed affluent resources for constructing profiles of students. The question is, how can we build the profiles?

Several studies have proposed to extract knowledge from the event logs recorded by the LMS with the EPM (Educational Process Mining) technology [5], [10]–[16]. They aim to understand the factors that influence skill acquisition and create models for the educational process [5], [14], [15], [17]. These methods analyze students’ learning patterns, for example, the learning behavior of high-score students and that of the low-
score ones. With the mining results, teachers can check the students’ learning situation that is good or bad. These methods have provided more ways to reflect the students’ learning situation, but they only have two or three fixed patterns. However, we want to get more detailed information about students’ learning situations, such as how many questions have been completed, the completion of questions, the mastery of knowledge, etc. The existing methods are difficult to satisfy such requirements.

With the idea of the metaverse, this paper constructs the virtual entities of students’ learning situations based on the event logs on the LMS platform. We propose a four-layer metaverse for the virtual entity from the macro perspective, containing the data acquisition layer, the technology layer, the model building layer, and the application layer. Furthermore, we visualize these virtual entities as students’ spatiotemporal digital profiles, including profiles of individuals and cohorts.

In the spatial dimension, the profile can reflect a student’s learning situation in different aspects, including the completion of assignments and experiments, the mastery degree of knowledge, and practical ability. In the temporal dimension, it can reflect a student’s learning situation at different learning stages. With the profiles, educators can monitor and analyze each student’s learning situation. Moreover, they can dynamically adjust the teaching methods to accomplish the teaching intervention. Students can also check their strengths and shortages at any time. These are convenient for teachers and students to complete personalized cultivation. Finally, teachers can make accurate teaching evaluations at the end of a course. The profiles of students’ practical ability are obtained by the machine learning method GBDT (Gradient Boosting Decision Tree) [18], [19], and the profiles of other dimensions are generated by the Knowledge Graph technology.

The main contributions of this paper are as follows.

- We propose a four-layer architecture of metaverse to construct the virtual entities of students’ learning situations. These virtual entities are visualized as students’ spatiotemporal digital profiles. To our knowledge, it is the first time to describe the learning situation with metaverse.
- The profiles are built with Graph Knowledge with LMS event logs, including students’ learning situations in different aspects and learning stages. Furthermore, we will generate the profiles of individuals and cohorts, providing a more comprehensive description of students’ learning outcomes.
- With the profiles, we can observe learners’ knowledge acquisition and ability acquisition at any time and do dynamic teaching interventions in teaching. Meanwhile, we can conduct an accurate teaching evaluation at the end of a course, which is more scientific, convenient, and comprehensive.

The rest of this paper is organized as follows. In Section II, we review the related work. Architecture of our four-layer metaverse is introduced in Section III. Spatiotemporal Digital Profiles and Teaching is described in detail in Section IV. In Section V, experimental results are given and analyzed. The conclusion is given in Section VI.

II. RELATE WORK

A. Metaverse

The concept of metaverse originates from the science fiction novel “Snow Crash” written by Neal Stephenson in 1992 [1]. David Baszucki, CEO of Robles, believed that the metaverse is a 3D virtual world that connects everyone in the real world [2]. The metaverse is the integration of the real and the virtual worlds [3], which is supported by the related technologies. At present, most technologies or products that embody the metaverse are mainly limited to the field of electronic entertainment. The text-based interactive game is the primary category of metaverse [20], such as MUSHs (Multi-User Shared Hallucination) [21]. With the rapid advances in computer graphics, virtual worlds equipped with 3D graphics appeared, such as ActiveWorlds [22]. Nowadays, massively multiplayer online video games are probably the most popular version of the metaverse, for example, Second Life [23] and Fortnite [24]. However, it is inappropriate to regard the metaverse as a video game. The metaverse can be applied to various fields, such as education, which breaks through the limitations of the physical world and creates a new virtual educational world through the online teaching platform [25–28].

B. Educational Process Mining

EPM is to extract knowledge from event logs recorded by Learning Management System, Massive Open Online Courses (MOOCs), or Intelligent Tutoring System (ITS). It focuses on the development of a set of intelligent tools and techniques aimed at extracting process-related knowledge from event logs [12], [15], [29]. The application of EPM can be divided into five dimensions, which are discovering learning behavior patterns, predicting the trend of learning outcome, improving teaching evaluation and feedback, providing teaching decision support, and improving education management service. Trcka et al. [30] converted students’ examination records of multiple courses into event logs to analyze the elective courses’ learning paths. Mukala et al. [31] used a fuzzy mining algorithm to extract students’ learning patterns in MOOCs. It has been found that the learning behavior pattern of unsuccessful students is poor and unpredictable, while the behavior pattern of successful students is generally similar. Pechenizkiy et al. [32] applied process discovery and other technologies to analyze online multiple-choice question data and evaluate feedback on the trend of students’ answering behavior. Cairns et al. [33] used conformance checking to analyze the fitness degree between the employees’ training paths and the established curriculum constraints. Anuwatvisit et al. [34] used conformance checking to detect discrepancies.
between the flows prescribed in students’ registration models and the actual process instances.

C. Educational Process Mining and Learning Management System

The LMS allows collecting records corresponding to all events, actions, and activities of students at different granularity levels [5]. Ardimento et al. [14] adopted the fuzzy-based process mining techniques to model the developers’ coding process. The event logs include low-level logs such as keyboard and mouse events and high-level logs such as commands issued at the IDE (Integrated Development Environment) level. Damevski et al. [35] presented a semi-automatic approach for mining frequent developer’s behavior patterns of IDE usage. This method recognized sequences of activities executed by developers, focusing on how developers interact with the IDE. Real et al. [5] aimed to adopt the EPM techniques to mine the students learning paths in an Introductory Programming course. The analysis of these results provided general and specific information on students’ behavior patterns. Ardimento et al. [13] used conformance checking to test coding behaviors from event logs on IDE and studied how developers carry out coding activities and what hurdles they usually face. Etenger et al. [36] attempted to uncover and analyze the patterns of behavior performed by students with higher scores and lower scores, understanding the online course usage patterns and their relationship with learning outcomes.

III. ARCHITECTURE OF THE FOUR-LAYER METAVERSE

At present, the application of metaverse in education mostly focuses on providing virtual learning platforms for learners and educators. Education contains two aspects, which are teaching and learning. But the existing studies mainly focus on teaching. Furthermore, the traditional teaching evaluation method often adopts exam scores, which are not objective and scientific. In this paper, we use metaverse technology to construct the learner’s virtual entity.

According to the characteristics of our application, we propose a four-layer architecture, as shown in Fig. 1, including the data acquisition layer, the technology layer, the model building layer, and the application layer.

- Data acquisition layer. In the data acquisition layer, learners’ learning process data on the LMS teaching platform, teaching evaluation data, and other interaction data are collected as the basis of the system.
- Technology layer. This layer integrates Big Data technology, Machine Learning technology, Knowledge Graph technology, and Digital Twin technology. The Big Data technology can help the system obtain, analyze, and normalize the educational data. The Machine Learning technology constructs students’ practical ability model by analyzing and processing learners’ log data. Digital Twins and Knowledge Graph provide algorithmic support for constructing learners’ virtual entities.
- Model building layer. This layer is the core for constructing the learner virtual entity, including the learners’ learning state model and practical ability model. With the visualization of the virtual entity, teachers and learners can better understand learners’ learning situations, and the horizontal comparison between entities is also more intuitive. The model is built on the Knowledge Graph and the Machine Learning technology, providing a new path for intelligent learning.
- Application layer. This layer provides a friendly interactive interface for students, teachers, managers, and other users to monitor and analyze the teaching process. Through the reports, charts, and other visual means, students’ knowledge network, cognitive ability, and learning behavior data are displayed to users, providing support for optimizing teaching methods, accurate teaching evaluation, and education management. Moreover, it can further stimulate learners to actively learn and enhance teachers’ confidence in cultivating students’ high-level thinking ability.
IV. SPATIOTEMPORAL DIGITAL PROFILE AND TEACHING

A. Digital Profile Based on Knowledge Graph

Knowledge Graph uses visualization techniques to describe the relationship between entities in the world. It can mine a large amount of heterogeneous data and extract their associated relations to construct a knowledge structure network. Triple is a general representation of the Knowledge Graph. The forms of triples include (entity 1 - relationship - entity 2) and (entity - attribute - attribute value). This paper uses the Knowledge Graph technology to handle event logs in LMS. It includes the following steps, data preprocessing, entity extraction, and digital profile generation.

1) Data Preprocessing: There is much information in the LMS platform, such as course information, questions, and learning process log data. Firstly, we extract these data from the learning platform. Secondly, we deal with these data to complete the data cleaning. Finally, data slicing, labeling, and normalizing are done according to the requirements of profile generation.

2) Entity Extraction: This paper extracts the following entity information, including courses, questions, assignments, experiments, exams, students, etc. According to the analysis results, we define the following entities and their attributes in Table 1.

<table>
<thead>
<tr>
<th>ID</th>
<th>Entity</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Course</td>
<td>Name, chapter, section, teacher</td>
</tr>
<tr>
<td>2</td>
<td>Question</td>
<td>ID, type, content, chapter, section, difficulty</td>
</tr>
<tr>
<td>3</td>
<td>Assignment</td>
<td>ID, questions, chapter, score, completion</td>
</tr>
<tr>
<td>4</td>
<td>Experiment</td>
<td>ID, questions, chapter, score, completion</td>
</tr>
<tr>
<td>5</td>
<td>Exam</td>
<td>ID, questions, completion time, score</td>
</tr>
<tr>
<td>6</td>
<td>Student</td>
<td>Student NO., name, password</td>
</tr>
<tr>
<td>7</td>
<td>Knowledge</td>
<td>ID, name, chapter</td>
</tr>
<tr>
<td>8</td>
<td>Practical ability</td>
<td>High, low</td>
</tr>
</tbody>
</table>

We can complete the query and display students’ learning situations according to these entities. Furthermore, analyzing the relationship between these elements to visualize the knowledge structure.

3) Digital Profile Generation: The individual spatiotemporal digital profiles are generated based on the event logs of their learning process and the Knowledge Graph technology. It can reflect students’ learning outcomes in different aspects, including knowledge mastery, completion of an assignment, learning situation in each chapter, practical ability, etc. Moreover, we also show the cohorts’ learning situations. For the cohorts’ profile, we will make statistics on their average learning situations, for example, high score, low score, average score, completion degree, etc. Furthermore, we can query students’ learning situations at any time to check their learning outcomes, providing real-time learning status data. The profile can also avoid the disadvantage that the teaching evaluation can only be carried out at the end of the course.

B. Multi-Granularity Practical Ability Model Based on GBDT

The cultivation of practical ability is one of the most important objectives of a course. Meanwhile, the log data of the learning process in LMS can reflect the students’ acquisition of practical ability for most STEM courses. Therefore, we model students’ practical ability with these log data and the Machine Learning technology GBDT.

Our curriculum system is a long and continuous cultivation process for students’ abilities. Students in different learning stages have different practical abilities. To effectively utilize the feedback data of the prerequisite courses and do fine management for teaching, we propose a multi-granularity modeling strategy for students’ practical abilities at different learning stages, for example, before and after a course. Before a course, we can build students’ primary ability model with the log data of the prerequisite course, and at the end of the course, we can build the advanced ability model with the log data of this course.

This paper adopts the Machine Learning method GBDT to model students’ practical ability, dividing into two steps, feature preprocessing and practical ability modeling.

1) Feature Preprocessing: We define the input dataset as \( D = \{(x_i, y_i)\}, i \in 1, 2, ..., n \), where \( x_i \in \mathbb{R}^z \) is the log feature of student \( i \) with \( z \) dimensions, \( y_i \in [0, 1] \) is the label of this sample, and \( n \) is the number of samples. The label \( y \) represents a student’s practical ability, and we define it as high and low.

2) The Practical Ability Model: According to the learning behavior logs of the prerequisite course and the target course, we build the students’ primary practical ability model \( pF_M \) and the advanced practical ability model \( aF_M \) respectively. Both models are built with GBDT [18], [37] in the same way. The modeling approach is in the [18], [37].

C. Teaching Intervention Based on the Digital Profile

The teaching process should match students’ learning situations to obtain better teaching outcomes. However, existing teaching methods cannot fully adapt to the idea of student-centered, and the teaching contents seldom change in the teaching process. Therefore, this paper does dynamic planning and intervention to the teaching strategy of a course based on the profiles. The teaching plan is divided into two levels, the global plan and the individual plan. The global teaching plan designs the teaching strategy before a course, and the individual teaching plan carries out personalized cultivation for students. Furthermore, we also conduct teaching interventions according to the real-time profiles of students in a course.

D. Teaching Evaluation Based on the Digital Profile

At the end of a course, students’ learning profiles are generated with their event logs of the learning process. With these profiles and the grades of each stage, we can analyze the learning outcomes of this course. In addition, we can also compare students’ profiles at different learning stages
to analyze the changes in cohorts’ abilities and individual abilities. With the above analysis results, the teaching outcome of the course is summarized. Meanwhile, the practical ability model is updated based on the new event logs. Finally, the closed-loop teaching process of the course is completed.

V. EXPERIMENTS

A. Experiment Settings

We take the CG (Course Grading) [38] platform and the Data Structure and Algorithm course to validate our instructional strategy. The study involved three grades in the School of Computer Science. The event logs of the two grades of 620 students are used as training data for the practical ability models. Meanwhile, the building of the student spatiotemporal profiles is conducted on 27 students of the last grade. We use Python language and the Neo4j toolkit to generate students’ spatiotemporal digital profiles.

B. Spatiotemporal Digital Profiles

We visualize students’ spatiotemporal digital profiles for learning situations based on the event logs on the CG platform, including individual completion of assignments and knowledge mastery, and cohorts’ learning situations. Our goal is to display students’ learning situations in each learning stage. Therefore, the profiles are not only displayed by course but also by chapter.

1) Completion of Assignments for Students: We can check the completion of students’ assignments at any time to supervise students to work hard. The score of the assignment for each student in chapter linear list is in Fig. 2.

Fig. 2 clearly shows the score of each student’s assignment in this chapter. We have graded the results and displayed them at different levels. Grade A to E denotes the grades from excellent to fail. $Q_i$-j represents question j in chapter i, $K_i$-j represents knowledge j in chapter i, and one knowledge can contain multiply questions. With this result, we can understand the cohorts’ completion of assignments and supervise the students with poor progress, for example, $stu_3$, $stu_7$, $stu_18$, and $stu_23$.

Furthermore, we can also visualize a student’s score for each question in an assignment to check the complete details. The knowledge of each question is also displayed. Student $stu_27$’s score of each question in chapter graph is as Fig. 3.

In Fig. 3, we can figure out what questions and knowledge are not well mastered, facilitating the improvement of weak knowledge. For example, $Q7_3$, $Q7_24$, and $Q7_35$, and their knowledge $K7_3$. While knowledge $K7_1$ is better mastered.

Moreover, we can show the scores and completion degrees of each assignment, which are shown in Fig. 4. It intuitively
displays the reason why a student does not get full marks. Is it because you didn’t complete all the questions or didn’t correct all the questions. In addition to the profiles shown in the paper, we can also click on the entity to view its detailed attributes, for example, student number, ID, and practical ability, which are shown in the upper right of Fig. 4.

2) Student’s Knowledge Mastery: In this section, we display the knowledge mastery of the individual and the cohorts, which are shown in Fig. 5 and Fig. 6.

The mastery of each knowledge is the average score of all the questions under this knowledge. In Fig. 5, stu_23’s mastery of all knowledge in chapter graph is low, showing that his grasp of these contents is not ideal. Therefore, we should pay more attention to him. Furthermore, the contents in this chapter are hard for most students, which can also be seen in Fig. 6. For this part, teachers should strengthen the guidance to students and urge them to do more exercises.

3) The Cohorts’ Learning Situations: Moreover, we can analyze the cohorts’ learning situations in a class at different teaching stages. The average scores, average completion, and max score of all students for some knowledge are in Fig. 7. The score is normalized by 0 to 10.

In Fig. 7, we can figure out the cohorts’ learning situations for some knowledge. The max scores of all knowledge are 10, indicating that some students are doing well. The completion of questions related to knowledge is high, but the average
scores of most knowledge are not ideal. For example, \(k_7^3\), \(k_7^4\), \(k_7^7\), \(k_6^2\), \(k_6^3\), and \(k_6^4\). This figure shows that most students’ mastery degrees of knowledge are not ideal, and everyone needs to do harder. With the cohorts’ profiles, we can easily understand the average mastery of knowledge and strengthen the training of weak points. Compared with the traditional method of score statistics, it is more diversified and effective.

In addition to the above profiles, we can also make various queries according to the log data on CG to display different aspects of students’ learning situations, providing data support for teaching design and teaching evaluation.

VI. CONCLUSION

To generate detailed spatiotemporal digital profiles for students’ learning situations, this paper employs metaverse technology to build students’ learning virtual entities. We propose a four-layer architecture to construct the virtual entity with the events logs on LMS. We extract the features from these logs and use Knowledge Graph to generate the digital profiles, including the learning status of different learning links and teaching stages. Furthermore, a multi-granularity practical ability model built with GBDT is proposed to describe students’ practical abilities at different teaching stages. Finally, we take the CG platform and the Data Structure and Algorithm course as examples to validate our model strategy. The experimental results show that the spatiotemporal digital profiles can be more intuitive and detailed for describing students’ learning outcomes. Therefore, educators can do accurate teaching evaluations based on the profiles. Furthermore, the digital profiles can also provide strong data support for teaching intervention, teaching evaluation, and personalized cultivation, forming a new path for intelligent teaching. In the future, we should continue to refine students’ digital profiles.

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User Interaction Satisfaction with Simulation Games Used in Learning about ERP Systems

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Abstract—This study attempts to evaluate the user interaction satisfaction with ERPsim games, using data from a survey of graduate students who used ERPsim games in a course of enterprise resource planning (ERP) systems. The results show that the respondents are generally satisfied with the user interaction with the ERPsim game. The results also show that the areas of screen factors, terminology, and system information, learning factors, and usability and user interface are found to have positive effects on the overall reactions to the ERPsim game, while the area of system capabilities is found to have no effect on the overall reactions to the ERPsim game. The results would be helpful to those who use ERPsim games as instructional tools as well as those who design the user interaction with ERPsim games and SAP ERP system in which ERPsim games run.

Index terms—simulation game, enterprise resource planning (ERP), user interaction, user satisfaction

I. INTRODUCTION

ERPsim is a set of computer-based simulation games for SAP enterprise resource planning (ERP) system in which participants use the system to manage their virtual company in a competitive market [1]. ERPsim games were developed by ERPsimLab at HEC Montréal and the games have been widely used as instructional tools in more than 225 universities worldwide as well as in many corporations [2]. While many students and business people have come to use ERPsim games in learning about SAP ERP system, it seems that little is known about how much users are satisfied with user interaction with ERPsim games and what areas of user interaction with ERPsim games users are satisfied with or not.

The objective of this study is to examine the extent to which users are satisfied with various areas of user interaction with ERPsim games. On a theoretical level, this study can help advance our understanding of user interaction as being associated with ERPsim games and SAP ERP system on which ERPsim games run and extend the line of research on computer self-efficacy and computer use. On a practical level, this study can help understand and improve the user interaction with ERPsim games on the part of developers and enhance user experiences with ERPsim games as instructional tools with reasonable expectations of user interaction on the part of users.

II. THEORETICAL BACKGROUND

A. User Interaction Satisfaction

This study attempts to extend the line of studies on computer self-efficacy into the user interaction satisfaction with ERPsim games. Computer self-efficacy is defined as a user’s ability to use the computer to perform a specific task [3], [4], [5]. Studies on computer self-efficacy suggest that computer self-efficacy is a significant determinant of an individual’s intention to use computers [5], [6], [7]. A wide body of studies has examined computer self-efficacy as it is associated with ERP systems. For example, Mouakket [5] shows that computer self-efficacy has a significant effect on ease of use of ERP systems, which in turn has a positive effect on the use of ERP systems. Park et al. [8] report on the positive impact of ERP systems on the absorptive capacity of users. Elkhani et al. [9] also show that computer self-efficacy has a positive effect on usefulness and ease of use of ERP systems, which in turn has a positive effect on the use of ERP systems.

While these studies have examined computer self-efficacy being associated with ERP systems, few have studied the constructs of user interaction as they relate to computer self-efficacy of ERPsim games that run in SAP ERP system. Understanding the user interaction satisfaction with ERPsim games is crucial to the successful use of ERPsim games as instructional tools on the part of users and to the effective improvement of user interaction of ERPsim games and SAP ERP system on the part of developers.

B. ERPsim Games

ERPsimLab at HEC Montreal provides several editions of ERPsim games including: Distribution, Logistics (Introduction, Extended, and Platinum), Manufacturing (Introduction, Extended, and Advanced), and Retail (Introduction and Extended) Games. All ERPsim games use SAP ERP system. SAP ERP system leads the ERP market with more than twelve million users in more than 121,000 installations worldwide [11].

For this study, we used the ERPsim Distribution Game, while we plan to extend the study to the other ERPsim games in the future. Fig. 1 shows the layout of the ERPsim Distribution Game. In the game, participants operate the process of planning, procurement, and sales of a wholesale distribution company that sells bottled water in Germany. The game runs for three rounds with each round running for 20 virtual days (1 minute per day).
Fig. 1. Layout of ERPsim Distribution Game

Fig. 2. Transactions and reports of ERPsim Distribution Game

III. DATA AND METHODS

For this study, we used the items of the constructs of user interaction satisfaction adopted from the Questionnaire for User Interaction Satisfaction (QUIS). Since the QUIS was developed at the Human-Computer Interaction Laboratory of the University of Maryland at College Park [10], many studies have used it in assessing user perception, interaction, and usability of various computer-based systems, for example, user perception of digital library [12], consumer evaluations of internet service quality [13], and user experiences with automatic video retrieval technology [14].

Fig. 3. Screenshot of change price list transaction of ERPsim Distribution Game

TABLE I shows the QUIS measures in the six areas of user interaction including: (1) screen factors, (2) terminology and system information, (3) learning factors, (4) system capabilities, (5) usability and user interface, and (6) overall reactions to the system, and the items of each measure and their scales. One item of the screen area and another item of the overall reaction to the ERPsim system were dropped (crossed out) in this study, as they appear to be irrelevant to the ERPsim game. Each item measures the user’s satisfaction with the respective interaction area on a 9-point scale.

Data for this study was collected from a survey of forty-three graduate students who took a course of ERP systems. Students filled in the survey in the last week of the semester after they practiced with SAP ERP system for various business processes including procurement, production planning and execution, fulfillment, and warehouse and inventory management and then used the ERPsim Distribution Game in the last week of the class.

Data collected was analyzed in three steps. First, we calculated the descriptive statistics of the items of the six constructs of user interaction satisfaction. Second, we performed the factor analysis on the six constructs to see the appropriateness of psychometric properties of the constructs. Third, we performed regression analyses to explore any effect of each of the five constructs (excluding the construct of overall reactions) as a predictor on the construct of overall reactions.

IV. RESULTS AND DISCUSSION

TABLE II shows the mean values and standard deviations of the items of the six constructs of user interaction satisfaction. It is worth noting that the mean values do not vary much across the six constructs, ranging from 5.6585 to 7.8571. The respondents in general seem satisfied with the user interaction with the ERPsim game, while there is still a room for improvement in all six constructs. The construct of usability and user interface (V5) shows the highest satisfaction, whereas the construct of system capabilities (V4) shows the lowest satisfaction. Two items – system speed and system reliability – in the construct of system capabilities show the lowest satisfaction among all the items. The relatively low satisfaction with these two items may be associated with such technical issues as the Internet
connection and remote servers, as ERPsim games use remote ERPsim servers via the Internet.

### TABLE III shows the results of factor analysis performed on the six constructs of user interaction satisfaction. Overall, the psychometric properties of the items of the six constructs seem appropriate. The QUIS seems highly reliable across diverse types of user interaction, as noted by the QUIS developers [10].

### TABLE IV shows the results of regression analysis of each construct as a predictor on the construct of overall reactions to the ERPsim game. Each of the four constructs including those of screen factors (V1), terminology and system information (V2), learning factors (V3), and usability and user interface (V5) has a significant positive effect on the construct of overall reactions to the ERP game (V6), indicating all these four constructs are significant predictors for the construct of overall reactions to the ERPsim game. However, the construct of system capabilities (V4) has no significant effect on the construct of overall reactions to the ERPsim game (V6). This result is interesting, as the construct of system capabilities (V4) also shows the lowest satisfaction among the six constructs (see TABLE II).

### TABLE V shows the inter-correlations among the six constructs of interest. All the correlations are found to be significant, except the correlations between the construct of system capabilities (V4) and the other five constructs. The construct of system capabilities (V4) even shows a significant negative correlation with the construct of terminology and system information (V2), indicating that the more satisfied with terminology and system information the respondents are, the less satisfied with system capabilities they are.

The results taken together show that the respondents are generally satisfied with the five constructs (V1, V2, V3, V5, and V6) of user interaction with the ERPsim Distribution Game. Further, the positive effects of the four constructs (V1, V2, V3, and V5) on the overall reactions (V6) in turn may have a positive effect on the use of the ERPsim game. Of course, we need more studies to explore any associations of the constructs of user interaction satisfaction with the use of the game. The results on the construct of system capabilities (V5) may be explained in part by the fact that all ERPsim games run on the same SAP ERP platform, and so, the results are more about the SAP ERP system in general, not the ERPsim game in particular. Also, the results of this study may be applicable to the other ERPsim games, as they run on the same SAP ERP platform. However, since each ERPsim game requires a separate set of knowledge that underlies the respective game’s business process, e.g., logistics, manufacturing, or retailing, the perceptions of user interaction with each ERPsim game may vary. In this regard, we need further studies to extend this study to other ERPsim games and explore any associations between user interaction satisfaction and the knowledge of underlying business process of each ERPsim game.

### V. CONCLUSION

This study attempted to evaluate the user interaction satisfaction with the ERPsim game used as an instructional tool.
Our results indicate that the respondents are generally satisfied with user interaction with the ERPsim game. Our results also indicate that the constructs of screen factors, terminology and system information, learning factors, and usability and user interface are significant predictors for the construct of overall reactions to the ERPsim game.

### TABLE III. FACTOR ANALYSES OF STUDY CONSTRUCTS

<table>
<thead>
<tr>
<th>Variables</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen (V1)</td>
<td>0.7401</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Characters on the computer screen</td>
<td></td>
<td>0.9172</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organization of information on the screen</td>
<td></td>
<td></td>
<td>0.9330</td>
<td></td>
</tr>
<tr>
<td>Sequence of screens</td>
<td></td>
<td></td>
<td></td>
<td>0.7974</td>
</tr>
<tr>
<td>Terminology and system information (V2)</td>
<td>0.7874</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of terms throughout system</td>
<td></td>
<td></td>
<td></td>
<td>0.8053</td>
</tr>
<tr>
<td>Terminology is related to the task you are doing</td>
<td></td>
<td></td>
<td></td>
<td>0.8723</td>
</tr>
<tr>
<td>Position of messages on screen</td>
<td></td>
<td></td>
<td></td>
<td>0.9176</td>
</tr>
<tr>
<td>Messages on screen which prompt user for input</td>
<td></td>
<td></td>
<td></td>
<td>0.8780</td>
</tr>
<tr>
<td>System keeps you informed about what it is doing</td>
<td></td>
<td></td>
<td></td>
<td>0.7757</td>
</tr>
<tr>
<td>Error messages</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning (V3)</td>
<td>0.8243</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning to operate the system</td>
<td></td>
<td></td>
<td></td>
<td>0.9024</td>
</tr>
<tr>
<td>Exploring features by trial and error</td>
<td></td>
<td></td>
<td></td>
<td>0.8272</td>
</tr>
<tr>
<td>Remembering names and use of commands</td>
<td></td>
<td></td>
<td></td>
<td>0.8378</td>
</tr>
<tr>
<td>Tasks can be performed in a straight-forward manner</td>
<td></td>
<td></td>
<td></td>
<td>0.7273</td>
</tr>
<tr>
<td>Help messages on the screen</td>
<td></td>
<td></td>
<td></td>
<td>0.8810</td>
</tr>
<tr>
<td>Supplemental reference materials (such as Job Aid)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System capabilities (V4)</td>
<td>0.9233</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System speed</td>
<td></td>
<td></td>
<td></td>
<td>0.9164</td>
</tr>
<tr>
<td>System reliability</td>
<td></td>
<td></td>
<td></td>
<td>0.8447</td>
</tr>
<tr>
<td>System tends to be: noisy to quiet</td>
<td></td>
<td></td>
<td></td>
<td>0.9026</td>
</tr>
<tr>
<td>Correcting mistakes</td>
<td></td>
<td></td>
<td></td>
<td>0.8623</td>
</tr>
<tr>
<td>Experienced and inexperienced users' needs are taken into consideration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usability and user interface (V5)</td>
<td>0.8259</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of colors and sounds</td>
<td></td>
<td></td>
<td></td>
<td>0.8901</td>
</tr>
<tr>
<td>System feedback</td>
<td></td>
<td></td>
<td></td>
<td>0.9163</td>
</tr>
<tr>
<td>System response to errors</td>
<td></td>
<td></td>
<td></td>
<td>0.9013</td>
</tr>
<tr>
<td>System messages and reports</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System clutter and user interface &quot;noise&quot;</td>
<td>0.8511</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall reactions to the ERPsim system (V6)</td>
<td>0.7653</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrible to wonderful</td>
<td></td>
<td></td>
<td></td>
<td>0.7667</td>
</tr>
<tr>
<td>Difficult to easy</td>
<td></td>
<td></td>
<td></td>
<td>0.9223</td>
</tr>
<tr>
<td>Frustrating to satisfying</td>
<td></td>
<td></td>
<td></td>
<td>0.9123</td>
</tr>
<tr>
<td>Rigid to flexible</td>
<td></td>
<td></td>
<td></td>
<td>0.9038</td>
</tr>
</tbody>
</table>

### TABLE IV. SUMMARY OF REGRESSION ANALYSES

<table>
<thead>
<tr>
<th>Variables</th>
<th>Dependent variable: V6</th>
<th>Beta</th>
<th>t</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V1</td>
<td>0.766</td>
<td>7.534</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V2</td>
<td>0.732</td>
<td>6.706</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V3</td>
<td>0.793</td>
<td>8.018</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V4</td>
<td>0.132</td>
<td>0.822</td>
<td>0.416</td>
<td></td>
</tr>
<tr>
<td>Model 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V5</td>
<td>0.794</td>
<td>8.151</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

The results of this study suggest that on the part of developers of the ERPsim game or similar computer simulation games used for instructional tools, enhancing the screen factors, terminology and system information, learning factors, and usability and user interface can help improve the overall reactions to the ERPsim game. Also, on the part of users of the ERPsim game or similar computer simulation games for instructional and learning tools, understanding the user interaction of the games could help them prepare with reasonable expectation of the games and improve their instructional and learning experiences with the games.

### A FEW LIMITATIONS

A few limitations are recognized in this study. First, the results of this study are somewhat attenuated because of the small sample size and inherent problems related to perceptual studies. We plan to collect more data from students who use ERPsim games in the class. Second, we considered only six constructs of the QUIS about the user interaction with the ERPsim game. We may need to develop more comprehensive and capable instruments with a high validity and reliability in order to capture and operationalize the factors associated with user interaction with ERPsim games and further SAP ERP system. Third, we examined only the perceptions of a group of graduate students in a classroom setting. It would be more desirable to examine the perceptions of other users of ERPsim games for more balanced and generalizable findings. Fourth, we used the data from students who used only one ERPsim game (i.e., Distribution Game) in the class. We plan to extend this study to other ERPsim games to examine the applicability of the results of this study. These limitations are certainly not exhaustive, but important ones. Obviously, these limitations suggest several possibilities for future studies.

### ACKNOWLEDGMENT

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### REFERENCES


Teaching Virtual Reality in Virtual Reality

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Abstract—Virtual Reality (VR) technologies have the potential to improve online education for students. This paper reports on a course on the topic of virtual reality using VR technologies and Mozilla Hubs. Findings from student questionnaire responses suggest that students appreciated the unique educational experience of learning about VR in VR and felt more present in VR when compared to other online learning experiences. However, it was noted that using a VR headset made it difficult to take notes and became uncomfortable for some students after long periods of time.

Index terms—virtual reality learning environment, evaluation

I. INTRODUCTION

Virtual Reality (VR) is an advancing technology with applications in sectors such as medical simulations [1], art design [2], and history [3]. Through computer equipment such as a computer monitor or a Head-Mounted Display (HMD) device, VR technology allows users to feel a heightened sense of presence in virtual environments. The benefits of VR have intrigued educators, motivating many to investigate the use of Virtual Reality Learning Environments (VRLEs) in their classrooms. Current research suggests that VRLEs boost student engagement and excitement for courses [4], [5].

While the authors have been involved with virtual reality development and instruction for quite some time, neither had ever taught a course using VR technologies. Thus, funding was obtained to purchase Oculus Quest units for every student (30 total) enrolled in a VR course so that students could experience VR while learning about it. This paper describes the authors’ development of a virtual classroom for VR instruction, and the evaluation of the student experience of taking the course in VR.

II. RELATED WORKS

This section explores previous and current applications of online social VRLEs and their benefits in education. In addition, the importance of designing VRLEs to enhance the sense of presence is discussed.

A. Application of VRLEs

Over ten years, research from Empire State College found VRLEs to be engaging, motivating, and flexible for students [5]. Courses were taught in the popular online VRLE platform Second Life. Second Life allows students to connect worldwide and provides a rich virtual landscape in which students can engage. The platform also allows students to customize certain areas on the virtual campus. The possibility for students to create content and collaborate could enhance student exploration of the platform because students are encouraged to revisit virtual areas together for a review of content [5].

The method in which the material in the VRLE is viewed is important for students. According to a National Science Foundation-sponsored study, students preferred utilizing an HMD device to access a VRLE as compared to a regular desktop monitor [6]. However, some students noted they would get motion sickness after prolonged time in the HMD and switched to a desktop monitor. This project used an online VRLE platform known as Mozilla Hubs that students can access through a web browser without installing any software. The accessibility of the platform allows students to visit the VRLE on most devices with a web browser. Compared to traditional video conferencing tools, VR was found to be more effective in delivering a sense of belonging and presence to students [6].

Researchers are beginning to explore the effects of using an online VRLE platform on educational outcomes. One project that compared the Mozilla Hubs platform to a video conferencing platform found no negative impact from using the VRLE [7]. There were findings to support the idea that the VRLE might be beneficial to use for smaller class sizes due to the technical limitations of some of the VRLE platforms. On the Second Life platform, research suggests that educational outcomes are similar to learning outcomes from in-person learning [8]. The authors of this paper seek to add to the body of research on using VRLEs and their impacts on students.

B. Design and Presence in VRLE

Presence is the feeling of physically being transported to another reality or world with the potential to act within the world [9]. The sense of presence in online environments supports the individual’s sense of belonging and enjoyment which could positively impact their educational experience [10]. Educators at Appalachian State University used an online VRLE campus designed for their students in hopes of improved engagement and enjoyment [4]. The students felt present and motivated in the online VRLE because they could associate social and learning experiences with the design of the virtual campus. For example, the virtual campus had a cafe in which students could hang out and study. A virtual classroom on the campus provided an area for the students to focus on educational topics. The student-centered design suggested improved presence and educational growth [4]. Simple design choices such as the color of the wall or the placement of objects impact student outlook.
and presence in a VRLE [11]. The student perspective is essential when applying the VRLE in the classroom [5], [12].

III. THE VIRTUAL REALITY CLASSROOM AND COURSE

A. Mozilla Hubs

For our course, we used the online social VRLE platform Mozilla Hubs because it offers access on many devices and allows for the development of custom virtual spaces. Because Hubs uses the latest WebXR software, Hubs can be accessed through a web browser with no downloads required. Students can also access Hubs through HMD devices, smartphones, and laptops. Virtual spaces can be developed for Mozilla Hubs using Spoke, a free online virtual world creator tool that allows developers to design a virtual space from scratch or build on top of existing templates. Once a virtual space has been completed, it can be uploaded from Spoke to Hubs and easily shared through an invite link. After following the link, participants have the choice to pick their avatar appearance and display name; then participants can join the virtual space. Once inside the space, participants can communicate through text, emojis, and their voice. Hubs also allows users to quickly add virtual objects to the space, and share their computer screens or webcams.

![Fig. 1. Our virtual reality classroom in Mozilla Hubs with instructor podium (lower left) and a projection screen for lecture slides (right).](image)

B. Design of the VRLE

As noted previously, the design of the VRLE supports the feeling of presence for students. Thus, we followed notes from previous research on designs of VRLEs [11] and designed our virtual reality classroom to be an open space with a curvature architecture. Familiar virtual furniture such as an instructor podium and projection screen provided an anchor for students to use during the lecture. As pictured in Fig. 1, the instructor used these design elements which students assembled around during class lectures. Mozilla Hubs supports spatial audio, meaning that the volume of the speaker’s voice becomes less the further away someone’s avatar is from the speaker. Thus, students had to assemble near the podium during lectures to hear the instructor. The instructor often had students complete activities in groups during class time. Thus, the VRLE was designed with spaces to support group work. Each group was assigned a designated space, and each space had its own projection screen, as shown in Fig. 2. The intent was to allow each group to easily collaborate virtually without interfering with others. Like an in-person classroom, if students wanted to collaborate with another group, they could navigate to the meeting place of that group.

![Fig. 2. A student group meeting at their assigned projection screen.](image)

C. Content of the Virtual Reality Course

The content of the virtual reality course was arranged into three units: applications, foundations, and evaluation. The structure of the course is described in more detail in [13]. During the applications unit, students learned about application areas of VR in modeling, training, and gaming. The course met in a physical classroom during the first part of this unit. Students were then presented with their Oculus Quests at the end of the applications unit so that they could attend future class sessions in the VRLE while wearing their Quest.

All class periods for the foundations unit took place in the VRLE. Most class sessions for the evaluation unit took place in the VRLE. However, student teams met in person to conduct usability testing sessions for their final VR projects. The class also met in person on the last day of the term to hold a VR Showcase at which students demonstrated their final projects. This event was open to the public. Two exams were held during the term. Students completed these exams through the Canvas course management system and thus were not required to attend class either physically or in VR. In total, 26 class sessions were held in our VRLE. Of these 26 class sessions, 10 were devoted to allowing student teams to meet at their assigned projection screens to discuss progress on their final projects with the instructor. During the other 16 sessions, the instructor taught the course content through a combination of lectures, discussions, and activities. Lecture slides were presented on the projection screen near the front of the VRLE (as shown in Fig. 1).

IV. EVALUATION

Thirty students completed the course during the fall 2021 term. Twenty-two students were enrolled in engineering and computer science graduate programs, and eight students were enrolled in computer science and emerging media undergraduate programs. During the last class session in VR, students were invited to complete an anonymous questionnaire through Canvas that asked about their opinions of many aspects of the course and the VRLE. The questionnaire was designed by the authors, and it was approved by the Institutional Review Board (IRB) at the authors’ university. Twenty-seven students
completed some portion of the questionnaire. The questionnaire contained the following six Likert scale items:

1) Which of the following best describes your agreement with the statement, “I enjoyed class sessions held in virtual reality”?

2) Which of the following best describes your agreement with the statement, “I felt that class sessions in virtual reality were effective”?

3) Which of the following best describes your agreement with the statement, “The spatial audio (the ability to hear more clearly the closer you got to another person’s avatar) in Mozilla Hubs increased my sense of presence during class sessions”?

4) Which of the following best describes your agreement with the statement, “The virtual podium and projection screen in our Mozilla Hubs classroom were more engaging than screen sharing in Zoom”?

5) Which of the following best describes your agreement with the statement, “Class sessions held in virtual reality and Mozilla Hubs were as effective as class sessions held in Zoom for other online courses I have taken”?

6) Which of the following best describes your agreement with the statement, “Class sessions held in virtual reality and Mozilla Hubs were as effective as class sessions held in person for other courses I have taken”?

Table 1 shows the results for the six Likert scale items. Students were also asked to explain their response to each of these six Likert scale items. The explanations were analyzed by identifying recurring themes.

**TABLE 1. RESULTS OF THE SIX LIKERT SCALE ITEMS**

<table>
<thead>
<tr>
<th>Item</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
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<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>11</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
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<td>8</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Regarding item 1 (“I enjoyed class sessions held in virtual reality”), 21 respondents agreed or strongly agreed with the statement, suggesting that an overwhelming majority of students did enjoy class sessions held in virtual reality. The most common theme in the explanations was that students appreciated the remote aspect of the course. For example, one student wrote, “I felt like I was in class but at home” and another wrote, “I could take the classes from anywhere.” Another theme was that class sessions held in VR helped students to learn about the topic of VR. For example, a student wrote, “It was a new experience and helped me see virtual reality used in a practical way”. A final theme was that students experienced challenges in attending class sessions in VR, such as “network stability”, “open mics”, and that it was “very difficult to take notes with the headset on.” These issues may help to explain why not all students indicated enjoying class sessions in VR.

Regarding item 2 (“I felt that class sessions in virtual reality were effective”), 15 respondents agreed or strongly agreed, and 12 were neutral or disagreed. One of the most common themes mentioned by students was that many aspects of VR classes were like real-world classes. For example, a student wrote, “What students can do when taking class in VR or taking a live in [person] class, such as ask questions or group discussion, are almost the same.” However, students indicated that there is “a huge need for learning tools that are accessible in VR” and “I often came to lecture via my computer rather than the Oculus to ensure I could take notes during class time.” It appears that while students felt VR course sessions could replicate much of what occurs in college classrooms, such as lectures, group discussions, and asking questions of the instructor, the difficulty of taking notes while wearing the Oculus Quest caused some students to abandon use of their Quest, and they instead attended class sessions on their personal computers.

Regarding item 3 (“The spatial audio in Mozilla Hubs increased my sense of presence during class sessions”), 15 respondents agreed or strongly agreed with the statement, and 11 were either neutral or disagreed with the statement. Two comments summarize well what students wrote regarding this item: “It increased my sense of presence because I felt as I was only talking to the people in my vicinity similar to a classroom” and “I feel that in theory, it would, but often I was able to hear people on the other side of the virtual world as if they were standing right next to me.” Students indicated that the spatial audio did increase presence because it was much like real-world sound. However, some students struggled to specify volume settings correctly so that they could only hear those around them, and not people throughout the entire virtual space.

Regarding item 4 (“The virtual podium and projection screen in our Mozilla Hubs classroom were more engaging than screen sharing in Zoom”), 17 respondents agreed or strongly agreed with the statement, eight were neutral, and one strongly disagreed. A student wrote, “Far more engaging. Zoom felt generic, and providing a virtual podium and projection screen made the overall Mozilla Hubs experience more engaging,” and another wrote, “When all the students face the presenter, it does feel like we are in a classroom environment.” However, one student responded, “the screen was often too small to read and other people’s avatars were in the way.” These responses suggest that students felt the structure of the VR classroom provided an engaging environment that reminded students of real-world classrooms. However, some students found it difficult to read the slides because of resolution issues and other students blocking their view. It should be noted that during the term, a student suggested to the instructor that “flying” should be enabled in the Mozilla Hubs classroom so that students could fly to better vantage points to see the slides and hear the instructor (flying students can be seen in Fig. 1). A student wrote, “I overall agree with this statement, but I did not before fly mode was activated. It was difficult to get a good view of the slides without constant student interference without fly mode.” Thus, allowing students to fly during class sessions may have improved the VR experience for some students.

Regarding item 5 (“Class sessions held in virtual reality and Mozilla Hubs were as effective as class sessions held in Zoom for other online courses I have taken”), 18 respondents agreed...
or strongly agreed with the statement, four were neutral, and three disagreed or strongly disagreed with the statement. One common theme present in the explanations for this item was that VR courses were “engaging.” For example, a student wrote, “Yes, they were more effective than Zoom classes. The virtual world made the class a lot more engaging than a class held in Zoom.” However, students did indicate some limitations to VR courses such as, “Zoom has the benefit of easier note-taking and being able to go back for the recording” and “Since the slides were difficult to see, it made it difficult to concentrate. These are not issues in Zoom.” Thus, while students felt that VR courses were engaging, the lack of tools for notetaking and class recording, and the difficulty in seeing the lecture slides, detracted from the learning experience for some students.

Regarding item 6 (“Class sessions held in virtual reality and Mozilla Hubs were as effective as class sessions held in person for other courses I have taken”), 13 respondents agreed or strongly agreed, two were neutral, and 10 disagreed or strongly disagreed with the statement. Clearly, there was considerable disagreement amongst the students towards this item. One comment seemed to summarize well many of the issues mentioned by students, “Besides the occasional issues with the audio and power point videos not playing correctly I think that Hubs was as effective as in person lectures. I would say I prefer the VR and remote version of the class as it makes things a bit easier to attend class as you can attend from almost any location.” Students appreciated the flexibility that online courses offered. However, students did experience many issues that detracted from the VR learning experience such as real-world distractions (“people talking to me, doors being knocked on, etc.”), “many technical problems”, and “the note-taking issue again.” Students also commented that the type of course might have an impact on its effectiveness in VR. For example, a student wrote, “Overall, I think in-person class is unbeatable learning-wise. But for a VR class, having sessions in VR seems like the best possible option.” Learning about VR in VR likely enhanced the educational experience for some students.

The questionnaire concluded with these five items:

7) What did you think about the virtual layout of our classroom in Mozilla Hubs? Do you have any comments about the placement of the virtual objects in the virtual classroom (podium, projection screen, …)?

8) What did you think was the best thing about having class sessions in virtual reality?

9) What did you think was the worst thing about having class sessions in virtual reality?

10) If you had an opportunity to take another course in a topic of interest to you using Mozilla Hubs and the Oculus Quest would you do it?

11) Do you have any suggestions for improving the way virtual reality technologies were used for instruction in COMP 193/253?

Note that items 7, 8, 9, and 11 were free response items. Subjects answered “yes” or “no” for item 10 and provided an explanation for their answers. As with items 1-6, free responses and explanations were analyzed by identifying recurring themes.

For item 7 (“What did you think about the virtual layout of our classroom in Mozilla Hubs”), two reoccurring suggestions were to make the main projection screen larger and to have the instructor podium on a stage so the instructor was easier to see. For example, a student wrote, “The podium can have a stage to make it higher, and the main projection screen can be larger, so we all can watch the screen. The classroom is crowded sometime.” Others mentioned having “platforms to stand on” so that students in the air were not just floating in space during class sessions. Some students also mentioned making “the group meeting points a little more isolated” and that it “would be interesting to have each team form their own room and paste the link to that room in the main lecture area. A world with gateways to other worlds.” Thus, some students suggested features like those found in lecture auditoriums (such as stages and large projection screens), while others recommended taking greater advantage of what is only possible in a virtual space (such as floating platforms to stand on and links to other virtual spaces).

For item 8 (“What did you think was the best thing about having class sessions in virtual reality”), there were two common themes. The first was the flexibility that online courses offer. A student made this comment, “I can be at home but feel like I’m in the actual classroom.” The second theme was the increased level of immersion that VR provides as compared to other online courses. For example, a student wrote, “The best thing about having classes in VR was the greater sense of immersion that it gave me when compared to a Zoom class.”

For item 9 (“What did you think was the worst thing about having class sessions in virtual reality”), most responses mentioned technical issues, such as “bad audio and poor connection”, and “people don’t have their mic mute when they are making noises.” These issues are likely not specific to virtual reality class sessions, but problems common to online courses in general. Others mentioned issues such as, “Difficulty in taking notes. Difficulty seeing slides.” These issues were mentioned in responses to previous items. One student stated, “Having the class within the headset during the day requires having to transport the headset around campus all day.” Having a smaller form factor for virtual reality headsets may increase access to virtual reality courses. Other students stated, “Lack of communication and engagement with fellow students” and that it was “different than human interaction.” While VR may allow for an increased sense of presence over course sessions held in other online modalities, our students still felt that it was not the same as course sessions in person.

Regarding item 10 (“If you had an opportunity to take another course in a topic of interest to you using Mozilla Hubs and the Oculus Quest would you do it”), 21 respondents answered “yes” and four answered “no. One student wrote, “When choosing between a class held in Zoom or a class held in VR or Hubs I would choose the VR or Hubs class over a Zoom class. This is because of the greater sense of immersion that I felt during the VR or Hubs class.” However, another student wrote, “After wearing the headset for a long time, I would start to get motion sick and my head would hurt. After that I would attend class through my laptop.” These comments suggest that, while students saw a benefit to the increased immersion offered by VR technologies, some students became uncomfortable to the point of no longer wanting to wear their Quest to attend class.
Others mentioned that it “depends on the class.” Some topics may lend themselves to instruction in VR better than others.

The final item on the questionnaire asked students, “Do you have any suggestions for improving the way virtual reality technologies were used for instruction in COMP 193/253?” Note that COMP 193 and 253 were the course numbers for the virtual reality course. Students mentioned issues described in responses to previous items, such as making the projection screen larger and finding ways to mute the microphones of students while the instructor was speaking. Other students wrote that the “current implementation doesn't take advantage of the 3-dimensionality” and “it would be awesome if students had the freedom to create virtual rooms to enter that the instructor could pull everyone back from at their leisure.” Perhaps future courses in VR could better attempt to take advantage of features that only VR can offer and allow students more opportunities to customize their three-dimensional learning environment.

A. Limitations

There are some important limitations to our study that should be discussed. First, our study involved a relatively small sample size (30 students, only 27 of whom completed the questionnaire). All students were from engineering, computer science, and emerging media majors. Students also self-selected for the study by choosing to enroll for the VR course. Thus, subjects may have already been favorable towards the use of VR technologies. Future studies could include more subjects, and randomly selected from non-technical backgrounds.

V. CONCLUSION

In this paper, we described our experiences designing a VRLE and teaching a course about virtual reality in virtual reality. We also discussed our process for evaluating the course and we presented our findings. Our impression of the data was that students felt learning about VR using VR technologies enhanced their educational experience. Students appreciated the flexibility of being able to take the course from anywhere that they had Internet access, and many felt that VR technologies provided a greater sense of presence than in other online courses they had taken. This improved sense of presence and engagement is aligned with previous studies using Hubs for instruction [6], [7]. However, students found it very challenging to take notes while wearing a VR headset, which we feel is one of the most important findings of our study. Others found it uncomfortable to wear the headset for long periods of time. This finding is consistent with that reported by Yoshimura and Borst, who used Hubs for online instruction [6], [7]. Similar technical issues were reported in Eriksson’s use of Hubs for instruction [7]. For these reasons, some students stopped attending class sessions using their VR headset and instead chose to attend class sessions on their laptop. Unique to our project, we provided VR headsets to each student and examined how this may have enhanced the course from the students’ perspective.

In the opinion of the authors, there is a great need to improve the availability of teaching and learning tools for instruction in VRLEs. An effective method for notetaking while in VR needs to be identified. Some of our students also indicated a desire to record VR classroom sessions for later review. Despite some of these challenges, VR remains an exciting medium with tremendous potential for online education. VRLEs can provide unique opportunities for instruction not available through other modalities while providing a sense of presence surpassed only by the real-world. For these reasons and others, we look forward to designing and teaching future courses in virtual reality.

ACKNOWLEDGMENT

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REFERENCES


Work-in-Progress—Embedding cross-cultural humorous and empathetic functions to facilitate language acquisition

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Abstract—Despite the growing attention paid to conversational chatbots, there is a lack of research in either offering culturally related empathetic strategies when English as additional language learners encounter emotional discomfort or simulating a sense of humour in language acquisition. This paper aims to propose a multivariate normal distribution model for cross-cultural class, BERT for humour detection and response, and NRC VAD to compute empathetic intensity values. The novel algorithm will contribute to significant and long-term outcomes of language learners when exposed to new cultural, cognitive and psychological experiences.

Index Terms—culture, humorous modelling, empathetic functions, language learning

I. INTRODUCTION

A chatbot is a software application designed to converse with a user or users via text or text-to-speech algorithm instead of providing face-face communication [1]. Chatbot applications have been around for decades, and some classical chatbots are ELIZA, ALICE, AliMe, and Apple's Siri. ELIZA. Since the early 1970s, chatbots have been used as pedagogical chatbots to support education environments. Embedded with AI technologies, pedagogical chatbots are used to facilitate and spring new opportunities for personalisation in learning, such as Intelligent Tutoring Systems (ITS) [2]. The design of pedagogical chatbots does not only make use of the most advanced computational algorithms in crafting an engaging environment but also takes into consideration of emotional and humorous concerns [2]. Yet, most pedagogical computational humour research on chatbots has primarily concentrated on the nature of linguistic-based humour and wordplay [3] without considering learners' cultural backgrounds.

Existing English as an additional language (EAL) chatbots primarily make use of virtual social chatbots to mimic the style of human interaction to prevent frustration when interacting with a computer in a more natural and more enjoyable way [4]; yet learners' cultural backgrounds have been overlooked when simulating a sense of humour to facilitate learners' language acquisition. As humour is universal but culturally tinted [5], it needs a significant cognitive effort to fathom its essential meaning behind words and phrases. Humour as a culture-bound component is an indispensable part of EAL acquisition, and it impinges on a lingua franca or a shared language or set of cultural norms to function [6].

Similarly, existing empathetic chatbots have been primarily used in a more supportive manner to analyse learners' emotions and generate appropriate responses with high empathic accuracy [7-9]. Nevertheless, in language learning, existing studies neglect the importance of the cross-cultural elements in the empathetic modelling design when learners encounter some emotional discomfort during the study [7]. Cross-cultural empathy entails empathic cross-cultural sensitivity, ethno-therapeutic empathy and social perspective-taking [7]. Therefore, this paper aims to develop a novel algorithm for integrating cross-cultural humorous and empathetic functions in an EAL chatbot. This will contribute to significant and long-term outcomes of language learners when exposed to new cultural, cognitive and psychological experiences.

II. LITERATURE REVIEW

A. Humour across cultures

Humour is universal but culturally tinted [5]. Learners from horizontal collectivist cultures emphasise sociability and interdependence with others in an egalitarian context and tend to practise affiliative humour. Whereas learners from a vertical collectivist culture (e.g., East Asia, India) conform to the hierarchical social system stratified by their in-groups and are prepared to perform altruistic acts for their in-group, they tend to employ self-defeating humour, and vice versa [10]. This contrasts with a low individualist culture (collectivism), where characteristics like being self-sacrificing, interdependent, and generous to others are of greater importance [11]. Thus, it is necessary to implement culturally related humour functions in EAL conversational chatbots as this type of humour develops the total power of the brain to improve learning outcomes [10]. The perception of humour engages both hemispheres in the brain, the left hemisphere is the "logical brain", which is involved in language competence and logical analysis, and detailed joke recognition, and the right hemisphere is the "creative brain", which is engaged in imagining and comprehending humour [12].

B. Intercultural empathy

Cultural empathy renders the capacity to apprehend the experiences of those from various cultures, which embraces high context cultures and low context ones [7]. By following certain social norms, values, and beliefs, a person develops and defines a sense of identity [9]. Learners raised in high context cultures are expected to identify the hidden nuance from their culturally ingrained intuitions, and they perceive low-context communication as extensively detailed. Whereas those who appraise a low-context style of communication describe high-context conversationalists as lacking transparency or unable to
convey ideas effectively [7]. Yet, no study has been conducted to investigate the effectiveness of computational support when EAL learners encounter emotional frustrations due to a lack of cultural understanding of the target language. Thus, it is vital to integrate cross-cultural empathetic responses in conversational EAL chatbots, identifying and determining how learners perceive and react to the learning content, by doing so to mitigate learners’ EAL anxiety and stimulate an individual learning momentum and outcomes [8].

Both humour and empathy have been proven to cause positive effects on students’ learning motivation and ease off negative emotions [13]. Yet, the current existing computational humour and empathy analysis may, by accident, dissociate from rather than associate with essential elements of learners’ cultural backgrounds, such as belief space, social protocol and population space [14]. The locus of attention of an EAL chatbot should be to enhance learners’ learning trajectory at ease to help better learners retain the target language [8]. The chatbot should be capable of improving during conversations as such communicative abilities and multifunctionality turn those chatbots into powerful pedagogical tools [8].

C. Existing studies on chatbot

Personalised user learning chatbots encourage students to engage in more linguistic activities than conventional classroom delivery [15]. Several studies investigated conversational chatbots based on Bayesian Networks, which store data in a historical log, subsuming students’ weaknesses and progress [16]-[17].

Even though some chatbots can record students’ progress and their current performance statuses, such as text for grammatical errors [18] and learning anxieties [19], many attempts have been made to develop chatbots to be empathetic about understanding EAL learners’ emotional states to elicit appropriate emotional responses [16, 17]. Unfortunately, only a few can generate empathetic responses due to the lack of quality training data and balancing consistent emotion throughout conversations [17]. To resolve this issue, Ghosal [20] designed a chatbot using the ConceptNet and the emotional lexicon NRC VAD to compute empathetic intensity values. ConceptNet is a compute empathetic intensity value. ConceptNet is a large-scale semantic knowledge graph representing general human knowledge associated with sentiment-related polarity [23].

Various studies have introduced humour to generate simple linguistic jokes to improve learners’ attitudes towards the system and increase learners’ motivation [24]. Yet, those studies did not elaborate on how to execute the humour functions and reduce the lexical ambiguity. Furthermore, based on the literature review, studies have yet to investigate the effectiveness of computational emotional support when EAL learners encounter frustrations due to a lack of cultural understanding of the target language.

III. MAIN CONTRIBUTION

A. Chatbot architecture

In order to bring out significant and long-term outcomes of language learners when exposed to new cultural, cognitive and psychological experiences, the EAL chatbot needs to combine three extra components: the cultural algorithm, cultural related humour functions, and culture related empathetic functions (see Fig.1.).

Fig. 1. Proposed EAL chatbot architecture.

Pertaining to cultural consideration, this study adopts cultural algorithms to consider learners’ cultural backgrounds as there is a knowledge layer consisting of dual-inheritance systems: the belief space, the population component and social protocol [14]. In terms of cross-cultural humour modelling, both Gaussian mixture model and BERT first separate and extract numerical features of each sentence and then tokenise them individually by adopting sentence embedding to prepare textual parts as numerical inputs. The main idea is to identify existing cultural relationships between sentences, such as the cultural punchline's relationship with the rest; it then examines meaningful impacts in determining the congruity of the text. In order to compute cultural empathetic responses, KEMP modelling is adopted [22] to smooth and refine emotion knowledge for culture-related empathetic response by embedding the ConceptNet and the emotional lexicon NRC VAD.

B. The proposed algorithm

Based on belief space, social protocol and population space, this proposal believes that there is \( p \times 1 \) cultural vector \( X \) that is distributed according to a multivariate normal distribution with a population mean vector \( I \) and population variance-covariance matrix \( \Sigma \), then this random cultural vector, \( X \), will have the joint cultural density function as shown in the expression below:

\[
\phi(x) = \left(\frac{1}{2\pi}\right)^{p/2} |\Sigma|^{-1/2} \exp\left(-\frac{1}{2}(x - \mu)^T \Sigma^{-1} (x - \mu)\right),
\]

\( |\Sigma| \) denotes the determinant of the variance-covariance matrix \( \Sigma \) and \( \Sigma^{-1} \) is just the inverse of the variance-covariance matrix \( \Sigma \).

For humour component, following the work of Clark, Khandelwal [26] the proposed algorithm sets \( \delta \) to measure the average attention distance \( D^h(T_a, T_b) \) between the two models at head \( h \):

\[
D^h(T_a, T_b) = \frac{1}{2} \sum_{n \in \delta} D^h_n(T_a, T_b).
\]

To emphasise empathetic information, this study adopts NRC_VAD to compute empathetic intensity values [25].

\[
emp(t) = \min - \max \left( \| V(t) - \frac{1}{2} \frac{A(t)}{2} \|_2 \right).
\]

Where \( \min - \max \) min-max normalisation, where \( \| \cdot \|_k \) denotes \( L_k \) norm, \( V(t) \in [0,1] \), and \( A(t) \in [0,1] \) denote the valence and arousal dimensional feature space in VAD(\( t \)) of word value, respectively.

C. Contributions of the research

The main contributions of this paper are: (a) expansion of literature work on chatbots with a focus on culturally related humour and empathy algorithms, (b) the identification of the gaps and limitations of chatbots implementation and application,
and (c) recommendation for future research on chatbot which considers a user's cultural background.

IV. CONCLUSION AND FUTURE WORK

This paper argued that there is a paucity of research considering E.A.L learners' cultural backgrounds when offering context-aware empathetic strategies and a sense of humour to facilitate learners’ language acquisition in order to achieve significant and long-term outcomes. Thus, the paper proposes the development of a novel algorithm that entails a Gaussian mixture model, a BERT modelling and a KEMP model to enhance learners’ language competence, logical analysis and creative comprehension while mitigating their anxiety. Future works should consider emotion detection in EAL acquisition for improving learners’ attitudes towards the system and increasing learners’ motivation.

V. ACKNOWLEDGEMENT

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REFERENCES

Work-in-progress—Developing an Evidence-Centered Model for Computational Thinking in Virtual Worlds with Children with Autism

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Abstract—This work-in-progress paper reports on the establishment of preliminary reliability for a domain-agnostic evidence-centered assessment model to measure computational thinking (CT) in an online virtual world. Preliminary reliability was established between two researchers through manually coding 800 minutes of recorded learning sessions and over 350 minutes of consultation. Participants were three adolescents diagnosed with autism spectrum disorder. Findings indicate an acceptable level of reliability between the two coders, opening the way to more extensive application of the model in future studies.

Index terms—computational thinking, evidence-centered design, behavioral coding, virtual worlds, autism spectrum disorder

I. INTRODUCTION

Jeannette Wing’s computational thinking (CT) applies computer science terminology and thought processes to general problem solving [1]. Despite Wing’s vision of CT being applied generally [1], most research in CT has focused on computer science, computer programming and other Science, Technology, Engineering, and Mathematics (STEM) subjects [2], [3]. Although the principles of CT readily agree with STEM, some advocate for the application of CT in non-technical domains, as originally conceptualized [4], [5].

Methods for assessing CT competencies continue to be refined [6]–[8]. For example, Siu-Yung Jong et al. and Tsi et al. developed survey-based scales for measuring features of CT [9], [10], however, evidence-centered observational assessments of CT competencies and disposition are less prevalent. Dagiene et al. [11] were among the first to suggest observable identifiers which indicate CT in action using the core competencies of CT confirmed by Selby and Woolard [7], but a reliable model has yet to be established. Furthermore, research in CT and STEM has largely ignored the marginalized population of children with autism spectrum disorder (ASD) [12].

The purpose of this study, therefore, is to measure the preliminary reliability of a model framework for assessing CT competencies in children with ASD. The following sections provide a background of the model’s development and a description of how researchers established a preliminary reliability rating, justifying more extensive use of the model.

II. BACKGROUND

Wing’s conceptualization of CT was abstract and introductory [1], but has since been interpreted more concretely by various researchers. Palts and Pedaste provide an overview of the theoretical relationships among CT studies since Wing’s original publication [13]. The present study aligns with the branch of CT research originated by Selby and Woolard whose review extracted the most common and well-defined CT competencies from the literature [7]. In addition to these, disposition has also been found to be relevant to successful CT [14]–[16]. Table 1 contains the eight CT dimensions included in the model developed for this study.

Assessment of CT requires a systematic framework for developing valid and reliable measurements of student learning. Evidence-centered design (ECD) is a principled assessment design framework that helps to specify and connect the target skills, work products, and tasks that students will engage in [17], [18]. ECD involves a conceptual assessment framework, where components and procedures needed for the assessment are defined. In this layer, assessment designers will focus on several models. 1) a student model for performance to be evaluated, 2) an evidence model for specifying student behaviors, and 3) a task model for determination of learning tasks that elicit students’ target behaviors. ECD has the advantage of evaluating multidimensional and complex performances in dynamic, interactive environments [17], such as virtual worlds.
### III. EVIDENCE-CENTERED COMPUTATIONAL THINKING MODEL

The evidence-centered CT model being developed in this study is shown in Fig. 1. On the left of the model are the core dimensions of CT and the right of the model depicts theory-derived observable behaviors which are indicative of the CT dimension they are connected to. The evidence-centered design of this model affords demonstrative reasoning based on learners’ observable behaviors within the CT model [19]. The first step of using an ECD approach is to conduct a domain analysis, identifying major conceptions included in the model for assessment [17]. A total of eight dimensions were identified as the focus of the model (see Table I).

### IV. METHOD & RESULTS

Data for preliminary reliability were collected from three purposively-sampled adolescents diagnosed with ASD who participated in a virtual 3D modeling and programming-based learning program to practice CT. Every two weeks the participants engaged in a learning module on the basics of programming non-player characters (NPCs) conducted entirely in OpenSimulator, an online virtual world. Each session was facilitated by a researcher who is a subject matter expert in computer science. All the sessions were recorded and subsequently coded using BORIS® (Behavior Observation Research Interactive Software) [20].

#### A. Inter-rater Reliability

Reliability of the raters was calculated by a modified percentage agreement method used by Galbraith et al. [21], which is determined by adding up the number of codes with total agreement between researchers within a margin of time (15 seconds in the present study) and then dividing the sum by the total number of codes entered in that session. According to Hartmann et al. [22], an inter-rater agreement percentage of 70% would be considered excellent for a coding system like the one deployed here.

To establish preliminary reliability, two researchers independently observed and coded 11 randomly selected learning sessions of two participants, which comprised 634 minutes of recorded video, or 16% of the total data for these two participants in this learning module. After coding each video researchers compared and discussed their behavioral coding, resulting in over 350 minutes of consultation. During these consultations, any discrepancy between the data was scrutinized until 100% agreement was achieved. Lastly, three additional videos were coded by the researchers, one from each of the three participants who completed the same learning module. These additional sessions totaled 166 minutes of recorded video. The codes derived from these sessions were used to calculate the reported percent agreement of preliminary inter-rater reliability.

#### B. Coding Procedure

To code observable behaviors of participants, the ethograms of CT dimensions were compiled before coding and revised as needed during the consultation sessions. Behaviors were coded through a series of modifiers, starting with the CT dimension and then the observable behavior, and lastly the state of the behavior (independent or assisted by the facilitator for CT competencies, and desirable (strong or weak) or undesirable for CT disposition). With our model, each behavior was treated as a state event with a starting and a stopping time. Also, each CT competency was coded without imbricating another competency, as CT competencies are distinct from each other, however, overlap between CT competencies and disposition was permitted. In this exploratory phase of the model’s use, a fixed time interval for CT competency behaviors was not imposed, but a sample (one 60-minute session from each coder) showed that CT competency behaviors endured for an average of 43.3 seconds (SD 23.3). Disposition behaviors, on the other hand, were confined with a 15-second minimum time interval as terminal points were ambiguous for these behaviors.

Results of the final reliability calculations returned an inter-rater agreement percentage of 86.2%, which is considered strong [22].

### V. DISCUSSION AND CONCLUSION

This study reported preliminary evidence of reliability in using a domain-agnostic, evidence-centered model for CT. Reliability was achieved after about 20 hours of coding and consultation. This study corroborates the practicality of using evidence-centered assessments of CT in addition to demonstrating the applicability of CT behavioral coding in online virtual worlds with individuals diagnosed with ASD.

Some unique challenges arose from coding behaviors in online virtual worlds. For instance, when using the evidence-centered CT model for coding, the behaviors needed to be germane to the competency in question, therefore it was important to distinguish between actions that took place in the

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<table>
<thead>
<tr>
<th>Dimension</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Decomposition</td>
<td>The ability to decompose large or complex problems into smaller and manageable ones by functionality, structure, or relationship [7].</td>
</tr>
<tr>
<td>Abstraction</td>
<td>The ability to reduce complexity by leaving out irrelevant details and focusing on essentials [7].</td>
</tr>
<tr>
<td>Algorithmic Thinking</td>
<td>The ability to develop solutions to problems in a step-by-step manner [7].</td>
</tr>
<tr>
<td>Evaluation</td>
<td>The ability to analyze and evaluate the problem-solving strategies and solutions in terms of efficiency and effectiveness [7].</td>
</tr>
<tr>
<td>Generalization</td>
<td>The ability to generalize specific problem-solving strategies or solutions to different contexts [7].</td>
</tr>
<tr>
<td>Tolerance for Ambiguity</td>
<td>Confidence in dealing with complexity and ambiguity [15].</td>
</tr>
<tr>
<td>Persistence</td>
<td>Patience and endurance in working with difficult problems [15].</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Communicating and working with others to accomplish common goals [14].</td>
</tr>
</tbody>
</table>

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**TABLE I. CT DIMENSIONS AND DEFINITIONS**

<table>
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<td>Decomposition</td>
<td>The ability to decompose large or complex problems into smaller and manageable ones by functionality, structure, or relationship [7].</td>
</tr>
<tr>
<td>Abstraction</td>
<td>The ability to reduce complexity by leaving out irrelevant details and focusing on essentials [7].</td>
</tr>
<tr>
<td>Algorithmic Thinking</td>
<td>The ability to develop solutions to problems in a step-by-step manner [7].</td>
</tr>
<tr>
<td>Evaluation</td>
<td>The ability to analyze and evaluate the problem-solving strategies and solutions in terms of efficiency and effectiveness [7].</td>
</tr>
<tr>
<td>Generalization</td>
<td>The ability to generalize specific problem-solving strategies or solutions to different contexts [7].</td>
</tr>
<tr>
<td>Tolerance for Ambiguity</td>
<td>Confidence in dealing with complexity and ambiguity [15].</td>
</tr>
<tr>
<td>Persistence</td>
<td>Patience and endurance in working with difficult problems [15].</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Communicating and working with others to accomplish common goals [14].</td>
</tr>
</tbody>
</table>
virtual world and actions that took place in the participants' physical environment. Some participants were distracted by something in their physical environment, or had technical issues with their computers, which could appear as an unresponsive avatar in the virtual world. These task-irrelevant behaviors needed to be recognized so as not to code them as, for example, undesirable persistence.

With preliminary reliability established, the authors are now further validating this evidence-centered CT model in a longitudinal virtual world-based active learning project for adolescents diagnosed with ASD.

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Work-In-Progress—CrimOPS—Gamified Virtual Simulations for Authentic Assessment in Criminology

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Abstract—Authentic assessment is the concept of using creative learning experiences to assess students’ skills and knowledge in conditions that simulate reality. The importance of authentic assessment in higher education is recognized as it helps measure student performance and attainment of skills related to the expected learning outcomes of the degree program, they study that map the skills required in their profession in the related industry. There is also growing evidence that authentic assessment can enhance student engagement and improve the student experience and learning outcomes. VR coupled with gamification offers the authentic context for students to apply their knowledge and skills while solving real-world problems. This paper presents a work-in-progress study that focuses on the creation of an educational resource that effectively supports teaching and learning crime-scene analysis and evidenced-based inferences in Criminology through simulated crime scenes. The paper describes a participatory design process involving students and academics as co-creators of a VR game, the CrimOPS, it presents the initial prototype derived from this collaboration and preliminary study results.

Index terms—Virtual Reality, Authentic Assessment, serious games, game-based learning, criminology

I. INTRODUCTION AND PROBLEM STATEMENT

Currently, case studies have been used to teach how to analyze salient features in a homicide committed by serial killers in our class. According to Sheen, Yekani, and Jordan [1] case studies have been used in several disciplines as a strategy for active learning and found to encourage student engagement and critical thinking.

However, Bonasio found that mixed reality and immersive experiences will play an increasingly critical role in modern education, and immersive learning is “a powerful vehicle for identity and knowledge transfer, both of which are crucial factors affecting learning outcomes” [2]. Akhgar, et.al. present how serious games can enrich and complement other training approaches, especially in the sense that they provide a link between the classroom, scenario-based training, and real-life operations [3].

This project has been created to support learning and teaching and improve students’ experience of criminal psychology for criminology students at the University of Westminster. As such, an inter-disciplinary collaboration was created between Social Sciences and Computer Science. A Participatory Design approach has been adopted, involving students and academics as co-creators of a gamified virtual simulation (GVS), namely the “Criminology Offender Profiling Simulation”: CrimOPS. CrimOPS combines VR technology and is designed to support the criminology students to apply their theoretical knowledge of offender and geographic profiling to a scenario that would be close to physical reality. The GVS would support the learners develop observation and problem-solving skills and critical thinking to understand what happened in a scenario. Additionally, students would learn to make inferences supported using empirical academic studies in an assessed report.

The rest of this paper presents the research questions driving this study, the methodology we followed, the research instruments we designed to support the study, and the preliminary results. The paper closes with a discussion and future directions.

II. RESEARCH QUESTIONS

The ultimate goal of this work-in-progress project is to study the effect of GVSs for authentic assessment. We unpack student experience as elements of student engagement, motivation, and learning compared to the use of case studies in supporting HE students in achieving deeper learning [4]. The research questions this project attempts to answer are the following:

RQ1 GVSs support authentic assessment.

RQ2 GVSs can help learners achieve deeper knowledge and critical thinking.
RQ3  Criminology students perform better in terms of achieving learning outcomes with GVSs compare to conventional paper-based material;
RQ4  GVSs compared to conventional paper-based material improves student engagement;
RQ5  GVSs compared to conventional paper-based material improves student motivation and experience;

III. RESEARCH METHODOLOGY

To study the research questions and address the project aims the study ensures the following systematic approach:

a) uses a Participatory Design process involving all the stakeholders (students and academics) for the design of an educational resource for authentic assessment.

b) uses criminology students who were taught offender profiling, as insiders to create the scenarios that can assess the knowledge of their peers.

c) it combines VR technology and gamification for the creation of an educational resource for authentic assessment, the CrimOPS, which will be used as a research instrument for the study.

d) it plans a comparative study to evaluate the achievement of expected learning outcomes in offender profiling, as well as the student experience comparing paper-based versus authentic assessment using a GVS, the CrimOPS;

e) uses analytics integrated into CrimOPS to evaluate the learner’s journey and learning behavior, like collecting evidence, completing tasks, and time-related to achieving those tasks.

f) user satisfaction is evaluated using the User Experience Questionnaire (UEQ) [7] and immersion based on the Immersive Experience Questionnaire (IEQ) [7].

The following sections elaborate on the creation of the research instruments to support the study.

IV. PROTOTYPE DESCRIPTION – VR INTERACTIVE GAME

To support the study two research instruments have been created: (a) a paper-based and (b) a GVS, both covering learning outcomes demonstrating recognizing salient features of a criminal case, such as:

- Modus Operandi (MO), actions necessary to commit a crime successfully [5];
- Signature, behavior going beyond what is necessary to commit the crime, almost as a ritualistic action, related to cognitive process and relatively consistent [5];
- Staging, intentional alteration of the scene before the arrival of the police [5];
- Trophy, item taken from the crime scene or the victim (something personal) by the offender to symbolize the offender’s triumph over the victim [6];
- Souvenir is a meaningful item taken by the offender to remember the incident and the pleasure gained from the crime [6]

Both research instruments covered the same learning outcomes to support the students to discover salient characteristics of the crime scene but simulated two different crime scenes so that the student performance could be compared. The GVS application consists of the following levels.

A. Level 1 – Crime Scene

The learners take the role of the criminal investigator who visits and explores a crime scene to collect evidence and recognize the salient features of the crime scene. The learners meet police and forensics investigators on site who also provide the information they collected at the crime scene (see Fig. 1). The learners collect evidence (see Fig 2.) and note down information in a notebook. There is no time limit to explore the scene and no system assistance about the clues to be found from a hint for the number of clues to be found, simulating as closely as possible a real-life crime scene investigation. Learners can take as long as they need to collect information and they could return to the scene if they needed to. The game also provides a map that shows the crime scene location.

B. Level 2 – Forensics Examination

The learners visit the crime lab and talk to a forensic medical examiner to gather the information derived from the forensics examination of the victim’s body (see Fig. 3).

C. Level 3 – Interviews

The learners return to the police station and support the police interviews with witnesses and people related to the case to gather the information that could help the crime investigation (see Fig. 4).

At the end of the investigation, the learners analyze the clues they have collected and the notes they have taken to conclude the case. They will then complete a report that combines their understanding of the case with the evidence-based inferences that they made with the support of academic studies.

V. THE STUDY

In this paper, we present a preliminary study involving a small number of second-year students in criminology/soc/crim, registered in a Forensic and Criminal Psychology module. The purpose of this preliminary study was to test the research instruments and the study plan. Participants have been presented with a paper-based scenario of a serial murder case and they have been asked to provide a 250 words summary of their understanding of the case and an analysis of the salient characteristics (e.g., MO, signature, staging, etc) (see Section IV). In the second part of the study couple of weeks later the students have been presented with a virtual simulation/game based on a different scenario to get accustomed to. To evaluate if the use of the different learning instruments supported students to achieve better learning outcomes, we compared the summaries and the salient features they presented for both scenarios.
To evaluate the design of the simulation, as well as the learners’ experience, motivation, and understanding participants received an online 5 Likert Scale questionnaire (Negative 1 2 3 4 5 Positive). That was organized into four parts collecting: demographics; feedback about game features; User Experience Questionnaire (UEQ) [7]; and immersion based on the Immersive Experience Questionnaire (IEQ) [7]. All collected data has been aggregated, allowing for all participants’ anonymity.

Only 7 students completed the survey and we found that students mostly disagree (somewhat disagreed/strongly disagreed) that the paper-based case was more engaging (n=4) than the gamified VR application. Most students found that the paper-based case was more real (n=6) and more stimulating (n=4) than the game-based case. Students had a shared feeling on whether the paper-based was more fun than the gamified VR application (3 agreed, 2 disagreed and 2 had no opinions). Students felt more frustrated (n=5) and anxious (n=4) with the simulation than with the paper-based.

The student had mixed feeling about whether they felt less scared or put off by the description of the crime or the autopsy reports of the paper-based case compared to the virtual simulation. They got the same results with the feeling of whether the paper-based case can help them in developing their observation skills better than the virtual simulation.

On the other hand, most students agreed that the paper-based helped them to develop their critical analysis skills better than the virtual simulation, but they felt that the paper-based could not help them in developing their problems solving skills.

Students agreed that the virtual simulation contributed to a more innovative and original experience, but they mostly disagreed on whether they preferred it to the traditional assessment form.

VI. DISCUSSION AND FUTURE WORK

The results of this preliminary study did not help us to conclude the effect of the gamified VR simulation for authentic assessment. This was down to the quality of the graphics and the interaction with the characters of the gamified VR simulation.

The gamified VR simulation has been originally designed in Unity and we are currently re-designing it in Unreal Engine which provides greater realism and smoother character animation. We are also integrating analytics in the VR simulation to collect information that could help us later analyze the learners’ journey and compare this too gained knowledge.

To evaluate our student’s learning experience and whether the gamified VR application, CrimOPS, can help them achieve some of the intended learning outcomes (ability to understand a case and its salient features) we are planning a study involving the whole cohort of approx. 125 second-year students in criminology/soc/crim, registered on a Forensic and Criminal Psychology module. This will provide adequate data to evaluate our research questions. The class will be divided into two groups: the first one will use the paper-based assessment instrument, and the second the virtual reality game. In the successive run, we will switch the groups and then administer the survey. A challenge we are facing is accommodating this large number of students to experience the resource using immersive VR. To address this we will create two prototypes one to be accessed as WebVR and one as an immersive VR resource.

ACKNOWLEDGMENT

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Work-in-Progress—Measuring Learners’ Subjective Experience in Augmented Reality: First Evaluation of the ARcis Questionnaire

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Abstract—In order to effectively use augmented reality (AR) for learning support, it is important to take into account learners’ subjective AR-specific learning experience. In this work-in-progress paper, a first version of the ARcis questionnaire intended to measure learners’ perception of contextuality, interactivity, and spatiality in AR-based learning environments is presented. Results of a first implementation of this questionnaire in four studies (total N = 456) with different AR-based learning materials are described. Analyses of reliability and factor structure of the questionnaire show promising first outcomes on which suggestions for adaptations and future validation strategies are made.

Index terms—augmented reality, experience, questionnaire, evaluation

I. INTRODUCTION

Augmented reality (AR) has been used to support learning and instruction in a lot of different contexts [1], [2]. AR applications enrich users’ experience of physical reality by adding virtual elements that can be displayed through different technologies, including video see-through on mobile devices or optical see-through in smart glasses. In educational settings, the technologies are thus used as tools for augmenting the real-world learning experience with virtual elements, which is expected to support various learning-related cognitive, motivational, and emotional processes. Azuma [3] described three characteristics of AR systems: combining real world and virtual elements, being interactive in real time and registering virtual elements in three dimensions (3D) inside the real world. While these are necessary technological features, AR augments learners’ perception of reality [4], which highlights the importance of learners’ subjective experience. From a human-centered perspective, three characteristics have been defined: contextuality (c), interactivity (i) and spatiality (s) [5]. Contextuality describes the simultaneous perception of real and virtual elements in AR, enabling different cognitive connections between the elements. Interactivity describes a combination of possibilities for physical, virtual and mediated physical-virtual interaction unique to AR. Spatiality describes the perception of virtual elements in AR as spatial and linked to a specific point inside the 3D real world. To measure learners’ perception of these ARcis characteristics and gain insight into their subjective experience, the ARcis questionnaire was developed. In addition to examining learners’ perception, the questionnaire enables the comparison to instructors’ or researchers’ intentions behind the design of educational AR applications with the purpose of leveraging or examining the ARcis characteristics. The focus differs from other questionnaires used to examine experiential constructs that are not primarily aimed at but applicable to AR-based learning environments. Constructs such as immersion and presence, for example, are considered in many virtual or mixed environments, but questionnaires are uniquely developed for AR like [6] and [7]. Constructs such as user experience, acceptance, and motivation are considered in many technology-enhanced settings and existing questionnaires may be used and not adapted when applied to AR like in [8] and [9]. In contrast, the ARcis constructs were specifically defined with AR-based learning and its distinction from other technology-enhanced learning in mind.

II. THE ARcis QUESTIONNAIRE

To allow for high content validity, the questionnaire was developed based on the definitions of the three characteristics contextuality, interactivity, and spatiality. (1) The contextuality scale covers the perception of virtual elements within the real-world context and their connection, the thematical relevance at that exact time and place, and the authenticity of the placement in the real world. (2) The interactivity scale includes the general amount of interactivity, the ease, authenticity and naturalness of the interaction, the mediated physical-virtual interaction, and the superiority in comparison to purely physical interaction. (3) The spatiality scale covers the spatial depth and three-dimensionality of the virtual element, the ease of understanding the connection between parts and imagining the spatial dimensions of the virtual element, the placement in the 3D space of the real world, and the increased spatiality in comparison to purely virtual objects. Learners are asked to rate their experience of an AR application with which they had learned beforehand through six statements for each characteristic in a seven-point response format from 1 (not at all true) to 7 (very true). All items used in the first evaluations of the questionnaire, translated from their original German wording, can be seen in Table I. The questions can be adapted to the specific form of virtual element (e.g., “the virtual model of the human heart”) and real-world environment (e.g., “the forest”) or can be used in a more general way (e.g., referring to “the virtual object” or “the virtual element” and “the real-world environment”).
### III. FIRST EVALUATION OF THE ARcis QUESTIONNAIRE

In four studies with a total of $N = 456$ German-speaking participants, we administered the German ARcis questionnaire in their general form, specifying the virtual and real elements in general instructions instead of the individual items. Item order was randomized and participants were aged 17 to 83 ($M = 24.70$, $SD = 8.96$), with 147 male, 308 female and 1 diverse. Participants were allowed to take part in multiple studies.

The studies included the self-directed usage of or videos showing the usage of purposefully developed AR applications. In each study, an experimental manipulation with two conditions took place. In the heArArt study, applications including a 2D ($n = 75$) or a 3D ($n = 75$) representation of a virtual model of a human heart AR were used in a laboratory study [10]. In the digestAR study (2D: $n = 30$; 3D: $n = 32$), the same manipulation with material on the human digestive system took place in an online study due to Covid-19 pandemic contact restrictions. In the powARplant study, learning material on a power plant was either integrated ($n = 50$) or included an active integration task ($n = 52$) in a laboratory study. In the buildAR study, due to Covid-19 pandemic contact restrictions, a video implemented in an online study showed the usage of an AR application for the instruction of building a bird out of blocks with integrated ($n = 72$) or separated ($n = 70$) material. The participants were asked to rate the 18 statements in the questionnaire based on their usage (or imagined usage) of the respective application.

Pairwise comparisons of the averaged subscale scores in the four studies and the eight conditions show significant differences, suggesting that the variance of the answers is influenced by the different learning materials and their specific designs. However, we expect that the reliability and factor structure of the questionnaire is not influenced by this and should remain the same or at least very similar with different materials. The following analyses in this paper are thus based on the whole sample with $N = 456$ participants. They include reliability analyses through average inter-item-correlation (recommended between 0.15 and 0.50 [11] and McDonald’s omega total ($\omega$) of the proposed subscales, which has less rigid assumptions than Cronbach’s alpha and has been suggested as a better measure of reliability [12]. The analyses also describe item characteristics including classical item difficulty (determined by item mean divided by 7), corrected item-scale correlation (item-rest correlations; recommended above 0.5 [13]) and McDonald’s omega if the item was deleted. Furthermore, a confirmatory factor analysis (CFA) with the three proposed subscales as factors is reported. Interpretations of the fit indices and loadings are based on [13] and [14].

### IV. RESULTS

#### A. Reliability Analyses

Mean inter-item-correlation was within the suggested range for contextuality (0.44) and interactivity (0.49), but slightly above the suggested upper cut-off of 0.50 for spatiality (0.52), which is adequate for narrower constructs [11] like the ones measured here. For all subscales, McDonald’s omega indicates a high reliability with $\omega > 0.80$ (contextuality: $\omega = 0.83$; interactivity: $\omega = 0.85$; spatiality: $\omega = 0.87$). McDonald’s omega for the whole questionnaire was even higher, $\omega = 0.93$. Furthermore, Pearson’s $r$ correlations between the three subscales were strong and significant: C – I: $r = 0.78$, $p < 0.001$; I – S: $r = 0.73$, $p < 0.001$; S – C: $r = 0.71$, $p < 0.001$.

In Table I, characteristics of the items including classical item difficulty, corrected item-scale correlation and McDonald’s omega total if the item was deleted are displayed. Classical item difficulty was between 0.56 and 0.78 for all items, showing that the scores on average were above the center of the scale (0.50).
and not too high (<0.80), indicating adequate item difficulty. Item-scale correlation was 0.50 or higher for nearly all items within their scales, except for c2 (0.48) and i6 (0.49), which still were at nearly 0.50. In general, this indicates adequate item-scale correlation. Omega total could not be increased by deleting items in the contextuality and spatiality subscales and only the removal of i6 in the interactivity subscale would slightly increase omega total from $\omega = 0.85$ to $\omega = 0.86$.

### B. Confirmatory Factor Analysis (CFA)

The fit measures for the CFA provided a mixed picture. The chi-squared test for fit of the model was significant, $\chi^2(132) = 474.86$, $p < 0.001$, rejecting the hypothesis that the estimated and the observed covariances are the same. Because this fit index is influenced by sample size, other fit indices were also examined here. SRMR indicates a good fit with a score of 0.047, which is below the proposed 0.10 [13]. RMSEA was at 0.075, 90% CI [0.068, 0.083], which is in the reasonable approximated fit range between 0.05 and 0.08 [14]. Neither CFI at 0.919 nor TLI at 0.906 were above the suggested 0.95 [14], although they were close. In Table I, factor loadings for all items are displayed. All loadings are above the suggested cut-off value of 0.40 [13], ranging from 0.54 to 0.81 (contextuality), 0.51 to 0.83 (interactivity) and 0.62 to 0.81 (spatiality).

Due to the item characteristics showing item-rest correlation lower than 0.50 for items c2 and i6, which also have the lowest factor loadings in their subscales, another factor analysis without these two items was executed. The fit measures were not better, $\chi^2(101) = 419.10$, $p < 0.001$; SRMR = 0.048; RMSEA = 0.083, 90% CI [0.075, 0.091]; CFI = 0.919; TLI = 0.904.

### V. Discussion and Outlook

The results show first indications that the proposed questionnaire structure is reflected in these data. While the general reliability analyses suggest adequate reliability, the fit indices in the CFA are inconclusive. Concerning the wording of the items it can be said that to better separate contextuality and spatiality, the items referencing a “connection” (c2, c3 and s3) need to be reworded as to make clear that for contextuality a thematic and for spatiality a spatial connection is meant.

While these analyses give first indications of good reliability of the ARcIs questionnaire, it is important to also consider its validity – does the questionnaire measure what it intends to measure? First indications of this were shown in the heArt study, in which the questionnaire was used as a manipulation check and revealed a very large effect ($d = 1.41$) comparing the 3D and 2D condition concerning perceived spatiality [10]. On the other hand, medium effects were also found for contextuality ($d = 0.42$) and interactivity ($d = 0.47$) in this study, indicating that it may be hard to distinguish the three characteristics, which is also supported by the high factor correlations found in the current analyses. It needs to be further examined if this difficulty of distinction comes from item wording and self-rating in the questionnaire, or if it is generally caused by the close connection of the three characteristics in common AR implementations.

The presented questionnaire is the first version of a scale to gather insights on learners’ perception of the three ARcIs characteristics when using different AR applications, although adaptations of some items are necessary for future analyses. To further develop the ARcIs questionnaire, a validation of a broader version with 13 items per subscale to identify wording effects is currently ongoing. Items with bad fit will be removed and replaced. More validation in studies with different AR learning material and more participants is necessary. The questionnaire’s content validity should be examined further in a study manipulating the extent of the ARcIs characteristics in AR learning settings to establish if the questionnaire can detect these manipulations. Furthermore, the test-retest reliability to determine how stable the questionnaire’s measurement is should be examined in the future. A version of the questionnaire for collaborative AR learning settings has also been formulated and will be validated in the future. The translation of the ARcIs characteristics into the ARcIs questionnaire as a way of examining the learners’ experience of AR can provide a basis for studying the learners’ perspective and drawing conclusions on how AR learning applications should be designed.

### References


Work-In-Progress—A Mobile Augmented Reality Application for Learning about Trademark Registration in Intellectual Property Education

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Abstract— Intellectual Property (IP) education plays a key role for support and creativity in society. However, research on IP education has not paid attention to the potential that AR could bring to this field. This work-in-progress paper presents an augmented reality mobile application developed in Unity for learning trademark registration as part of the first phase of a research project studying the uses of AR in intellectual property education. This paper describes the design of the application and some screenshots of the final developed version, the research method, instruments to evaluate the application, and preliminary findings. The main contribution of this paper is a use case of AR in the field of intellectual property education, an example of designing an app for this topic and some insights into the benefits of AR in the field of intellectual property education.

Index terms—Intellectual property, trademark registration, augmented reality, mobile learning, educational affordances

I. INTRODUCTION

According to the World Intellectual Property Organization (WIPO) [1], "Intellectual property (IP) refers to creations of the mind – everything from works of art to inventions, computer programs to trademarks and other commercial signs". Intellectual property is very important for the economic growth of a country because it secures the rights to the social and cultural assets of society [2], [3]. Many companies around the world have substantial assets in the form of IP [4] and it is also considered as a liquid asset [5]. Thus, intellectual property can produce positive effects in the economic and social development of the countries that promote it. In that regard, intellectual property education plays a key role in supporting creativity and innovation in society [6]. As part of industrial property, one can find the registration of trademarks. “Use of WIPO’s international trademark system for the protection of brands surged by 14.4% in 2021 to reach 73,100 filings, the fastest year-on-year growth since 2005” [7]. It is important to highlight that Drivas [8] found a positive relationship between technological capabilities, technological stock, and new trademark applications. The same conclusion was reached by Fakhimi and Miremadi [9].

Augmented Reality (AR) is a technology that allows a real-time combination of virtual objects and real objects so that it seems that the virtual objects are part of the real world [10]. In educational settings, AR is gaining momentum in education [11] [12] thanks to the advances in the field. Research on AR in education has shown that AR has been effective for increasing students’ motivation, learning performance [13], creativity and innovation [14]. On the other hand, AR has been evaluated considering the conditions that must be met to achieve the different learning outcomes. In this context, the intention to use technological innovations has been evaluated based on their perceived usefulness and ease of use, as well as on the individual’s skills, knowledge, and abilities. Among the most widely employed models to analyze user experience and the effect on learning are the technology acceptance model (TAM) [15] and its reformulation or TAM2 model Venkatesh et al. [16] that includes the user’s cognitive-level work goals and work task performance [17]. More recently, Schuster et al. [18] have examined AR acceptance using a scenario model for the evaluation of this acceptance: this trajectory model synthesizes and simplifies some previous models applied to industrial assembly, in particular the Unified Theory of Acceptance and Use of Technology (UTAUT) and the Technology Acceptance Model (TAM). However, most of the research has been conducted in the field of engineering education, science education and medical education [19]. There is a need of more research on the possibilities offered by AR in other social sciences such as Law, Human Resources management [20] and intellectual property education [21]. To fill part of this gap in the literature, this ongoing work introduces a mobile AR application for learning about trademark registry in the field of intellectual...
property education to investigate the affordances of AR in this field in terms of its effect on student motivation and learning performance. Some general questions that remain unanswered in this field are: is AR effective for learning about intellectual property education or increasing student motivation in this context? What are the possibilities and limitations for learning and motivation of using AR in intellectual property education?

II. MOBILE AR FOR TRADEMARK REGISTRATION

A mobile augmented reality application was co-designed with a teacher expert in intellectual property education. The AR app co-design process was adapted from that proposed by Bacca et. al. [22]. When the app design was approved by the expert teacher, the development phase began. The application was entirely developed by one of the authors in Unity using the Vuforia package. During the development phase constant feedback was received from the expert teacher to improve the application and consider some aspects that were missing during the development. Some prototypes were created during the development phase until the final version was completed. The learning objectives covered by the AR application are to identify the different types of trademarks and their main characteristics as well as to know the steps and requirements to be followed to apply for the registration of a trademark.

We decided to use mobile AR instead of AR glasses because the application can be easily installed in the students’ mobile devices and students can use the application at anytime, anywhere. The following sections describe in detail the different modules that were designed and developed.

A. Educational affordances

Since AR has been found to be effective for increasing student motivation, learning performance [13], augment the learning context and provide multimodal interaction [23], we decided to use AR technology to increase motivation toward the topic of trademark registration in the field of intellectual property. The main goal was to use AR as a motivating way of presenting the learning content and providing alternative ways of interaction with the topic. Previous studies have reported positive results when AR is integrated for supporting learning. However, the lack of research on the possibilities of AR in the field of intellectual property education motivated this on-going project.

B. Learning Mode

The learning mode is a marker-based AR scene that shows a classroom on top of the AR marker. On the classroom walls, students can see the different types of trademarks and students can select each trademark to read about its main characteristics. Moreover, some examples of each type of trademark are provided. Once students have read the information about each trademark, additional information is provided about the steps and requirements to apply for a trademark registration. The learning mode is in line with the learning objectives described above. Figure 1 shows a screenshot of the learning mode. In summary, in learning mode students have access to the learning content.

C. Assessment Mode

In the assessment mode, students are challenged to test their knowledge. In this mode, a marker-based AR scene shows a room with walls in which students can see different types of trademarks and the students’ task is to identify the type of trademark and identify whether the trademark meets some requirements to be registered. In this mode, a timer records the time students spend answering to all the questions. Moreover, for each correct answer, ten points are added to the score and for each incorrect answer, ten points are subtracted from the score. The design decision behind the development of the learning mode and the assessment mode stems from evidence in the literature about AR in education research that indicates the need to provide various levels of difficulty to increase students’ motivation toward the topic [24]. Figure 2 shows an screenshot of the assessment mode.

D. Ranking Module

In order to provide a competitive environment for students using the application, a ranking module was developed to show the top 15 students who obtained the best scores in the evaluation mode.

III. RESEARCH METHOD AND INSTRUMENTS

At the time of writing, the AR mobile application has been tested by 11 university students belonging to the Marketing and International Business Administration undergraduate programs at Fundación Universitaria Konrad Lorenz in Colombia. The students voluntarily participated in the research study and their informed consent was obtained. In addition, the research study was approved by the Institutional Ethics Committee of the university. An expert teacher in the field of intellectual property education designed a pre-test and a post-test to measure students’ knowledge of trademark registration. In addition, an instrument...
suggested by Nikhashemi [25] was adapted and translated into Spanish to collect information about students’ perceptions on the following dimensions: utilitarian benefits, quality of AR, AR Vividness, AR customization, computer anxiety, hedonic benefits, experience satisfaction, psychological inspiration, and intention of continued use of the application. The instrument was validated with experts in terms of content to identify questions that may be difficult to understand. The pre-test was applied one week before the intervention. During the intervention, students used the AR application at their own pace for a period of three weeks and then the post-test was applied.

IV. PRELIMINARY RESULTS

Due to the restrictions in the paper length, we only present part of the results obtained so far. One of the dimensions we evaluated after students used the mobile AR application was the intention of continued use with two questions using a 5-point likert scale: 1) I will use this app frequently in the future (M=3.36; SD=1.12) and 2) I strongly recommend that other users use the application (M=3.9; SD=1.13). These results show an overall positive perception of the app by students but the results are not conclusive; we are still testing the application with more students to increase the sample size.

V. CONCLUSIONS AND FUTURE WORK

This work-in-progress paper presents a mobile AR application for learning about trademark registration in the context of intellectual property education. The application was entirely developed in Unity and is currently being tested by some students at the university level. To the best of our knowledge, this is one of the first studies exploring the possibilities and benefits of AR in the field of intellectual property education, for both students and entrepreneurs. Future research directions include analysis of all the data collected by the app to identify trends in its use and the correlation between this information and the dimensions evaluated using the self-reported instruments. Moreover, it may be possible to deploy the application to AR glasses so that students can see the trademarks in their surroundings and interact with them to evaluate the learning effectiveness of AR glasses vs mobile AR for this topic in intellectual property education.

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Work-in-Progress—Digital Human Factors Measurements in First Responder Virtual Reality-Based Skill Training

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Abstract—First responders engage in highly stressful situations at the emergency site that may induce stress, fear, panic and a collapse of clear thinking. Staying cognitively under control under these circumstances is a necessary condition to avoid useless risk-taking and particularly to provide accurate situation reports to organize appropriate support in time. This work-in-progress applied a flexible virtual reality (VR) training environment to investigate the performance of reporting under rather realistically simulated mission conditions. In a pilot study, representative emergency forces of the Austrian volunteer fire brigade and paramedics of the Johanniter organization participated in an exploratory pilot study that tested a formalized reporting schema (LEDVV), applying equivalent stress in both, (i) real (physical strain) and non-immersive (cognitive strain), and (ii) fully immersive training environments. Wearable psychophysiological measuring technology was applied to estimate the cognitive-emotional stress level under both training conditions. The results indicate that situation reports achieve a high level of cognitive-emotional stress and should be thoroughly trained. Furthermore, the results motivate the use of VR environments for the training of stress-resilient decision-making behavior of emergency forces.

Index terms—Virtual reality, first responders, human factors, cognitive-emotional stress, wearable biosensors

I. INTRODUCTION

First responders engage in highly stressful situations at the emergency site that may induce stress, fear, panic and a collapse of clear thinking, their physical and cognitive readiness is of highest importance to enable appropriate decision making [1]. Staying cognitively under control is a necessary condition to avoid useless risk-taking, to empower those in need, and to provide accurate situation reports to remote units to organize appropriate support in time. First responders maintain situation awareness by following the international LACES framework (Lookouts, Communications, Escape Routes, and Safety Zones [2]) that is applied in Austria within the LEDVV command scheme for situation reporting. Training the first responders in the LEDVV routine improves resilience towards stressors in hazard conditions. Training in real environments requires a high expenditure of resources and allows only limited training frequency and variability. For these reasons, virtual reality (VR) training environments with realistic simulations are necessary. Advanced training of first responders with typical operation scenarios is one of the upcoming challenges of the near future.

Fig. 1. Situation reporting under cognitive-emotional stress, following the LEDVV command scheme.

II. RELATED WORK

VR-based training in disaster preparedness has been increasingly recognized as an important additional modality to traditional real-life skill training [3]. The increased realism in the practice enables first responders to reinforce their individual performance, in particular, to execute tasks appropriately under stress and apply decision making under conditions close to reality. Mills et al. [4] estimated that a mass casualty triage training of paramedic students in a real-world simulation is about 13 times more expensive than in VR, while the simulation

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efficacy has been found near identical. Recent research [5] has even indicated superior performance in simple search tasks following VR and AR training of first responders as opposed to traditional classroom and real-world training.

III. EXPLORATIVE STUDY ON FIRST RESPONDER TRAINING

VR training system. The training system in this work is based on the VROnSite platform [6] that supports immersive training of first responder units’ on-site squad leaders. This training platform is fully immersive, entirely untethered to ease use and provides two means of navigation — abstract and natural walking — to simulate physical stress and exhaustion. The development of the software has been closely interlocked with stakeholders from multiple fire brigades to gather early feedback in an iterative design process and is commercially available by MPD MasterMind Development GmbH.

Sample & Experimental design. Participants (N = 13, 11 males, 2 females; age: 17-70, M: 38.85, SD: 15.02) consisted of representative emergency forces of the Austrian volunteer fire brigade of Gumpoldskirchen (n = 7) as well as paramedics of the Johanniter organization Vienna (n = 6) in sufficient number for an exploratory pilot study that aimed to induce equivalent strain in both, real/non-immersive environment training scenarios (‘Reality Condition’ – ‘RC’) and VR-based, immersive training scenarios (‘VR Condition’ – ‘VR’). Therefore, two identical training procedures were developed, each of which was in turn divided into a (i) cognitive-emotional (immersive in VR and non-immersive simulated in RC) and (ii) a physical strain block (immersive in VR/treadmill, real in RC/running outdoors). Both blocks were repeated twice in each procedure. Each participant carried out both training procedures, RC and VR. To avoid order effects, a crossover design was used, whereas group A received the first training procedure in RC and the second training procedure in VR, and group B the other way around (see Table 1). The study took ~160 minutes for each participant to complete.

Strain induction. Physical strain was induced by a 5-minute endurance run on the emergency forces’ test site (RC) and on a VR-supported treadmill (VR). In both conditions, participants wore heavy operational clothing and a 20 kg backpack, which resembled usual operational equipment.

Induction of cognitive strain was applied in 3 phases: (i) mission scenario videos were presented to the operator (phase ‘monitoring’, Fig. 3), then the first responder was (ii) informed by the mission leader to prepare a situation report in mind (phase ‘anticipating’, duration of one minute), and finally, the first responder (iii) reported on the scenario within one minute (phase ‘reporting’). This procedure was designed in parallel to the Trier Social Stress Protocol [7] and through psychophysiological recordings allowed the assessment of strain. The reports were following the LEDVV command scheme which relates to observations (monitoring / situation awareness), considering consequences (anticipating / decision making), and communicating actions (reporting / execution).

First evaluations showed that this is a promising method to measure situation awareness of first responders during their training, which should be further evaluated in following studies. For the analyses, statements of the reports were assigned to the three levels of Endsley’s concept of Situation Awareness [8] on Perception, Comprehension and Prediction. Scores were then given for each correct statement. These first analyses showed that the situation reports were of a comparable quality in both conditions (see Fig. 2).

![Fig. 2. Situation Reports—number of correct statements for each level of Situation Awareness (N=13).](image)

![Fig. 3. Presentation of relevant scenarios to evaluate situation awareness: (a) car accident with injured persons and inflammable liquid (VR), (b) the same scenario presented in non-immersive environment (RC).](image)

Instruments and measurement methodology. For quantitative measurements about psychophysiological strain, subjects were equipped with mobile BIOPAC BioNomadik® sensors providing EDA (electro dermal activity), ECG (electrocardiogram), and respiratory data. Statistical features from an EDA were extracted from the phasic part (SCR, skin conductance response) following recommendations of Boucsein et al. (2012), using a baseline estimation window of 5 seconds and a threshold of 0.02 µs for minimum conductance changes in SCR detection. In addition, the heart rate variability (HRV) was extracted using Ambu BlueSensor® long-term electrodes for better adhesive properties. First, we semi-automatically checked the ECG for artefacts and corrected them. Then, we automatically extracted the SDNN, i.e., the standard deviation of IBIs in a defined time interval. Finally, VR-based eye tracking provided additional features about eye movements, such as, about fixations, saccades, blinks and pupil dilation.

IV. RESULTS

Physical strain. For the evaluation of physical strain, the Borg-Scale of perceived exertion [10] was used (Fig. 4). A two-way repeated measure ANOVA showed a significant effect for time (F1.5, 16.1 = 59.21; p = .00; η² = .84). Posttests for time effects showed significant differences (p = .00) between
training with the purpose to investigate human factors, i.e., physical strain as well as cognitive-emotional stress levels in the context of situation reporting, under rather realistically simulated mission conditions in an exploratory pilot study. The results indicate that physical strain was substantial and that LEDVV-based situation reporting achieved in both conditions a rather high level of cognitive-emotional stress and should be thoroughly trained. The distributions of the EDA-based measurements do not significantly differ between RC and VC conditions. However, future thorough investigations in the context of equivalence testing will provide more detailed information. Furthermore, there is a potential for risk stratification of situation awareness from eye tracking. These results motivate the use of VR environments for the training of stress-resilient decision-making behavior of emergency forces.

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Abstract—Galleries, Libraries, Archives, and Museums (GLAM) are known to embrace new technologies so they can offer a more informative visitor experience, merging physical artifacts with supporting information offered in a digital format. It is proposed that university and corporate research laboratories can take the form of a GLAM if appropriated as a virtual entity. A virtual GLAM can subsequently support a holistic overview of research projects undertaken by associated researchers to ensure academic affinity with the overall research theme and facilitate the planning of future research. The paper describes the development of a virtual GLAM as a Case Study and adopts reflective practice as a lens through which to evaluate 12 years of research projects.

Index terms—GLAM, reflection, virtual reality

I. INTRODUCTION

University and company laboratories fall into one of three categories: research laboratories, development laboratories, and test laboratories [1]. Each has a specialized focus with a specific thesis to be researched, developed or tested. Within the laboratories a number of related themes may be researched. The Virtual Human Interaction Lab (VHIL) at Stanford University, USA provides a good example (https://stanfordvr.com). The Lab has an explicit Mission: “… to better understand the psychological and behavioral effects of Virtual Reality (VR) and, more recently, Augmented Reality (AR)” (https://stanfordvr.com/mission/), and Founding Director, Jeremy Bailenson, aims to determine how virtual experiences lead to changes in perceptions of self and others to support effective VR in training and education. The students’ projects within the VHIL are varied but all fall within the Mission purview: for example, Psychology of Augmented Reality; Empathy and Perspective Taking; Medical Virtual Reality; and Integrating VR into Classrooms and Curricula (https://stanfordvr.com/projects/). Over a number of projects, a Principal Investigator or research supervisor collates the experiences and outcomes into a general narrative or framework, and publish as informed text for corporate investors, news media or as academic publications. The productive outcome of innovative progress is shared for others to implement and further develop. Experience on Demand by Jeremy Bailenson, for example, is a book with examples taken from the Virtual Human Interaction Lab [2] with the result that the text becomes an historical artifact of the VHIL’s combined knowledge.

Museums are known to embrace new technologies to offer a more informative visitor experience, merging physical artifacts with supporting information offered in a digital format. Two especially personal examples are volumetric 360 degree photography used in the display of the Apollo LM (https://dbiela.com/vrgallery/) and Augmented Reality using iPads to portray previously unseen inner chambers of Egyptian tombs at Amsterdam’s Allard Pierson museum (https://allardpierson.nl/en/). It is therefore not surprising that research laboratories also exist outside the university and corporate sectors. In 2019 researchers from the British Library and the Danish Royal Library proposed the inclusion of research-focused Innovation Labs within galleries, libraries, archives, and museums [3]. The premise was that futures innovation within historical structures offer opportunities for GLAMs to be “… dynamic, adaptive, tolerant and active to the emerging social, political, natural and digital environments” [3]. A number of benefits point to increased access, past and present information embedded in multi-modal artifacts, new perspectives of future relevance, and the offering of a broader range of knowledge to subsequently enhance the visitor experience.

An alternate, switched, proposal is the immersion of GLAMs within an Innovation Lab. An imagined scenario was portrayed in the 1994 film Disclosure where the main protagonist (i.e., a detective played by Michael Douglas) enters a Virtual Reality library seeking incriminating information among virtual card stacks (https://www.youtube.com/watch?v=qk3PK3W_vvo). More recently the concept of a gallery within VR has been adopted by Shu Yamamoto to display paintings using the ENGAGE VR application. In addition, the Louvre's ‘Mona Lisa: Beyond the Glass’ VR exhibit enables viewers to virtually meet the real Mona Lisa, Lisa Gherardini, and learn more about the famous painting (https://www.louvre.fr/en). The paintings come alive as the characters interact with the viewer in Virtual Reality for puerile entertainment or constructive learning, respectively. Museums are also adopting Virtual Reality to augment the visitor experience either physically or virtually (https://www.museumnext.com) EUseum (https://thevirtualdutchmen.com), for instance, aims to enable an experience of all the European museums in one virtual location.

It is posited that the virtual GLAM can therefore be adopted by researchers to display past and present projects, thereby facilitating an opportunity to reflect upon research and gain a holistic oversight of the research laboratory. The paper continues...
with a review of GLAMs and virtual environments, followed by a Case Study detailing the development of a virtual GLAM to facilitate a holistic reflection of 12 years of research. Finally, the Case Study is evaluated through the lens of reflective practice.

II. LITERATURE REVIEW

To maximize the impact of teaching and research, whilst simultaneously reaching new audiences, university museums and galleries can be influential resource centers bridging the dissemination of knowledge and the understanding of science, as well as being repositories of collected artifacts. Consequently, university-affiliated GLAMs have evolved significantly: “No longer simply repositories of knowledge and stewards of objects, academic libraries and museums play critical roles in the intellectual engagement, cultural enrichment, and personal as well as professional development of the many constituents they serve” [4]. In addition, libraries have survived due to their “… culture of cooperation and innovation... becoming centres of digital practice... navigating changes in digital content and scholarly communications” [6]. It has been acknowledged that as universities progress from delivery of content to a more engaged student-centred experience, so too must the supporting institutions that act as repositories of that content [4].

GLAMs can offer faculty and student support in specialized, interdisciplinary, and international contexts leading to a richer and broader learning experience. Also, collections and exhibitions can bridge the academic divide between Humanities and the Sciences. As faculty pedagogy reacts to changes in the digital landscape (pre and during pandemic) and course syllabi evolves, so too are the galleries, libraries, archives, and museums. Lynch termed the juncture as the network turn: “increasingly, we can represent collections in digital form and do things with them that we could not do before ... There’s also though ... the network turn ... which takes a turn to the digital as a prerequisite, but goes far beyond that and I think changes a lot of the rules about everything from inter-institutional collaboration to public engagement and I think in some ways, may have more lasting impacts on our strategies going forward than simply the ability to represent and capture material in digital form” [5]. In other words, it is not enough to simply digitize content for passive viewing, but a more collaborative, immersive, interactive, and engaging experience is required.

Hoang et al propose a tapestry of Alternating Reality: a “… narrative that supports the communication of cultural heritage as an interweaving experience that alternates between real and virtual environments” [7]. The storytelling as narrative is established practice in museum settings [8]. Also, interactive artifacts have been established using projection screens, near-field technologies, wearables, portable devices, and motion capture [9]-[11] to promote a connection between the visitor and the information on display at the museum. In addition, “… a VR system can offer users the opportunity to record their performance, reflect on it and experiment again supporting in that way the enhancement of teaching performance” [12], and this premise can also apply to researchers.

Merging the institutions into a proposed laboratory format for the purpose of sharing research, a GLAM Lab can be considered a place for experimenting with digital collections and data [3]. The meeting of experts at the Innovation Labs at Qatar National Library event, for instance, recommend that “… (t)he lab should be grounded in user-centred and participatory design processes” [3]. The inclusion of a Lab within a library, for example, allows the reuse of cultural heritage collections and data in innovative and creative manners, even involving makerspace activities where visitors can print 3D replicas. Similarly, Labs in galleries enable stories to be told and re-told in multiple ways using technology. Additionally, archival Labs are large scale repositories of data that are organized by computational methods.

Gaining traction within an understanding of the benefits of viewing research in VR is the concept of presence. Presence is defined as the psychological sensation of being in a virtual place [13]. Within a virtual environment, for instance, as the participant views past projects, there is a sense of engagement as presence increases. This has been shown to enhance the learner experience [14] and thus similarly facilitate the reflection of the compendium of research projects within a research laboratory.

III. METHOD

As a Case Study contextualizing the proposal, the International Virtual Environment Research Group (IVERG) Lab was set up in 2008 with initial funding from the UK Prime Ministers Initiative (PMI2) and the Japan Society for the Promotion of Science (JSPS). The overarching theme of the iVERG Lab is to research extrasomatic communication: communication outside the body. Crowley and Heyer’s Communication in History states that communication has progressed through non-verbal gestures and an evolving system of spoken language [15]. As the world became more complex the shared memory of a group was limiting, so a memory outside of the body was required (termed extrasomatic memory); from wall paintings to stone tablets to iPhones, these are the arbiters of extrasomatic memory. Communication is becoming even more complex though as we enter other worlds such as Virtual Reality. For instance, a person partakes in extrasomatic communication as they interact with others in VR, with others outside VR, and with artificial entities in and out of VR. Extrasomatic communication is complex but can be defined as relating to, or being something that exists external to, or distinct from, the individual human body or being. Subsequently, the interlocutor is mentally removed from reality and, when fully immersed in a state of flow, may also be considered physically removed.

A number of projects in the iVERG Lab by undergraduate and Masters students vary in thesis topics but the underlying theme has always been to learn more about communication when using three-dimensional virtual spaces. Since 2008 the Principal Investigator, international collaborators, and student researchers have collated data in the form of diaries, videos, photographs, computer screen captures, flowcharts, and drawings. In-house and international conference presentations have reported developments, in addition to publications within peer-reviewed journals detailing the research. All these artefacts have had to be stored for academic evaluation (e.g. external moderation) and ethical compliance. An overview of the projects is displayed in the flowchart (see Fig. 1).
As the COVID-19 pandemic took hold in early 2020, and with government restrictions preventing students from physically entering institutes of education, a virtual representation of the iVERG Lab was proposed. To prepare the virtual GLAM, a post-graduate student was employed. The development of the virtual GLAM progressed through five instructional design phases: Analysis, Design, Development, Implementation and Evaluation (ADDIE). The five stages constitute a set of activities that target specific outcomes. More specifically, the five stages were:

- **Phase 1:** Analysis of research projects along a timeline, and their connection to the main iVERG Lab theme of extrasomatic communication.
- **Phase 2:** Design the virtual GLAM to reflect the longitudinal process and significant epoch moments displayed in multiple media formats.
- **Phase 3:** Develop the virtual GLAM using Unity, and also prepare the photogrammetry tools.
- **Phase 4:** Implementation of the virtual GLAM using Oculus Rift HMD.
- **Phase 5:** Evaluation through user experiences, and refine the virtual GLAM with recommended improvements.

To save time, a pre-designed structure was purchased from the Unity Asset store (see Fig. 2). The advantage was that the structure could be used as a template upon which to include the iVERG Lab artifacts in multiple media formats (such as video, photographs, presentation slides, and virtual animations). Thereafter, research images, information slides, pedagogical frameworks, short videos, sound files, and 3D objects as virtual artifacts were added (see Figs. 3–5).

Due to the restrictive access imposed by COVID-19 regulations, the development was undertaken remotely using Unity, PlasticSCM and Teamviewer. The researcher was allowed to be physically located within the university while the student developer remotely accessed the main PC for developing the virtual GLAM. Iterative updates were synchronized using the distributed version control tool PlasticSCM (https://www.plasticscm.com), and then viewed using the connected Oculus Rift HMD. Plastic SCM allows a remote developer to iteratively update content within the GLAM. The update is subsequently viewed by another developer or
researcher who, in turn, can accept, merge or edit the update. The PlasticSCM interface is shown in Fig. 6 where each node represents an update.

![PlasticSCM interface](Fig. 6. PlasticSCM interface.)

To display the hardware used throughout the research projects, such as LEGO EV3 and Arduino robots, required the programming of a dedicated photogrammetry application. Photogrammetry is the process of taking multiple overlapping photographs and then stitching them together with the aim of creating exact 3D representations. The student developer decided to use Apple’s XCode to program a bespoke photogrammetry application, but it was left to the researcher to physically capture images of each robot. This required a turntable, an iPhone 12 camera, a tripod, lighting, and a light box (see Fig. 7).

![Photography hardware set up](Fig. 7. Photography hardware set up.)

Each object required 96 photographs which were then transferred to a required M1-chip Apple computer. The application, named phog, then blended the photographs into a 3D model saved in usdz format. This was then converted to required dae format for the Unity Project and uploaded to, and positioned in, the virtual GLAM. Within the virtual GLAM the 3D model can then be rotated 360 degrees, thus providing detailed, multi-perspective, and omnidirectional views. Fig. 8 displays a 3D representation of a student-designed VR haptic glove in the photogrammetry application.

![Photogrammetry application and subsequent 3D model capture](Fig. 8. Photogrammetry application and subsequent 3D model capture.)

Photographs, videos, screen captures, flowcharts, images, presentation slides and past papers were all collated for consideration as representations of 12 years of research within the iVERG Lab. Once all the screens and panels within the virtual GLAM were utilized, the Unity Project was then exported for use as a stand-alone artefact viewable within the portable Oculus Quest by any user.

IV. DISCUSSION

Reflection is “… a learning mechanism that includes the process of stepping back from an experience and through extensive consideration get a better and deeper understanding of a phenomenon” [12]. Reflection on learning is a student-centered activity most often associated with course content or disciplinary practices. The aim is to develop learners’ cognitive strategies to enhance self-regulation skills in order to prepare students for continuous learning beyond specific subject content. Similarly, reflection within a research environment aims to promote informed deliberation in the discovery of new or additional knowledge to the topic under investigation, and often incorporates the use of researcher diaries in the form of text, audio, video, drawings, flowcharts or a combination of multiple media artifacts. Progress reports and secure reliable data collection are essential to meet the requirements of valid research practice and ethical expectations.

A reflective structure of three components specific to research is proposed: research projects have to be context specific, meaningful, and trustworthy. The context of research is the circumstance or situation in which its process or outcomes are implemented. It is the weaving together of thoughts, ideas, information, data, and knowledge in order to position results into existing paradigms. “The circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood” [16]. Research has to be meaningful; i.e., practically useful and stimulating [18]. Meaningful, high-quality research is characterized as a multidimensional concept: “… researchers’ conceptions of research quality [include] a multitude of notions [which] span from correctness, rigor, clarity, productivity, recognition, novelty, beauty, significance, autonomy, difficulty, and relevance to ethical/sustainable research” [17]. Research
must also be trustworthy; i.e., abide by trust and personal responsibility. Helmer et al., “… advocate more personal responsibility for researchers, creating space for them to apply their own intellectual judgment…” [18] though not at the expense of research validity and reliability. In addition, trustworthiness may be apportioned externally through international peer-reviewed publications.

The culmination of 12 years of research was able to be viewed within the virtual GLAM in order for the researchers to reflect upon their implementations and progression. This had the added advantage of identifying strengths and opportunities, thus becoming more focused when planning future research proposals and recruiting students. Table 1 summarizes reflective commentaries after touring the virtual GLAM, observing video clips, reading short summaries, looking at photographs, screen captures and posters, listening to snippets of captured data, viewing graphs and frameworks, and watching short clips of conference presentations given physically and virtually. To reiterate, the iVERG Lab’s primary research theme is extrasomatic communication (i.e., communication in and out of virtual environments between people as well as sentient objects). It can be seen that all 10 major research projects in the iVERG Lab adhere to the aim of determining recognition and metrics of extrasomatic communication.

**TABLE 1. REFLECTION ON A SAMPLE OF IVERG LAB RESEARCH BETWEEN 2008 AND 2020**

<table>
<thead>
<tr>
<th>Research</th>
<th>Reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context</strong></td>
<td><strong>Meaningful</strong></td>
</tr>
<tr>
<td>Title: Processes, outcomes and metrics for assessing synchronous and asynchronous collaboration in Virtual Worlds. (Prime Minister’s Initiative 2 (PMI2) Science Connect Research)</td>
<td>To determine successful metrics for assessing tasks in emerging Virtual Worlds.</td>
</tr>
<tr>
<td>Title: Beyond iStorm: Mindstorms in Virtual Spaces. April 2008 – March 2009.</td>
<td>Immersing students in activities and communication in a virtual space will lead to specific, measurable learning outcomes and concurrent metrics for assessing related tasks.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Title: The Virtual Institute</td>
<td>Criteria for building an institute in a</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>April 2009 – March 2010.</strong></td>
<td>virtual world where activities can be undertaken by students.</td>
</tr>
<tr>
<td>Title: Augmented worlds</td>
<td>April 2010 – March 2011.</td>
</tr>
<tr>
<td>Title: Augmented reality for science literacy (JAIST Challenging Exploratory Research)</td>
<td>April 2010 – March 2012.</td>
</tr>
<tr>
<td>Title: Collaborative Learning, Cognitive Processes and Telerobotic Communication in Virtual Spaces</td>
<td>April 2012 – March 2013</td>
</tr>
<tr>
<td>Title: Robot Mediated Interaction</td>
<td>April 2013 – March 2014</td>
</tr>
<tr>
<td>Title: New ERA for virtual collaboration</td>
<td>April 2014 – March 2015</td>
</tr>
</tbody>
</table>

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V. CONCLUSION

It has been posited that research laboratories can take the form of a Gallery, Library, Archive and Museum (GLAM) if appropriated as a virtual entity. The subsequent virtual GLAM can then support a holistic overview of research projects undertaken by associated researchers (i.e., Principal Investigator, collaborators, and students) to ensure academic affinity with the overall research theme and facilitate the planning of future research. A limitation of this proposal is its narrow focus on one Case Study though. However, it is posited that the emergence of VR as an accessible and reliable technology will enable researchers to reflect on their projects and consider sharing their efforts to a broader audience in the form of virtual GLAMs.

ACKNOWLEDGMENT

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Which Types of Learners Are Suitable for the Virtual Reality Environment: A fsQCA Approach

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Abstract—While virtual reality has become a research hot spot in the education field, few studies considered the students’ individual differences (e.g., attitude, knowledge), which may influence their learning. This study aimed to investigate, which types of learners are suitable for the virtual reality environment. A fuzzy set analysis was conducted, we found: (1) high autonomy virtual reality environment suitable for students with a solid foundation of knowledge; (2) low autonomy virtual reality environment cause more cognitive load for learners compare to high autonomy virtual reality environment; (3) a positive attitude towards VR may lead to worse learning outcomes for learners with low prior knowledge. The findings indicated that teachers should personalize their use of educational technology based on their students.

Index Terms—virtual reality, virtual museum, autonomy, cognitive load

I. INTRODUCTION

Virtual reality (VR) is an advanced, human-machine interface that simulates a realistic environment [1]. When the VR environment is combined with other equipment such as a head-mounted display (HMD), headset, joystick, or other devices can provide the user with multiple senses (visual, auditory, tactile, and olfactory) and can create an environment with a high sense of immersion and presence [2]. These technologies affordances provide VR a great potential for educational use. Museum learning is an effective method to facilitate students’ understanding of the cultural heritage, natural landforms, and biological habits as well as some knowledge that is hard to learn in formal classrooms. With the development of VR technology, a virtual museum learning environment that is similar to the real museum can be built through authentic 3D models, not just presenting the 2D environment on the web page [3]. To this end, it is sensible to carry out museum learning through the VR environment [4].

Self-determination theory assumes that people have an inherent tendency to be curious about their environment and that teachers support students’ autonomy in the teaching process, which contributes to students’ academic performance [5]. Autonomous behavior arises from a person’s integrated self-awareness, whereas controlled behavior has externally perceived causality and is experienced as being pressured by needs [6]. The autonomy of students comes from the support of teachers, and the choices provided by teachers will make students feel more autonomous [7], [8]. Accordingly, we assumed that students’ learning performance may vary from VR interventions with different autonomous designs.

In recent years, while more and more researches on VR in the field of education, the finding of impact on students’ learning is mixed. The results of many studies have shown that VR helps learners to learn and to better understand specific knowledge, whether in terms of conceptual knowledge or motor skills [9]. However, Merchant assumed students in the group, that the sequence of learning actives was controlled by the computer programs outperformed the students who can select the sequence [10]. Moreover, Makransky suggested learning in VR may overload and distract the students [11]. Some studies showed that individual differences of learners had an impact on the learning outcomes of learners in VR environment [12], [13]. Individual differences in students may explain why there are different results in the same VR environment, as it plays an important role in the context of visual representation learning [14], [15]. That’s why we conducted this study.

This study answered the question “which types of learners are suitable for the virtual reality environment?” by conducting fuzzy-set Qualitative comparative analysis (fsQCA). Two versions of the VR museum with different levels of autonomy were proposed to facilitate students’ learning on the Tujia culture, which is an important cultural heritage of China. We chose foundation of knowledge (FK), autonomy (AUT), attitude towards VR (AVR), experience with VR (VRE) as the moderator variables (Table I). This study tried to answer the following three questions (Q):

Q 1: Are there any necessary conditions leading to high pro-test grade (HPT), low pros-test grade (~HPT), high cognitive
load (CL), and low cognitive load (~CL) among FK, AUT, AVR, and VRE of learners?

Q 2: What configurations (i.e., the specific combinations of FK, AUT, AVR, and VRE) of learners caused HPT or ~HPT sufficiently?

Q 3: What configurations (i.e., the specific combinations of FK, AUT, AVR, and VRE) of learners caused CL or ~CL sufficiently?

TABLE I. MODERATOR VARIABLES

<table>
<thead>
<tr>
<th>Moderator variables</th>
<th>Abbreviation</th>
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<tbody>
<tr>
<td>Foundation of knowledge</td>
<td>FK</td>
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<tr>
<td>Autonomy</td>
<td>AUT</td>
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<tr>
<td>Attitude towards VR</td>
<td>AVR</td>
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<td>Experience with VR</td>
<td>VRE</td>
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<tr>
<td>High pros-test grade</td>
<td>HPT</td>
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<tr>
<td>High cognitive load</td>
<td>CL</td>
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II. MATERIALS AND METHODS

A. Design

A quasi-experimental design was conducted and 47 college students were randomly assigned to two groups: a high autonomy group and a low autonomy group, with 23 and 24 people, respectively. Both groups browsed and learn the Tujia culture of China in a VR museum, which was developed by our research team. Students in the high autonomy group were able to browse materials in the VR museum freely, while students in the low autonomy group must browse the materials through the predefined route. Participants (male=7, female=40) were aged 18 to 25. They were all graduate students from a university in central China, and none of them had studied Chinese Tujia culture before. All participants joined in the experiment voluntarily, and the results of this study would not have any negative impact on them.

B. Measuring Instrument

In this study, data were collected from five resources:

Demographic Questionnaire (DQ) was used to collect participants’ basic information such as sex, age, grade, and so on, which ensured participants were randomly assigned to two groups.

Tujia musical instruments knowledge test (TKT) was used to access participants’ comprehension of Tujia music culture; it comprised 14 questions (10 multiple-choice questions and 4 true or false questions). The items were designed to be closely related to the materials in the VR museum. The maximum test score is 70 points (five points for each item).

Prior VR experience Questionnaire (VREQ) was used to measure the students’ VRE; it was revised based on the Taylor et al.’s Game Experience Measure (GEM) which was used to assess participants’ prior experience and knowledge of video games [16]. Research suggested using GEM can better understand the relationship between video game experience and a host of other variables [16]. We adapted the questionnaire by slightly changing the computer games to VR [16], [17]. In reality, the Cronbach’s alpha of GEM was 0.903, higher than 0.8, indicating good reliability.

Attitude towards VR Questionnaire (AVRQ) was used to measure the students’ AVR. This study used the questionnaire, which was designed by Davis, into AVRQ and used terms VR and VR museum to replace terms such as email system and handheld technology in the initial questionnaire [18]. In practice, the Cronbach’s alpha of the whole test was 0.968, and the Cronbach’s alpha of each aspect was all higher than 0.8, indicating good reliability.

Cognitive load Questionnaire (CLQ) was used to measure the students’ CL. The cognitive load survey was originally developed by Sweller and Paas [19]. This study takes the survey used in Hsieh and Tsai’s study and adapts it to a VR museum learning environment [20]. Mental load that measures the degree of cognitive ability to process the information in the VR museum and mental effort that measures the level of an individual’s invested cognitive ability to process information presented in the VR museum, were collected in the survey [21]. In reality, the Cronbach’s alpha values of the two scales were 0.87 and 0.72, respectively, and the overall Cronbach’s alpha value was 0.82. The above data showed that the instruments are sufficiently reliable to investigate the cognitive load experience of students learning in a VR museum.

C. Procedure

Before the treatment (Fig. 1), participants were asked to complete DQ and VREQ. Then, the participants had 5 minutes to complete the prior TKT. Afterward, participants received a verbal introduction, describing how to use the VR equipment and the VR museum. Participants could learn in the VR museum for 20 minutes. After that, participants had an additional 5 minutes to complete the TKT. Finally, participants had to finish AVRQ and CLQ.

D. Data Analysis

Fuzzy-set Qualitative comparative analysis (fsQCA), which was developed by Charles Ragin, is a way to obtain linguistic summaries from case-related data [22]. fsQCA is an analytical method for small sample sizes that can be used for contextual analysis [23]. While in most cases fsQCA had been applied in the fields of sociological research and marketing, recent studies...
are using fsQCA in the education field to investigate the influence of various factors in the learning environment on the learning effect of learners.

First, Calibrating Fuzzy Sets of the data were conducted to convert the data value into membership degrees ranging from 0 to 1 [24]. For independent degree, assign 1 to the high autonomy group and 0 to the low autonomy group. Other conditions and outcomes are calibrated according to the degree of membership (full nonmembership, cross-over point, full membership) [25]. Generally, the item which is “full membership” represents that the membership is 0.95 or higher; the item which is “full nonmembership” stands that the membership is 0.05 or lower, and membership of 0.50 represents the point of maximum ambiguity of membership in the set. Fuzzy set membership is assigned using a “membership function” that maps the measure of interest for all items in the set to the interval [0, 1] [26]. We calibrated using the calibrate(x,n1,n2,n3) function, and set the value ranked 5%,50% and 95% as the threshold for n1,n2,n3.

Second, we performed the necessary analysis for each condition. As shown in Table II, this study found that none variable could be the necessary condition for different outcomes (consistency < 0.90), namely, HPT, ~HPT, CL, and ~CL. Therefore, this study looked for potential configurations of these causal conditions that lead to the above outcomes.

The final step was to generate the truth table, including entire logical and reasonable combinations of causal conditions. Considering this study had four causal conditions (FK, AUT, AVR, VRE), the ideal number of combinations of the truth table should be 16 (2^4). However, the cases in the sample might not necessarily satisfy all possible combinations in the truth table. The truth table must be fine-tuned to isolate relevant configurations by setting frequency cut-off and consistency cut-off [24]. This study considered combinations with at least one case and chose 0.8 as the consistency threshold. This is a common setting, and it has a reasonable practical implication—if more than 80% of the students with the same combination of conditions achieve good learning outcomes, we consider this combination of conditions to be feasible [27]. In addition, the analysis results using QCA included complex solution, parsimonious solution, and intermediate solution. The intermediate solution was chosen for interpretation of results because it includes simplifying assumptions and has greater interpretability [24].

III. RESULTS

A. Configurations of learning outcomes

As shown in Table III, we analyzed the configurations of HPT and ~HPT respectively. The results showed that two configurations (i.e., A1, A2) produced HPT, and two configurations (i.e., B1, B2) produced ~HPT. It is worth noting that the configurations of high and low pros-test grades were not exactly symmetric.

Configuration A1 showed that FK*AUT (‘*’ means conditions exist at the same time) could cause HPT (consistency = 0.82). Specifically, based on FK, students could better learn and understand the learning materials presented in the VR museum [28]. When people experienced a sense of autonomy, their learning performance could be better. This is probably because students with autonomy are motivated and better understand the concepts in the course and stick to learning activities better, leading to better grades [29]. Configuration A2 showed that students with AVR and VRE can get HPT even in low autonomy VR museums, regardless of whether FK or ~FK (consistency = 0.81). This configuration could be divided into two subsets, FK*~AUT*AVR*VRE and ~FK*~AUT*AVR*VRE, according to the difference in FK.

<table>
<thead>
<tr>
<th>TABLE II. NECESSARY CONDITION ANALYSIS RESULTS</th>
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<tr>
<td>Consistency</td>
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<td>FK</td>
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<td>~FK</td>
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<tr>
<td>AUT</td>
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<tr>
<td>~AUT</td>
</tr>
<tr>
<td>AVR</td>
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<tr>
<td>~AVR</td>
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<tr>
<td>VRE</td>
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<td>~VRE</td>
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B. Table III. Configurations causing HPT and ~HPT

<table>
<thead>
<tr>
<th>TABLE III. CONFIGURATIONS CAUSING HPT AND ~HPT</th>
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<tr>
<td></td>
</tr>
<tr>
<td>FK</td>
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<tr>
<td>AUT</td>
</tr>
<tr>
<td>AVR</td>
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<tr>
<td>VRE</td>
</tr>
<tr>
<td>Consistency</td>
</tr>
<tr>
<td>Raw Coverage</td>
</tr>
<tr>
<td>Unique Coverage</td>
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<tr>
<td>Solution Coverage</td>
</tr>
<tr>
<td>Solution Consistency</td>
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</table>

b. ● indicates that this condition exists, ☒ indicates that this condition does not exist, the space means that it doesn’t matter whether this condition exists or not. HPT high pros-test grade, FK foundation of knowledge, AUT autonomy, AVR attitude towards VR, VRE experience with VR.

Configuration B1, B2 showed that if only ~FK*AVR*~VRE (consistency = 0.85) or ~FK*AUT*AVR (consistency = 0.82) satisfied, ~HPT could be caused. Among the two configurations, the presence of ~FK and AVR were deemed as necessary conditions because they covered both configurations. Similar to configuration A1, the VR museum has no significant impact on ~FK students. Parallel to the finding of Chen et al., VR-based digital learning had no significant effect for students with low prior knowledge [30]. According to configuration B2, students with ~FK even with AVR and learning in high autonomy VR
museum still cannot achieve HPT. This is in line with Schneider et al.’s finding, autonomy can increase intrinsic motivation, effort, and perceived competence, while subsequent learning scores were not significantly increased [8].

B. Configurations of cognitive load

The truth table of causing CL (i.e., C1, C2) and ~CL (i.e., D1, D2, D3) is showed in TABLE IV. It is worth noting that the configurations of high and low cognitive load were not exactly symmetric.

<table>
<thead>
<tr>
<th>TABLE IV. CONFIGURATIONS CAUSING CL AND ~CL</th>
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<table>
<thead>
<tr>
<th>Configuration</th>
<th>FK<em>AUT</em>AVR*~VRE</th>
<th>FK<em>~AUT</em>AVR*VRE</th>
<th>~FK<em>~AUT</em>AVR*VRE</th>
<th>~FK<em>~AUT</em>AVR*~VRE</th>
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<tbody>
<tr>
<td>C1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>D1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D3</td>
<td></td>
<td>×</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistency</td>
<td>0.79</td>
<td>0.83</td>
<td>0.86</td>
<td>0.90</td>
</tr>
<tr>
<td>Raw Coverage</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Unique Coverage</td>
<td>0.17</td>
<td>0.05</td>
<td>0.002</td>
<td>0.04</td>
</tr>
<tr>
<td>Solution Coverage</td>
<td>0.002</td>
<td>0.12</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>Solution Consistency</td>
<td>0.82</td>
<td>0.86</td>
<td>0.90</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Configuration C1 showed that ~AUT*~AVR*VRE could cause CL (consistency = 0.83). Configuration C2 showed that as long as ~FK*~AUT*AVR*~VRE is satisfied, CL could be caused (consistency = 0.86). For students with ~FK*~AUT*~VRE, their enthusiasm and interest in VR may come from the novelty of VR rather than the connection between VR and knowledge. For such learners, high autonomy VR museum might distract their attention while studying and cause negative effects. Among the two configurations, the presence of ~AUT was deemed as necessary conditions because they covered both configurations. This is probably because when students have a high degree of autonomy in the learning process, the internal cognitive load is low [8].

Configuration D1 showed that FK*AUT*~VRE could cause ~CL (consistency = 0.83). Configuration D2 showed that if only FK*AUT*AVR existed, ~CL could be caused (consistency = 0.86). Notably, D1, D2 were the subset of A1. This is in line with Seufert et al.’s finding, that intrinsic load should be high for students with low levels of knowledge in a particular domain, while learners with higher prior knowledge levels should be low in intrinsic load [28]. Students with FK*AUT had a lower cognitive load and were able to achieve the high pros-test grades. Configuration D3 showed that only if ~FK*AUT*AVR*VRE satisfied, ~CL could be caused (consistency = 0.86). To summarize, among the three configurations, the presence of AUT was deemed as a necessary condition because they covered all configurations. This result was exactly symmetrical with the above conclusion that ~AUT was a necessary condition of causing CL.

IV. Conclusion

The purpose of this study is to discuss which types of learners are suitable for the VR environment. Corresponding to relevant literature, this study seeks to understand how the combination of students’ foundation of knowledge, autonomy, attitude towards VR, and prior VR experience explains conditions leading to good or poor learning outcomes and high or low cognitive load. The fsQCA was conducted, the result showed that none of these are either necessary or sufficient factors to achieve the above four results. Instead, combinations of variables as causally sufficient configurations to cause the above results.

The configurations, which caused HPT and ~HPT, indicated that the high autonomy VR environment is more suitable for participants with a solid foundation of knowledge. This resonates with Grolnick et al.’s argument that an autonomy-supportive environment increased learners’ engagement, resulting in better learning outcomes and greater understanding of learning materials [31]. For students with solid foundation of knowledge, studying in a high autonomy environment can better promote learning achievements. And VR Museum is not suitable for students with ~FK. Because VR museums present information in the form of text and video, Baceliciute et al. argued that the form of delivery was more difficult in the VR-reading condition than in the Real-reading condition [32]. For students with ~FK, not only does VR museum not facilitate their learning, but it will also put additional cognitive load on them.

The configurations, which caused CL and ~CL, indicated that in the learning environment with low autonomy, students have a high cognitive load. Both high and low autonomy VR environments are not suitable for learners with low prior knowledge. VR is not suitable for the initial stage of knowledge learning. It will be better for learners to use VR equipment for further learning when they have a certain knowledge base. For example, learners still learn conceptual knowledge in traditional classrooms and then practice hands-on training in a VR environment. It is more appropriate to apply VR to the applied knowledge and retrospective knowledge stages because at this point the learner already has a certain knowledge base.

The main findings of this study revealed the learning outcomes of VR would great vary among students with different characteristics. This requires educational practitioners to provide personalized teaching plans according to the characteristics and personalities of learners [33]. Furthermore, fsQCA shows great potential to address the problem of outcome correlates, especially when dealing with nonlinear relationships, asymmetric relationships, and causal conditions involving multiple concurrent relationships [34].

Some limitations should be mentioned. First, the findings of the study mainly depend on the context of Tujia musical instrument learning. Different learning contents may lead to different results. Therefore, it is recommended that this study be replicated in different learning settings in future research. Second, the sample size was small, the generalizability of this result maybe not be enough. In future research, we should recruit
more participants to generalize a more robust finding. Third, we may still lack consideration for some moderators, and we can consider including more in the future. Finally, the larger age difference of the participants in this experiment may have an impact on the findings, and future research needs to consider the age and gender of the participants.

ACKNOWLEDGMENT

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Work-in-Progress—Using Virtual Reality in Museums to Assist Historical Learning

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Abstract—Museums are always looking for new ways to attract and engage their visitors. Virtual reality (VR) is becoming an increasingly viable option for doing this and enables the recreation of historical sites/structures for visitors to explore. This paper describes a VR application being developed in partnership with the Bawdsey Radar Museum to recreate the radar transmitter towers that stood on the site and were pivotal in winning the Battle of Britain. This paper describes the application’s development and discusses user trial results to determine whether VR can be effectively used within a museum setting to assist in historical learning.

Index terms—virtual reality, usability, museum, learning

I. INTRODUCTION

With devices such as the Oculus Quest 2, virtual reality (VR) headsets are becoming more portable and affordable than ever, which is increasing the prevalence of VR in our everyday lives. As well as allowing individual consumers to enjoy a completely different way of gaming or viewing online content, VR headsets also enable a host of new opportunities with regards to learning and education.

This paper will explore one such opportunity by investigating how the use of VR can assist the learning of historical information within the museum setting. The VR exhibit discussed in this paper has been developed in collaboration with Bawdsey Radar Museum. Section II will give more detail on the museum and the main purposes of the VR exhibit, whilst Section III explores prior literature around this topic. Section IV describes the VR exhibit and Section V explains the experiments conducted and the results gathered to answer this research question. Section VI discusses these results. The final section will draw conclusions for both the exhibit itself and the results of the experiments.

II. BACKGROUND

The Bawdsey Radar Museum, located in the Southeast of England, tells the story of radar, starting with its conception at the Bawdsey site itself. A vital part of this story is how the 360ft steel radar transmitter towers operated at sites like Bawdsey all along the East and South coast during the Battle of Britain. However, the four towers that once stood at the Bawdsey site have since been dismantled—very few of these original towers still standing in the country.

Consequently, museum visitors can no longer gain a full appreciation of the size of these towers, rendering them unable to comprehend the daunting task of conducting repairs to this vital wartime infrastructure. The potential role of VR in this case would be to enhance a visitor’s learning by virtually recreating the site as it stood back in World War II, allowing them to scale the tower and experience the view from the top in a safe environment.

III. LITERATURE REVIEW

A study comparing the usability of a VR and non-VR version of a virtual tour application within a museum setting found an improved System Usability Scale (SUS) score for the VR version compared to the non-VR version (72.10 vs 68.10) [1]. Other studies have also found that the feeling of presence induced by VR can assist the learning process [2]. Additionally, there are studies that show the introduction of technological dimensions to museums can elicit positive emotions such as senses of immersion, curiosity, enjoyment, and authenticity [3]. Alongside this, there may be potential for increasing visitor satisfaction. For example, the VR exhibit in one cultural heritage institution was found to be the most popular exhibit of all [4]. Another study comparing immersive VR to two-dimensional desktop or video instruction found that the immersive users enjoyed their experience most and reported the most desire to continue learning about the subject [5]. Finally, VR allows visitors to engage with structures and historical sites which are either inaccessible or no longer exist, with examples being the recreation of the Cathedral of Palermo [6] and Notre-Dame [7].

IV. THE IMMERSIVE BAWDSEY RADAR EXPERIENCE

A. Features

The objective of the application is to supplement the educational value of the museum’s exhibits, by allowing the user to experience the scale of the Bawdsey radar towers from the
perspective of the engineers who maintained them. The application includes four accurately scaled transmitter towers, one of which is shown in Fig. 1, and photo-realistic 3D models of historically significant site buildings. This allows the user to understand their bearings in relation to the transmitter block, now the museum building. The infrastructure is complemented by semi-realistic detailing of the landscape and vegetation and a Spitfire fly-by animation. The primary interactive feature is the tower ladder climb, designed to replicate the site engineers’ job as they climb to the top of the 360ft towers.

Fig. 1. Bawdsey Radar VR Exhibit.

B. Accessibility Considerations

To ensure that most people have a comfortable and meaningful experience when using the exhibit, the accessibility requirements of a wide range of demographics were considered. To bridge the gap in technical ability, the volunteers that will assist with the physical execution of the exhibit have been trained to guide users of varying ability through the application. The application allows the use of teleporting for movement, which is a standard mechanic in VR headsets and is recommended for users who are more prone to motion sickness, therefore allowing a wider range of users to comfortably use the application. A range of accessibility settings have been implemented into the application, from subtitles for the audio narration for those with hearing impairments to coloured overlays.

C. Implementation

The Oculus Quest 2 VR headset was chosen for being a standalone headset able to track a variety of body movements without the need for external sensors, enabling 6 degrees of freedom. The application was constructed in the cross-platform game engine, Unity. Custom C# scripting and Unity modelling was used to create the application, and the pre-existing Oculus player object was used to utilise the default controls.

V. EXPERIMENTATION AND RESULTS

A. Participants Selection

A sample of 26 participants took part in the trial of which 42.31% identified as male, 50% female, 3.85% non-binary and 3.85% preferred not to say. Volunteers were recruited via emails and an internal newsletter sent to specific departments within the company. As a result of this, most of the participants work within the technology industry. This potential bias was considered when analyzing the results (Section V C).

Fig. 2 shows the spread of participants across each age group and indicates that the ages 10-19 were the most represented in the trial. Comparing this distribution with the age demographic of museum visitors from 2021 [9] reveals that the majority age range for museum visitors of 19-64 at 52.96% is closely matched when the trial statistics covering ages 20-59 are aggregated, giving a total distribution of 57.68%.

However, with 27.07% of the 2021 visitors [9] being aged 65 and over, this age group is underrepresented in the sample in relation to the museums’ usual visitor demographic. This was a result of the sampling method as opposed to deliberate exclusion and will be rectified through further rounds of trials with targeted sampling of this age range, however this will not be included in this paper.

B. Methodology

During the trial, participants were seated and guided through the experience by a museum volunteer. This helped enrich the experience by allowing the user to hear more about the history of radar from an expert, replicating the presentation of the exhibit within the museum.

A participant feedback survey was constructed, consisting of two sections. The first was completed before the trial and aimed to understand the demographics, technical competence, and their prior experience with VR. By analysing this data, we could identify any deviations from the museum’s footfall data and thus, whether the prospect of virtual reality encourages new audiences. The second section was completed after the participant had completed the trial, to gather usability metrics via the SUS [8], and qualitative feedback via open ended questions captured comments about how much they had learnt.

The qualitative data would be analysed to give an indication of the benefits that visitors got from the experience and whether the VR assisted with their learning, while the usability data would indicate whether there were any problems during their experience that would’ve hindered their ability to learn. When analysed together, the extent to which the VR exhibit assists in the museum’s delivery of information should be clear.

C. Results

SUS was used to measure the participant’s perception of the application. By following the SUS process [8], and averaging the scores across the participants, an average SUS score of 79.8 was calculated. [8] This is deemed “Good” and for reference,
any SUS score above 68 should be considered above average [8].

88.4% of participants had used VR prior to trialling the application. However, the 11.6% of users who had not used VR before reported an average SUS score of 83.3 which is higher than the overall average reported. Therefore, having no prior VR knowledge did not impact the participant’s experience.

92.3% of participants reported that they learnt something new from the application. Out of these participants 69.6% had learnt something new relating to either the Bawdsey site or the usage of Radar in WWII as shown in Table I.

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<tr>
<th>Aspect Learnt</th>
<th>Reported Participants’ Learning (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge related to WWII and the history of radar.</td>
<td>34.8%</td>
</tr>
<tr>
<td>An understanding of the size and height of the historical site.</td>
<td>34.8%</td>
</tr>
<tr>
<td>VR hardware usage</td>
<td>21.7%</td>
</tr>
<tr>
<td>Uncategorised learning</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

VI. DISCUSSION

Results from the initial study indicate that participants were confident in using the application and found it interesting. Many expressed that the application allowed the size and height of the transmitter towers to be clearly understood. This is difficult to portray in a typical museum exhibition and was one of the main objectives for the application.

Another reason for using VR within museums is to attract a younger audience. In 2019/20 visitors to museums and galleries were typically between 25 and 74 years old [9]. This statement coincides with the Bawdsey Radar Trusts’ 2021 annual report [10] where 52.96% of its visitors throughout the year were aged between 19 and 64. After advertising the Bawdsey Radar VR trial, 38.5% of participants that volunteered were between 10 and 19 years of age, whilst only 15.14% of visitors to the Bawdsey Radar Museum in 2021 were aged between 5 and 18 [10]. This supports the idea that VR could be used in museums like Bawdsey to encourage younger generations to engage in historical learning activities. All participants of the trial within the 10-19 age bracket responded with either agree or strongly agree to the question “Given the opportunity you would use this application again” further highlighting the positive response in the younger generation to an immersive educational experience. The average SUS score of 79.8 also demonstrates that it does not only benefit younger visitors as the trial included participants up to the age of 69 and those with no prior VR experience.

VII. CONCLUSIONS AND FUTURE WORK

This paper describes the VR application being developed for the Bawdsey Radar Museum to recreate the historical site and discusses the results of user trials and how they show the benefits of VR in assisting with historical learning.

User survey results found that almost all participants learnt something new from the experience, with a third having a greater appreciation for the scale of the site, therefore achieving the main goal of the application. Given that the trial also attracted a broad age range of participants, with the majority group being between 10-19 years old, the presence of immersive technologies such as VR can be said to attract a whole new generation of visitors to the museum and assist with their learning of historical information.

In future, we plan to further enrich the experience by incorporating environmental sounds and oral history audio clips so that the user can listen to stories from the site’s wartime operators. We will also complete further trials to continue to get a wide spread of results from a range of audiences.

ACKNOWLEDGMENT

We would like to thank the Bawdsey Radar Museum for providing us the opportunity to work on this project, with specific thanks to Graham Murchie for being our main point of contact and an integral part of the project. We would also like to thank our BT colleagues Anasol Peña-Rios, Adam Ziołkowski and Paul Veitch for their help in reviewing this paper prior to submission.

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Abstract—In the study of art, where works often reside in museums or are experienced on screens in classrooms, artistic creation can seem distant and abstract. Although exposing learners to art making by asking them to create art themselves can be a way to facilitate understanding, it can require expensive materials, equipment, and space. Drawing, painting, and sculpture also have steep learning curves. Sloppy Forgeries and Choppy Forgeries VR are two work-in-progress games that attempt to overcome some of these obstacles by exposing players to art making in a fun, lighthearted context with an emphasis on careful observation and coordination.

I. INTRODUCTION

Copy, mimic, recreate; these are actions intimately entwined with education, often with negative connotations. Copying is commonly associated with plagiarism. Imitation can imply a thoughtless process or inauthenticity. However, it is also becoming increasingly apparent that imitation is crucial to human development [1]. Its value is also obvious in certain educational contexts (e.g., a foreign language classroom, understanding math proofs). One of these contexts is studio art and art making education [2]. A manifestation of this can be seen in the “master study,” a common exercise in drawing, painting, sculpture, and even ceramics education [3].

In a master study, a student selects an aspirational work of art and attempts to reproduce it through careful observation, study, and action. The process can help a student appreciate and analyze different aspects of a given artwork including its composition, use of color, and use of materials among other things. Actively recreating a work of art requires a level of engagement and consideration that would be challenging to achieve any other way.

Since this kind of engagement and consideration is an important aspect of art appreciation but can be challenging to achieve considering the passive method learners traditionally use to experience art, why not have learners complete master studies of considered artworks? Some reasons may be that materials are expensive, studio space can be hard to find, making art can be very time consuming, and the process can be intimidating to those without experience.

Two game prototypes, Sloppy Forgeries and Choppy Forgeries VR were created, in part, to provide players with the opportunity to experience a version of art creation that requires careful observation and coordination, but without the materials or space usually required. While the games provide dramatically different physical experiences to painting and sculpture, the perceptual, prioritization, and spatial challenges faced can be similar. The games also incentivize sustained attention and close scrutiny. The games are framed in a lighthearted context and only take a few minutes to complete, which can make it less intimidating to inexperienced art makers.

II. SLOPPY FORGERIES

A. Overview

Sloppy Forgeries is a fast-paced, two-player local multiplayer painting game. Each player is given a mouse, a blank canvas, and a few simple paint tools. Each round, an abstracted famous painting from art history is revealed. Players race to copy the painting as quickly and accurately as possible.

![Sloppy Forgeries](image)

Fig. 1. In Sloppy Forgeries’ main menu, the five selectable paintings cycle between the original painting and the highest scoring painting created thus far (shown above).
B. Setup

The main menu of the game allows the players to select a painting they would like to recreate. Currently, the paintings available are Dance by Henri Matisse, Starry Night by Vincent van Gogh, Arrangement in Grey and Black No. 1 by James McNeill Whistler, The Scream by Edvard Munch, and Mona Lisa by Leonardo da Vinci. The paintings have all been artistically abstracted to consist of a palette of 4-5 colors to simplify the challenge. Gameplay starts after each player presses their own play button, declaring themselves ready.

C. Gameplay

Upon starting the game, each player is given their own blank canvas, color palette, brush size options, score, and hint bar. The chosen painting and time remaining are positioned in the middle of the screen. Players have 90 seconds to reproduce the chosen painting as accurately as possible. Each player’s score is given by comparing the pixels in their copied painting to the reference painting and calculating the percentage painted with the correct color. Each player also has three seconds of “hint,” which they can activate by pressing the right-button on their mouse. This superimposes the reference image over their current painting, offering a direct comparison of the two images. When the 90 seconds is over, the player with the higher percentage of correct pixels wins.

III. CHOPPY FORGERIES VR

A. Overview

Choppy Forgeries VR is a fast-paced sculpting game made for virtual reality headsets. The game is intended to give players the opportunity to practice and appreciate the skills associated with sculpture in a fun, light-hearted, competitive context. The game requires players to closely examine and engage with famous classical sculpture from art history through its gameplay.

B. Setup

In the main menu, the player is presented with abstracted versions of three classical sculptures in voxel form. The sculptures currently available to choose from are Discobolus by Myron, David by Michelangelo, and The Thinker by Auguste Rodin. The original 3D models of the sculptures were obtained from the Scan the World project and abstracted using 3D modelling software [4]. The player can choose from low, medium, and high-resolution settings, roughly equating to difficulty.

C. Gameplay

After starting the game, the player sees the classical sculpture they selected along with a rectangular slab of the same size and resolution. Behind the sculpture is an informational display with a timer, an accuracy score, and a “hint” time. The player must then use their hand as a chisel by erasing any voxels they touch, attempting to carve the rectangular slab in front of them into a copy of the selected classical sculpture over the course of three minutes. As they carve, the accuracy score is displayed as a percentage, determined by counting the number of correctly placed voxels divided by the total number of voxels in the slab.

During play, the player can rotate the sculptures by using a joystick on their virtual reality controller. Resizing their carving tool is also possible. Holding down the B button increases the tool size, while A decreases it. Players also have access to three seconds of hint time, which momentarily replaces their recreation with the original sculpture, allowing players to immediately see the difference between the two. After time is up, the player can view their creation in relation to the original, along with their accuracy score. They can also use the hint button to see the two sculptures co-located, making it easier to spot differences, facilitating reflection. A high score board for each resolution and sculpture has yet to be implemented.
IV. FUTURE DIRECTIONS

Both games are currently functional prototypes that have yet to be released publicly. Additional development would be required to ensure the games would run properly for different resolutions and on different platforms. Choppy Forgeries VR also needs some additional structure to guide the player through the experience. This could take the form of a series of objectives that would unlock other sculptures upon completion. More documentation, video, and information about the games’ development can be found at https://playfulsystems.com.

Once development of the games is complete, a study could be completed to evaluate their potential as tool to enhance observation and visual memory. How would studying a work of art in a traditional context compare to studying it within Sloppy Forgeries or Choppy Forgeries VR? Which group would perform better on a test focused on visual recollection and observational detail? Would the subjects using the game-based approach perform better at recalling details of the artworks form, composition and/or details of what’s being depicted?

V. CONCLUSION

Sloppy Forgeries and Choppy Forgeries VR are two simple, competitive art making game prototypes that ask players to carefully observe, consider, and ultimately recreate famous works of art. In a sense, these games ask players to produce a master study, an assignment traditionally used in studio art courses to help students appreciate how a given work of art was created, but without the materials, space, and time usually required. By overcoming many of these practical obstacles, placing the challenge in a lighthearted context, and incentivizing close observation, these games could potentially serve as a creative tool to help facilitate art appreciation and art education.

REFERENCES

Doctoral Colloquium—Artmaking: From a Hands-On Process to a VR Translation

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Abstract—In this doctoral colloquium a time when our lives become increasingly virtual, art follows. This research investigates the potential framework where the creative process in visual arts could be equally effective and intuitive in a virtual environment. This paper presents the main research questions of this PhD study. It describes the proposed methodology to answer those questions and identify a potential toolkit of existing VR platforms which could act as an analogue counterpart for the artist in a virtual environment.

Index terms—VR platform, artmaking, creativity, visual arts, artistic process, artist, affordances, embodiment

I. INTRODUCTION – MODES AND ELEMENTS OF CREATIVITY

When we speak of creativity in our mind and everyday life, we mainly mean creativity as it is met in Art or problem solving; thus, an imaginative way to address the world. More specifically, in 1961, Mel Rhodes’ [1, pp.305] answer to the question of “what is creativity?” was, “The word creativity is a noun naming the phenomenon in which a person communicates a new concept.” In his attempt to find a unitary definition for creativity [2], he stated that no one could create in a vacuum, thus implying external factors that affect the process.

His unified model of creativity was the Four P’s (1) person, (2) process, (3) press, and (4) product. In this model, the person is used to indicate the creator themselves, as a personality, intellect, temperament, traits, habits, and behaviour; the process consists of the motivations, the perception, learning methods, and ways of thinking; the press refers to the relationship to the environment; and finally, the product refers to the tangible form that an idea can take.

Rhodes’ framework, along with Wallas’ [3] Four Stages of the Creative Process (1931) and Guilford’s [4] distinction between convergent and divergent thinking (1950), were the most often-used structures in creativity studies according to Runco’s annual review presentation of creativity in 2004 [5].

Further into the research on the understanding of creativity as a process, Glâveanu (2013) proposed the Five A’s framework [6], which is a model that is based on Rhode’s Four P’s, but it addresses its limitations; each element is not regarded isolated but rather as an interaction which each other and the cultural environment. His model now consists of (1) the actor embedded in the field of social interactions specific to any human community and society; (2) the action as a psychological and a behavioural process; (3) the artefact, which refers to the cultured nature of the creation in human groups and societies; (4) the audience which relates to societal forms of press, such as criticising, assisting and contributing; (5) the affordances which are the available interactions of a subject and its surroundings [7].

While the research on the definition of creativity continues, there is a tendency to introduce models that view the creative process holistically. But of which type of creativity do we speak of, and how is this related to our experience?

Until recently, there were two directions: the Big-C creativity [9], referring to the creative greatness, and the little-c creativity [10], investigating the everyday creative activities. However, in 2009 Kaufman & Beghetto [11] introduced the Four C Model, which gives a more inclusive system in the subdivisions between the two initial directions. Thus, their model comprises the mini-c, little-c, Pro-c, and Big-C creativity. The mini-c category is what is known as personal creativity [12], constructing personal knowledge. On the other hand, the Pro-c category, as the name indicates, refers to a professional level of expertise in any creative area. The above model offered a broader distinction between the types of creativity, therefore, including a more comprehensive range of the process from trivial everyday activities to learning, expertise, and paradigm-shifting creations.

Finally, as the creative process is an experience, in 2021, Creely, Henriksen, and Henderson [13] proposed that there are three modes of its existence in the world. Revisiting Glâveanu’s [6] and Csikszentmihalyi’s [8] models, the tri-modal model emphasises the ontology of creativity. Therefore, the Visceral mode indicates the potential of the body to work with the material world, in actions, in touch, in soma; the Ideational mode refers to the mental processes (thinking and imagining) that humans conceive new designs; finally, the Observational mode is about the evaluation and critique from external reference points.

Reframing the answer to the initial question about what creativity is, it seems that it is “a phenomenon that emerges within a dynamic and unique set of personal actions, experiences, and embodiments” [13, pp. 313].

II. VIRTUAL REALITY

As we are visually dominant creatures [14], we will need to see something to consider it real. Since the second half of the 20th century, our lives have existed in three realities [15]; the physical – which exists independently of our existence -, the psychological – which is directly related to the observer – and
the virtual, which stands somewhere between the first two, although it exists only under certain technological conditions. Virtual reality is actual only by virtue, almost real but not precisely. The mind may occupy a world, but the body lives in reality [16].

An important aspect is the presence which refers to experiencing the computer-generated environment rather than the actual physical one – being immersed. Witmer and Singer [17, pp.225] describe immersion as “the psychological reaction or response to a virtual environment, which causes the participant to be enveloped by and interact with an environment that provides a continuous stream of virtual and haptic stimuli and experiences.” The more participants’ senses are involved without perceiving, the higher the level of immersion is achieved.

However, it seems that still, there is not one commonly used precise definition of virtual reality. Instead, the number of related terms is increasing [18]. In this research, the definition that will be used is, as proposed by Kilmon et al. [19, pp.315], “a computer-generated simulation of a three-dimensional environment the user can view and manipulate or interact with.” This term is selected among the others as it leaves enough space for many uses and interpretations of the virtual environment and its affordances.

III. RESEARCH QUESTIONS

The current research aims to investigate:

RQ1: The possible manner that the creative process in visual arts can be translated into an equally intuitive and effective procedure within the means and affordances of virtual reality.

RQ2: The assemblage of a virtual reality toolkit from existing platforms could facilitate the artist’s creative process as their analogue counterparts do.

IV. RESEARCH METHODOLOGY

This paper proposes a methodology to prepare the ground for the main PhD study that consists of the following stages:

- **Scoping review** of the literature identifying the gaps in the creative process research in virtual reality and visual arts.

- **Participatory design study** identifies artists’ platforms and preferred processes and the VR tools required to assist them in artmaking.

V. RESEARCH FRAMEWORK

To understand and discover how the creative process in visual arts could be translated into a similarly productive process in VR, there is a need for a study framework to conduct the PhD research. From the mentioned literature review on the definition of creativity and virtual reality, some elements could be considered typical when one is in creative mode and virtual mode. Thus, this research will focus on:

- the duality of the Visceral and Ideational mode, as they could be similar to when one is using analogue or VR tools.

- the dipole of the Actor and Affordances as common denominators, as they are both essential to the creative process in both the physical and virtual space.

- the Pro-c creativity as a category/type of the creative process, as this research will focus on artists who have expertise in their field.

VI. SCOPING REVIEW

Having the research framework at hand, there is the need to investigate the relevant written work regarding the mentioned aspects of creativity in virtual reality. In particular, the aim will be to identify the research gaps in these two fields. In order to reach informed conclusions, the intended methodology will be based on the model used by Beck, Morgado & O’Shea [20].

The scoping review will draw information from papers and articles written in English using combinations of keywords that appear in the title or the subject. The keywords derive from the research framework described above (Section V). The initial keywords used are VR, immersion, artmaking, and creativity. These are the main concepts this research focuses on in combinations with visceral, ideational, actor, affordances, modes, and denominators, further above shown in (Table I).

**TABLE I. STRINGS OF KEYWORDS FOR SCOPING REVIEW TO IDENTIFY CRITICAL BIBLIOGRAPHY REFERRING TO THE GAPS IN VR TO SUPPORT THE ARTMAKING PROCESS**

<table>
<thead>
<tr>
<th>Proposed strings of keyword research:</th>
<th>VR AND Creativity</th>
<th>VR AND Artmaking</th>
<th>Immersion AND Creativity</th>
<th>Immersion AND Artmaking</th>
<th>VR AND VR</th>
<th>VR AND Affordances</th>
<th>VR AND Actor</th>
<th>VR AND Visceral</th>
</tr>
</thead>
</table>

However, to reach as many citations as possible, alternatives for each keyword were used but similar in meaning. There were the following replacements:

i. Artmaking by Creativity x Visual Arts

ii. Visceral by Embodied/Embodiment

iii. Ideational by Conceptual/Conceptualization

iv. Actor by Artist/Creator

This literature review aims to put together a panorama regarding ongoing or undergone research for the creative process in visual arts in virtual environments, seen as an ongoing procedure by artists in relevant set-ups – such as art/design schools.

VII. PARTICIPATORY DESIGN STUDY

The participatory design study brings together 20 artists working with VR or other XR media, as they are considered to have reached the level of expertise for Pro-C creativity, to work together to address the research questions. The participatory design process is threefold:
Online workshop – initiate the discussion about the platforms and frameworks VR/XR artists use and the definition of creativity in the artmaking process.

Empirical Study A – the participants will be introduced to various platforms in VR. Afterwards, they will take part in two parts using two VR platforms, where they will have 50’ in each to pursue the creative exercise: one desktop platform and one headset platform. In the first exercise, they will be given a concept, and they will have to create a VR environment while having a short learning curve for the software. In the second one, they will continue the creation of the VE but this time fully immersed by using a VR headset and controllers. This study will help us observe how artists accustom their processes according to the tools they can use.

Empirical Study B – the participants will participate in a creative exercise focusing on the elements of collaboration in a VR platform and presenting the artefacts produced by this process.

The expected outcome of this initial exploratory study is:

• an overview of preferred VR platforms already used by VR/XR artists and identification of processes they follow for the artmaking.
• initial results deriving from the studies related to the tools the VR platforms should provide to support the artmaking process when artists work solo, in collaboration with others.
• a consideration of the methods to analyse such data systematically and objectively.
• an evaluation of the proposed research method for the main study.

VIII. DISCUSSION, FUTURE DIRECTIONS, AND EXPECTED CONTRIBUTION TO KNOWLEDGE

The present stage of the project has the following aims in support of the future study: (a) a definition of creativity and the component of the artmaking process standard in VR and analogue; (b) to identify the gaps in knowledge regarding the research in VR and artmaking as a creative process based on systematic literature review and empirical results; (c) to develop an initial approach to the research method and review its validity. The main PhD study will step on the outcomes of this initial study and further investigate what grounds an artist could be creative in VR. The expected contributions to the knowledge of this doctoral research impact the VR and art community, as well as remote learning:

• identification of the gaps in VR to support creativity and the artmaking process.
• assemblage of a VR toolkit capable of facilitating the artistic process as analogue media, thus bridging the gap between the initial concept and final communication of the work on digital platforms.
• opening the art creation in digital/VR platforms, thus bringing together a more comprehensive network of artists regardless of their location or other limitations.
• facilitate the dissemination of the benefits of the art process to the public and other disciplines.

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REFERENCES

Doctoral Colloquium—Treasure Hunt AR for Enhancing Visiting Experience in Cultural Sites

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Abstract—Cultural heritage sites serve as tools for the public to perceive cultural elements and are the cornerstone of our modern society. For years, museums and cultural institutions have been transforming how they practice visitor experiences, moving from "objects" to "people" through several different approaches. Museums are searching for innovative ways to engage their visitors to accomplish their mission, meet educational goals and provide a memorable experience for their visitors. There is a growing body of research on the use of gamification in cultural sites to improve visiting experiences and encourage visitors to engage actively in museum activities. The goal of this paper is to investigate whether gamified experiences in cultural sites can improve visitor experiences through the use of treasure hunting AR. This paper presents the research questions of this study and discusses a framework that is being developed to address those.

Index terms—AR, treasure hunt games, visiting experience, mobile

I. INTRODUCTION AND PROBLEM STATEMENT

In recent days, cultural sites are becoming more audience-focused, and such trends necessitate the development of activities that encourage visitor engagement while also meeting the emerging demands for learning and enjoyment. The audience-centered approach is being used as a strategy to mitigate the impact of government financing; this evolution is being pushed by social media, political, and economic pressure, and thus adaptation to socio-cultural is heating [1]. The conventional model is based on exposition and directs visitors’ behavior along pre-determined routes, whereas today's museum curators are more likely to study visitors' perspectives and engage to create meaningful experiences. As a result of the foregoing, an increasing number of organizations are seeking new ways to better exhibit and communicate the tangible and intangible heritage they preserve, while also engaging visitors in an educational yet entertaining experience.

Learning in cultural sites involves problem-solving, decision making, and critical thinking. Playing in cultural sites and museum settings can enhance learning and challenge creativity through imagination, exploration, and collaboration [2]. Gamification is increasingly being used by museums to support the creation of immersive and engaging visitor experiences [3]. Treasure hunt or scavenger games integrate the concept of gamification. Their potential to improve the visiting experience in cultural sites has been recognized [4]. Treasure hunt games engage visitors in meaningful activities that help them uncover information about the location they are visiting in a fun and entertaining manner. These activities are typically intended to depict the storytelling of the cultural site’s topic. They offer a meaningful way of enhancing communication and collaboration that can contribute to creating a unique experience. The Louvre and Diefenbunker Museums offer examples of outdoor adventure games that allow visitors to explore the area outside the Museum and the entire Museum respectively and unveil their secrets [5].

Mobile phones nowadays bring to cultural sites the opportunity not only to engage but to immerse their visitors in memorable personalized experiences efficiently addressing visitors' motivational drives. This can be achieved without the need to make changes to the exhibition space and without investing in equipment, like interpretation systems, as most visitors have smartphones with adequate technical specs to run advanced technological solutions. Mobiles paired with Augmented Reality (AR) offer great new opportunities to treasure cultural sites.

This research studies the effect of treasure hunt AR on visiting experience in cultural sites. To achieve this, it attempts to define the elements that contribute to the creation of enjoyable and immersive experiences in cultural sites. It creates a framework, namely the ITDF (Interactive treasure-hunt design framework), to guide the design of immersive applications that can enhance the visiting experience in cultural sites. It evaluates the framework by building a/more treasure hunt AR apps and testing those on-site with visitors to evaluate their impact on their visiting experience.

In this paper, we present the research questions of this study; the research methodology; the research instruments that are being created; the study plan, and we close by discussing expected contributions to knowledge.

II. RESEARCH QUESTIONS

The research questions that drive this work are the following.

RG1: Can mobile AR coupled with gamification enhance the visiting experience in cultural sites?

RG2: Can the ITDF framework increase fun and support enhanced visiting experience (strengthen communication, collaboration, interaction) in cultural sites?
RG3: Can the ITDF framework lead to a better learning experience (learn more, remember for longer) in cultural sites?

RG4: Can the use of the ITDF Framework lead to increased fun in cultural sites?

RG5: Can the use of mobile technology facilitate cultural sites to understand better their visitors’ behavior and motivational drives and thus impact the services and the experiences they offer?

III. THE PROPOSED RESEARCH METHODOLOGY

To evaluate the research questions this study follows a rigorous methodology that consists of the following stages:

- It conducts a systematic literature review to define the elements that contribute to an enhanced, enjoyable and immersive experiences in cultural sites
- It creates a framework based on the cognitive theory of multimedia learning [6] and gamification to guide the design of immersive applications that can enhance the visiting experience in cultural sites
- It evaluates the framework by building a/or more if required treasure hunt AR app for cultural sites mapping different visiting requirements
- It plans a series of studies using the treasure hunt AR app in different cultural sites testing on-site with ‘real’ visitors their impact on their visiting experience, looking at their behavior, their social interaction, and the motives for their active participation.

IV. INTERACTIVE TREASURE-HUNT DESIGN FRAMEWORK (ITDF)

The Interactive treasure-hunt design framework (ITDF) framework is the cumulative work of the MDA (Mechanics, Dynamics, Aesthetics) Framework [7], the Octalysis Framework [8], and the Cognitive Theory of Multimedia Learning [9].

The MDA framework sets the tone of the treasure hunt AR game. Fundamental to this framework is considering games as artifacts, which helps frame them as systems that build behavior via interaction. It supports clearer design decisions and analysis at all levels of study and development. Mechanics, stand for providing a precise description of the game and actions at the level of data representation and algorithms. While dynamics ensure the runtime behavior that emerges from Mechanics. Aesthetics describes the player’s emotional response when they interact with the game. Key elements of Aesthetics are narrative, challenge, discovery, and expression.

The Octalysis Framework for gamification and behavioral design provides guidance on choosing the motivational drives to design a well-balanced game that appeals to the target audience, engages them, and motivated them to complete their goal [10]. The Octalysis framework organizes those motivational elements into 8 core drives which are based on an octagon shape hence its name. The Octalysis Framework follows a Human-Focused Design approach that capitalizes on users’ behavior to fulfill their objectives.

While the Cognitive Theory of multimedia learning principle ensures an effective way of learning, providing instructional media in the light of how the human mind works. The cognitive theory of multimedia learning is based on three cognitive science principles of learning: (a) the dual-channel assumption; (b) the limited-capacity assumption; and (c) the active processing assumption. The theory focuses on the idea that learners seek to build a meaningful connection between words and pictures. The theory suggests learners make a coherent representation from presented material and try to assume while being an active participant, thus ultimately constructing new knowledge [6].

V. RESEARCH INSTRUMENTS

The treasure hunt AR apps are created with the use of Actionbound [11]. Actionbound is a web-based platform that allows to the creation of bespoke treasure hunt activities for smartphones and tablets. The platform supports the creation of tours based on a digital timeline of events or places, with the use of GPS coordinates, pre-placed QR codes, and narratives. It supports the creation of quizzes and missions around a site and set up tournaments. It allows the integration of QR codes, location recognition with GPS, and integration of maps and guides. In terms of motivational elements, it allows rewards, points, time constraints, and monitoring progress. To evaluate the experience, it keeps user analytics of the entire gameplay process, it allows surveys and direct feedback. In addition, it allows sharing the experience. The treasure hunt games can be public or private and they can be played indoors or outdoors, by a single player or multiplayer, online or offline.

We are currently in the process of developing one of the prototypes focusing on the Barbican Centre in London. The Barbican Centre is a performing arts center in the Barbican Estate of the City of London and the largest of its kind in Europe. The center hosts classical and contemporary music concerts, theatre performances, film screenings, and art exhibitions. It also hosts houses, a library, restaurants, and a conservatory. The main motivation of the Barbican Centre is to provide information to their visitors about places that not always are accessible to them, for example, a gallery in preparation, a concert hall that hosts an event and is not accessible to the visitor at the time they visit the center. They are interested to achieve this by engaging their visitors in a fun activity allowing the visitors to immerse themselves in the game plot.

Three prototypes are being created for this first study:

- paper-based – activating the visitors by challenging them to follow a route to visit the center discover information and solve a puzzle;
- single player – follows the design concept of the paper-based prototype, but it is designed for mobile AR consisting of gamified elements, specially designed to assist one player journey across the cultural site;
- multiplayer – follows the design concept of the paper-based prototype, but it is designed for mobile AR consisting of gamified elements, specially designed to support play against multiple participants.
The treasure hunt game is designed with the scope to engage the participants in an exploratory activity that will allow them to discover the site with the motive to solve a puzzle. The treasure hunt gives a mission and guides to discover the place. The game contains a map that guides the players to certain points of interest on-site that need to be visited to discover clues to solve the puzzle. When GPS is unable to precisely locate a site, the treasure hunt AR game acts as a digital tour guide, directing users to a point of interest using drawings and coordinates. After reaching a point of interest on the site where a clue is hidden, players will receive multimedia information about that point, along with points and a hint that will aid them in the puzzle’s solution (see Fig. 1). Various challenges using different mechanics are created to keep players interested in the game. The different game mechanics contribute to the fun of the game, but they also play a significant part in the learning experience. Reward, status change, and leader boards are acquired by completing tasks individually, or as a team. This strengthens the empowerment and social influence which are core drivers of the Octalysis framework.

![Fig. 1](image-url)  
Fig. 1. A snapshot of the treasure hunt AR that reveals a clue for the puzzle to be solved after a challenge has been completed.

VI. THE STUDY

This initial study focuses on evaluating the ITDF framework by testing the Big Barbican Adventure treasure hunt AR app visiting experience. We aim to recruit 60 participants for this first study. The participants will split into three groups interacting with the following research instruments:

- Group A: paper-based treasure hunt AR material
- Group B: single-player treasure hunt AR app
- Group C: multiplayer treasure hunt AR app

The participants will collect the research instrument at the entrance of the Barbican Centre and they will be asked to explore the place following the guidance provided by the research instruments. Prototypes B and C collect analytics of the entire process that will help evaluate the visiting experience. For example, task completion, duration to reach a point of interest, and points gained. For the prototype, A participants will be asked to manually provide similar data to allow comparison of the 3 cases. At the end of their journey participants will be asked to complete a survey to evaluate their experience.

The study will determine the direction for the development of other prototypes to test how effectively the ITDF framework can map the needs of different cultural sites.

VII. EXPECTED CONTRIBUTIONS TO KNOWLEDGE

The main expected contribution to the knowledge of this research are the following:

- Empirical based results that will help to develop a better understanding of how treasure hunt AR affects visiting experience in cultural sites
- The ITDF framework and a set of guidelines that capture the elements that contribute to the design of a successful visiting experience in a Museum or a Cultural site

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REFERENCES

Inclusion, Diversity, Equity, Access, & Social Justice (IDEAS)
Using Virtual Environments to Reveal Teacher Bias Towards Students’ Socioeconomic Status

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Abstract— Research suggests that the socioeconomic status (SES) of students plays a role in teacher perceptions, but it is unclear if virtual simulation technologies can detect this bias. In this exploratory study, a convenience sample of former and current teachers was asked to evaluate students’ performance in a virtually simulated classroom environment. Teachers using the virtual classroom exhibited biased judgements when shown students from varying SES backgrounds who made equivalent progress on a literacy task. Most teachers judged low SES students as making more progress than high SES students. Teachers reported feeling immersed in the experience, and immersion was correlated with bias in teacher judgements. This underscores the value of immersive simulations as a mechanism for inducing realistic situations that draw out unconscious biases. This approach may be of particular value when teachers must recognize that they have biases, as a necessary step in unlearning these by practicing unbiased strategies in simulated environments, with the aim of transfer to real world classrooms.

Index terms—bias, immersion, teachers, pedagogy, education, socioeconomic status

I. INTRODUCTION

In the present research agenda we build on research involving teacher preparation through virtual simulations, specifically by focusing on identifying barriers that keep teachers from building childhood early literacy in the most effective ways. One such barrier is teachers’ unconscious biases about their students. Many teachers carry an implicit bias into their teaching, and oftentimes fail to realize that this bias influences their teaching practices. In the present study we use a digital puppeteering system (Mursion, www.mursion.com), and execute a study in which teachers are placed within a virtual classroom with simulated students of varying backgrounds. The results provide evidence that such a digital context can reveal biases on how teachers perceive their students’ skills, and on how they manage and group their classrooms. Based on this work, we plan to develop and study simulated authentic situations in which teachers and parents learn to identify their biases, and overcome challenges in early literacy development.

Teachers’ perceptions of their students have significant implications for students’ academic trajectories and achievements. Research suggests that the socioeconomic status (SES) of students plays a role in how teachers perceive them. According to a recent study, students at low socioeconomic schools were perceived as needing background knowledge and discipline, while their peers at high socioeconomic schools were viewed as needing enrichment [1]. Given that students perceived as high-achieving are rated as more competent and are given more individual attention [2], it is important to detect and help mitigate any implicit biases that teachers harbor towards certain groups of students, in order to give all students opportunities to succeed.

Scholars have studied the power of immersive media to aid with “unlearning”: letting go of a routinely practiced, emotionally rooted identity to achieve transformational change to a different, more effective set of behaviors [3] argue that the result of unlearning may be moving from knowing to not-knowing and from action to non-action, as a transitional step towards developing some transformed form of knowing and acting. Studies in virtual reality show that unlearning can be based on a series of powerful experiences that influence the mind/brain cognitively and affectively, intrapersonally and interpersonally [4], [5]. In particular, studies have documented the effectiveness of immersive authentic simulations for improving teacher effectiveness [6]–[9].

Recognition of implicit biases is a necessary step in unlearning these and practicing unbiased strategies in simulated environments, with the objective of transfer to real world classrooms. In this study we examined whether immersive technology could aid in detecting teachers’ implicit biases towards certain types of students and, if so, in what ways. Specifically we investigated the questions:

RQ1: Can immersive media reveal teacher biases based on knowledge of student socioeconomic status (SES)?

RQ2: Does the degree of perceived “presence” provided by the immersive medium relate to the strength of bias revealed?

RQ3: How do teachers use SES information in evaluating students?
In this within-subjects study, a convenience sample of former or current teachers was asked to evaluate simulated students’ literacy performance in a virtual classroom environment. Our hypothesis was that teachers might have implicit bias against students from lower socioeconomic families, and, even if teachers are not aware of these biases, they might be more likely to exhibit biased behavior unconsciously in a virtual environment.

II. RELATED WORK

Theory and evidence have shown that immersive virtual environments are powerful for learning and transfer [10], [11]. In particular, virtual simulations of practice have proven of value in preservice teacher education, by employing varied strategies for teacher training. For example, some simulations have helped preservice teachers learn or rehearse communication techniques. A study by [12] involved practicing skills in communicating with a co-teacher, and a study by [13] enabled practice in communicating with a parent. In both cases, the simulation provided an opportunity to practice skills newly learned in preservice methods courses, and to simulate practice in a safe environment similar to the real world. The researchers compared the utility of the simulation versus a role play or examined participant reflections on the perceived value of the simulation, and found that participants considered the virtual simulations a more authentic and more useful practice method compared to practicing with peers or compared to observing peers during traditional practice.

Another set of related studies has enabled preservice teachers to gain experience through a progressive series of virtual simulations where coaching or course activities were provided after each attempt to apply skills [14] measured communication skills across four different simulations, where teachers interacted with a parent, co-teacher, paraprofessional, and administrator [15] used a cycle of simulations taking place in the middle school classroom, in which preservice teachers were asked each time to demonstrate a different practice, such as asking effective questions, facilitating discussions, and surfacing avatar student prior knowledge. [16] had preservice teachers meet avatar students in the classroom three times to find out each avatar’s favorite subject, establish classroom rules, and introduce a lesson [17] found that coaching between simulation sessions enabled substantial improvement in preservice teachers’ skills relative to unaided self-reflection between sessions.

A third strategy is, through a single simulation, to offer preservice teachers iterative cycles of goal setting, practice, and reflection until mastery of the targeted skill is achieved. The investigators then examine participant behavior in the real classroom to measure transfer of learning. As an illustration, [18] had preservice teachers repeat the simulation until mastery of the targeted skill was achieved, leading to improvements in teachers’ understanding and confidence, then implementation of the skill was measured in an actual classroom or through another assessment at a later date.

These prior studies demonstrate the promise of immersive virtual simulations for altering teacher perceptions and behaviors. Our study builds on their strategies and insights, applied to studying teachers’ implicit bias about students’ socioeconomic status. Previous research has shown that teachers’ perception and evaluation of students’ abilities can be influenced by perceptions of the students’ access to resources or group membership [19]-[22], typically leading to underestimating the skills of underprivileged students. For example, [19] found that socioeconomic status influenced teachers’ perception and accuracy of their students’ abilities, whereby teachers in higher-achieving and higher-SES classrooms overestimated their students’ literacy skills, and teachers in lower-achieving and socioeconomically-disadvantaged classrooms tended to underestimate students’ literacy skills. Similarly, in [22] while examining the effect of teacher assessment training on evaluating students’ academic competence, the authors found that teachers who did not receive assessment training underestimated lower SES students’ academic competence. Such biased judgements have far reaching implications especially for underprivileged students. Incorrect teacher judgments, either via over- or under-estimating ability, can contribute to school tracking and have a greater impact on the future achievement of students from lower income families compared to their more affluent peers [21]. These studies underscore the importance of developing tools that can reveal teacher biases and assist in bias training programs. In the current study we further this research agenda by exploring how implicit teacher biases manifest in a virtual classroom environment.

III. STUDY DESIGN

The study was designed as a within-subjects study where all participants experienced a similar sequence of activities performed in a virtual classroom. A convenience sample of teacher participants was recruited from the teacher training program of a northeast USA university, which included experienced and novice teachers, all of whom had prior teaching experience in K-12 classrooms. Prior to the study, teachers signed a consent form and completed a demographics pre-survey. In the study activity, which took roughly 30 minutes, the teacher participant interacted with the Mursion digital puppeteering system (Fig. 1), which showed a virtual middle-school classroom populated with simulated students. The virtual students were controlled by a hidden human researcher who directed their gestures and speech, as well as artificial intelligence which directed students’ nonverbal gestures such as directing their attention to the speaker and fidgeting. After the virtual experience, teachers completed a post-survey and post-interview.

The virtual experience simulated a middle-school literacy classroom where students of various socioeconomic backgrounds made progress during a reading task. The teacher’s task was to judge student performance. The activity steps are outlined in Fig. 2. The activity started with a short period of life-like interaction with the whole classroom, in which the teacher introduced themselves and then read a familiar story book to the students. During this phase, virtual students who were not used in the rest of the study would interrupt and make comments about the story, in order to create a feeling of realism for the teacher.
After the story reading, the teacher observed two pairs of students retelling the story. For each pair, the participant was provided with information about each student’s background (which includes covert information about their SES level, as described below). The teacher was told that they would watch two recordings of each student doing a retelling of the story (the first retelling being recorded from “day 1” and the second from “day 3”), and then assess student improvement based on these recordings. The teacher then observed the two recorded retellings for each student. After this activity, the teacher was asked to rate students’ performance on each of the observed days.

Each teacher observed four students in total, and the experiment was designed to isolate the impact of SES information on teacher judgements. Teachers were given background information about each of the students (Table I). For two students, this information suggested that the student’s family is of high SES or low SES background; for the other two students, no SES information was provided in the background description (Table I). The teacher saw the students in pairs – students in the first pair were randomly assigned to each of the “Control” backgrounds; for the second pair of students, the students were randomly assigned to each of the high SES and low SES backgrounds. The performance of each simulated student was randomized and equivalent among the four students, regardless of the SES background information provided to teachers. Although the “control” pair was always presented first (and served to help familiarize the teacher with the activity), the order of speaking was randomized within the control/experimental pairs (i.e., in the second pair, the low SES student preceded the high SES student 50% of the time; this counteracted any order effects between low SES vs high SES students).

Furthermore, students in the virtual classroom had visual features that made them appear racially diverse (without researcher ability to control this variable), but this was counterbalanced by randomizing the background information that was assigned to each student (i.e., the low SES background was assigned with equal probability to each race). Each student spoke in a unique voice (the software modified the human researcher’s voice), and this was counterbalanced as described in the previous sentence. Finally, the gender of students was kept constant throughout the experiment (all 4 students were male), to avoid gender effects. By controlling or counterbalancing these variables, we isolated the effect of SES information on teacher judgements of student performance.

A. Metrics

We asked teachers to judge each student’s abilities and progress during the retelling activity. Each student’s abilities and progress were controlled to be equivalent regardless of their SES/background information, as described in the preceding section. Therefore, when teachers showed preferences or skewed judgements in favor of one student over others, this was seen as indicative of bias. We used two metrics to measure teacher perceptions. After seeing each pair of students, teachers were asked to indicate which of the students made more progress in their learning. This was asked immediately after the teacher observed each pair of students, two times during the study: once after the group of ‘control’ pair, and once after the low/high SES pair. At the end of the study, we also asked teachers to assign a score (between 0-100) for each of the four students, indicating the students’ ability during the first and last day. Student improvement was then calculated using relative learning gains, a measure of the relative improvement that occurred between the first and last day.

![Introduction & Book Reading](image1)

![Sequence of activities in study. C1, C2 = control group (no SES differences); L = low SES background, H = high SES background.](image2)

**Fig. 2. Sequence of activities in study. C1, C2 = control group (no SES differences); L = low SES background, H = high SES background.**

**Table I. Background information provided about each of the four students.**

<table>
<thead>
<tr>
<th>Pair of control students.</th>
<th>Pair of experimental students.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL STUDENT 1, is almost 9 years old and has two siblings. His parents are supportive and care for their children's education. He loves to play basketball with his brothers and sisters.</td>
<td>LOW SES STUDENT, is 8 and a half years old and grew up in a single parent household. He receives reduced-cost lunch meals at school. He loves playing soccer and eating with his friends in the cafeteria.</td>
</tr>
<tr>
<td>CONTROL STUDENT 2, is 8 and a half years old and is adopted. Both his parents are educated and enjoy taking him to the museum. He loves walking around the city and spending time with his family.</td>
<td>HIGH SES STUDENT, is also 8 and a half years old. He enjoys traveling on vacation with his parents. Having visited many countries, he loves eating food from different cuisines. He is very friendly and loves to make friends at school.</td>
</tr>
</tbody>
</table>

Fig. 1. Teacher participant (left) interacting with virtual students, that are controlled by the puppeteer (right).
We measured teachers’ sense of presence by using the Presence Questionnaire, from [19] as adapted by the UQO Cyberspsychology Lab. The survey was designed to gauge participants’ perceptions and feelings about the virtual environment. The reliability of the Presence Questionnaire has been tested (alpha = 0.84), which is considered very reliable. We adapted UQO’s questionnaire and included 17 out 24 questions relevant to our study. Teacher personal experience was recorded using a custom questionnaire asking about demographics, years of teaching experience, and amount of experience with technology.

This study used quantitative and qualitative methods to answer the research questions. For quantitative measures, we used descriptive statistics to determine characteristics of the data, along with Binomial tests (for RQ1 and RQ3), T-tests (RQ1), and Pearson Correlations (RQ1 and RQ2). For qualitative analysis (RQ3), interview transcripts were used to provide qualitative data for elaborating the quantitative findings, and thematic analysis was used to generate themes. Two researchers transcribed and discussed the participant interviews, and one researcher performed the thematic analysis.

IV. RESULTS

Twenty-seven teachers participated in this study. All participants were former or current teachers of students ages 5-8 years old. 29% of participants identified as male with the rest identifying as female. Participants had an average of 10 years teaching experience with a range from 2-20 years of experience. With respect to use of technology (e.g. using social media tools, using other online tools, and having access to 1:1 student devices), responses were mixed, as some participants used technology extensively and had access to 1:1 devices, whereas other participants reported rarely using such technology.

A. RQ1: Can Immersive Media Reveal Teacher Biases Based on Knowledge of Student Socioeconomic Status (SES)?

Immediately after teachers observed each pair of students, we asked them to answer the question “Which of the two students made more progress?”. This question was asked for the pair of low-vs-high SES students, and for the pair of control students. The performance of each of the four children was controlled to be equivalent as described in the preceding section. The expected value of choosing one student in a pair as making more progress was 50% due to random chance; teachers also had the option to say that both students progressed the same amount.

When teachers were asked which of the two “control” students made more progress, there was no statistically significant difference from chance in teachers choosing one student over the other. However, when asked about the low-vs-high SES students pair, teachers chose the low SES student significantly more often (74% of the time) than the high SES student (26% of the time). This result was statistically different than the expected 50% random chance (Binomial test, p=0.019), indicating bias was present in teacher perceptions. Furthermore, although no significant differences were detected between teacher perceptions of low SES and high SES student scores on the first day of retelling, the bias in teacher perception towards low SES students as making more improvement was visible when teachers were asked to rate all students at the end of the activity. Teacher ratings were significantly different when judging the low SES vs the high SES students (t(26)=2.25, p=0.03), whereby teachers judged the low SES students as making higher relative improvement (69% relative improvement on average) than the high SES students (52% relative improvement on average) (Fig. 3).

We analyzed whether teacher bias is related to demographic information, and found significant results at the 90% confidence interval (p=0.1). We chose this threshold due to the exploratory nature of this research, and we report these results while acknowledging that this high threshold allows for a high degree of Type-I error, noting that these exploratory results need to be confirmed with studies of higher statistical power. In our sample, teachers who reported using more technology in their teaching activities tended to score a smaller improvement between low SES vs. high SES students (r = -0.49 ; p <0.1), indicating a weaker bias. It may be that teachers who have access to more technology also have access to more resources, such as bias training; or that teachers who use more technology hold different mindsets in their perception of students. No other statistically significant correlations were found between perception of students and teacher demographic background.

B. RQ2: Does the Degree of Perceived “Presence” Provided by the Immersive Medium Relate to the Strength of Bias Revealed?

We measured teachers’ sense of presence in response to exposure to the Mursion virtual classroom. All measures of presence were significantly higher than the baseline (p<0.05; the baseline corresponded to the lowest level of each scale item) (Fig. 4). There was a positive significant correlation detected between teachers’ Overall Presence and their ratings of difference in relative improvement between low SES and high SES students (r = 0.46, p = 0.046). This indicates that teachers who reported higher presence also reported a higher bias toward the low SES student, which hints at the possibility that biases may be more easily revealed by technologies that evoke a higher sense of presence.
**C. RQ3: How do Teachers use SES Information in Evaluating Students?**

During the post-interview we asked teachers to reflect on how they used SES information to inform their teaching. Self-awareness of bias was assessed through post-interview questions such as “Do you feel the background of the students biased you in any way?” 

Teacher answers were categorized ranging between “Yes”, “Probably”, “Not in this context here”, “Hopefully not”, and “No” (Fig. 5). We compared the percentage of teachers who acknowledged their bias in the interview (by answering “Yes” and “Probably”), to the percentage of teachers who selected the low SES student as making more progress during the experiment. We found that teachers who acknowledged their bias accounted for only 14%, and this significantly differed than the expected 74% proportion of teachers who explicitly selected the low SES student as making more relative improvement (Binomial test p<0.001).

“Do you feel the background of the students biased you in any way?”

Teachers who did not perceive themselves to be biased in the experimental task made statements such as “I think background info is helpful but I don’t think it was helpful for this task.” Or “Not for this particular one [task]. But maybe If I was continuing this and actually teaching these kids I would absolutely use their backgrounds to inform my instructions”. Teachers who acknowledged being biased said things such as “I found myself overthinking and second guessing my own responses based on what I knew about the kids’ background. It almost felt distracting to me to be like… ok did this kid actually do a worse job, or am I biased to think that he might struggle more because he has a more challenging home life?” and “I think yes, in that bias is something I have to always deal with a white straight male teacher. (...) If I don’t pause and ask if that is going to affect my judgement, then it probably will. At least take the time to think about it. At my school that is something we talk about regularly to make sure we aren’t doing it unconsciously.”

During follow-up questions, the teachers revealed other ways that SES information is integrated in their teaching practices. These themes surface when teachers interact with students in real classrooms and are expected to be present when teaching happens in virtual classrooms. Teachers discussed the importance of changing their expectations of students based on the support that a student has at home, or the skills they bring to the classroom: “Understanding the support that a student has at home, or the skills they bring to the classroom, is useful for teachers to adapt the expectations they place on students ability to receive support: If Ethan comes and says no one helps me at home, I will say OK, I’ll pair you with Harrison and then you can come tell the story together to me.”

Teachers also discussed taking the role of caretakers in order to provide basic needs for their students: “You have to sometimes give marginalized people more chances in your classroom so they can feel safer.” Teachers mentioned using background information to build rapport with students and to tailor the content to be engaging for students: “It just helps you to build relationships, to know students’ background. That’s how students learn, it’s when they feel a connection to their teacher, and they know the teacher knows things about them.”

Finally, teachers also highlighted the importance of understanding the unique backgrounds of children and adapting the instruction and assessment: “Some kids show their knowledge better in different ways. So if you’re talking about how you’re going to evaluate things, somebody might do something better by drawing a picture as opposed to writing a story. I think asking every child to do the same, that’s what’s what standardized testing is, and that sucks.”

**V. Discussion**

Through the present study, we found that teachers using an immersive virtual classroom exhibited biased judgements, indicating that our virtual simulation was effective in eliciting biases, and revealing a need for improved bias training for our participants. When presented with students from high SES and low SES backgrounds who made equivalent progress on a literacy task, most teachers judged the low SES student as making more progress than the high SES student. Based on interviews with the teachers, we found that teachers perceive
and treat low SES students differently than high SES students, while striving to ensure equity in the classroom. Teachers need to cater to the skills and circumstances of low SES students in different ways than for high SES students.

The results suggest that teachers perceived the low SES students more favorably than high SES students. These results appear opposite to previous research suggesting that teachers are biased against low SES students and underestimate their skills, while overestimating their high SES peers. One explanation may be due to the assessment approach used in this study, whereby teachers were asked to perform a direct comparison between low SES and high SES students who are presenting identical levels of skills in a short amount of time. The direct comparison and short exposure may yield different scores than in a real classroom where teacher exposure to students is different. Another possible explanation may be related to teacher expectations. We found during interviews that some teachers experienced positive surprise when perceiving that low SES students make as much improvement as the high SES students; or negative surprise when perceiving that high SES students made as much improvement as the low SES students. Similar to findings from previous literature, teachers in our study may have had initial low expectations for the low SES student and/or higher expectations for the high SES student, but the direct comparison caused them to be surprised and/or disappointed. These unmet expectations may have influenced the scores assigned to students, by potentially inflating the assessment given to low SES students and/or deflating the assessment for high SES students. Finally, it is worth noting that in our study the high and low SES students were compared against one another rather than against a baseline, thus making it unclear whether teachers were actually favoring low SES students or simply judging against the high SES students. In the future, similar studies should discern whether teacher judgements are in favor of low SES students, or against high SES students, or both.

Teachers’ awareness of their own biases showed variability during our study. Although the majority of teachers showed biased judgements, most teachers did not believe they are biased at all; thus hinting that our participants could benefit from training aimed at specifically increasing participants’ self-awareness of their own biases, as well as increasing general understanding of how biases may unconsciously be present in teaching practice. No relationship was found between teacher self-awareness of bias vs. amount of bias in judgement of students. However it is worth noting that this nonsignificant result may be due to low sample size, as the number of teachers who acknowledged bias was small. Furthermore, the amount of self-awareness of bias appeared related to years of teaching, where more years of teaching was associated with a stronger belief that the teacher was not biased. Further research should investigate the factors that contribute to self-awareness of bias, and whether bias in judgements can be mediated by bias awareness training.

Technology immersion was found to be correlated with teacher bias, reinforcing the value of using virtual simulations for teacher bias training. Teachers reported feeling immersed in the experience, and the degree of perceived immersion was correlated with more imbalanced teacher judgements between low-vs-high SES students. This underscores the value of immersive simulations as a mechanism for inducing realistic situations that draw out unconscious biases. Additionally, the interactive nature of our virtual classroom allowed teachers to create emotional bonds that may not be present in less interactive research environments to build believability of student realism and naturalness of the classroom. This perceived authenticity is especially important at the beginning of the study.

Future work needs to investigate whether similar results would be gained from the use of other mediums – such as teachers being presented with student information through traditional paper-based readings of student progress, or through semi-immersive mediums such as text-based chatrooms where students cannot be seen but can be communicated with. It is expected that in less immersive mediums, and with traditional approaches for eliciting bias, teachers may remain more aware of the experimental nature of the research environment, and biases may not be accurately revealed. Future work is needed to compare between different mediums for eliciting biases of varying immersion and varying interactivity.

Follow-up research is needed to understand how these results can be used to first build the capacity of preservice and inservice teachers to recognize their biases, and then to overcome the influence of this biases in their classroom practices. The current study method can be used to assess whether a teacher holds biases, and to what degree. These data could be collected as part of a regular teacher training program, then presented to the preservice or inservice teacher in a context of bias training. Teachers could be presented with anonymized aggregated data to understand how existing teachers are exhibiting biases, or presented with their individual data, in order to become aware about their own biases. The data collection and presentation could be part of iterative cycles of simulated activities and reflection, and leveraged to involve coaching and personalized simulation activities targeting specific biases. The method of collecting biased behaviors and presentation of this information is beyond the scope of this research, but it is important for future studies to investigate how this information can motivate educators to first become aware of own biases, and then engage in bias-reduction practices.

Furthermore, teacher education programs and personnel responsible for professional development in school districts can use findings from this type of assessment in order to raise awareness of the need for bias training programs at a district or national level, or to focus bias training programs on topics that are significantly biasing the judgements of teachers within specific geographical areas. Additionally, future research is needed to understand how these kinds of bias detection and training programs will impact student achievement over longer term through multiple years, especially as they relate to current practices of grouping and tracking low achieving students. Finally, future research can investigate how preservice and inservice training programs can be designed to be specifically catered towards personalization based on these data, and whether such programs are more effective than generic interventions which do not use teacher-specific data.

VI. LIMITATIONS

There are several limitations to acknowledge. In this research, we focused on performing an exploratory study of the
potential of virtual environments to elicit teacher bias. A limitation introduced by our low sample size and convenient sampling method is that we could not investigate the source of teacher biases, beyond comparing between perceptions of high vs. low SES students. Biases may be introduced by other student factors such as race, sex, household composition, etc., in addition to teacher factors, such as previous exposure to specific kinds of students, teacher SES level, education level, school district demographics, familiarity with judging students on the topic of literacy, etc.

Future work involving larger samples of teachers is needed to understand how teacher biases are related to these variables. Furthermore, while highlighting that the researchers followed a predetermined script in interacting with all participants, we acknowledge that this study design and analysis may be influenced by unconscious biases within the research team, which is composed of 4 males and 2 females, across 3 ethnicities, at a higher education institution in a western country.

Additionally, the instruments for measuring teacher perceptions in this study could be adjusted to be more reliable. In order to compare teacher judgements, we used subjective teacher measurements, whereby teachers were asked to assign rank and grade the observed students. Although all teachers had exposure to literacy education and were former or current teachers of elementary school children, it is possible that different teachers used different rubrics to evaluate students. In the future, a grading rubric will be provided to teachers in such a study, in order to standardize and more accurately compare teacher judgements.

Finally, a few teachers noted that the information provided about the high SES student background (i.e. that the student travels a lot) created an expectation of their vocabulary level which did not match the student’s spoken words. This cognitive dissonance may have contributed to poorer judgement of high SES students. Furthermore, this may indicate that teacher judgements may not always be due to a perception of SES level, but rather due to expectations about students’ vocabulary exposure. In the future, the information provided about the high SES student can be adjusted to not include information about exposure to different languages, and participants could be asked to confirm which student they believe is higher or lower SES.

VII. CONCLUSION

This research used quantitative and qualitative methods to investigate whether virtual simulations can be used to reveal biases in teacher judgements based on information about student SES levels. We found that teachers exhibited biased judgements, as most teachers judged the low SES students as making more progress than high SES students. This underscores the value of immersive simulations as a mechanism for inducing realistic situations that draw out unconscious biases. Follow-up research is needed to understand how these results can be used to build the capacity of preservice and in-service teachers to recognize their biases, and then to overcome how those biases influence their classroom practices. Recognition of implicit biases is a necessary step in unlearning these biases and practicing unbiased strategies in simulated environments, with the objective of transfer to real world classrooms.

VIII. ACKNOWLEDGMENTS

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IX. REFERENCES


Work-in-Progress—Decolonizing the Digital Divide: Problem Based Spatial Design Through Immersive Technology for STEM Education in Minority Populations

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Abstract—This work-in-progress paper reports preliminary findings from surveys, participant observation, and co-design discussions with educators and elders of a Native American community about how to modify STEM learning activities for their unique tribal culture in afterschool settings using immersive technology and spatial design.

Index terms—native american, STEM, virtual reality, culturally relevant teaching

I. INTRODUCTION

When used in education, technologies such as Virtual Reality (VR) and Augmented Reality (AR) have been known to facilitate knowledge acquisition and increase the motivation of students to pursue Science, Technology, Engineering, and Mathematics (STEM) majors and careers [1]. Introducing students at an early age to these technologies will prepare them for the future workplace. In this paper, we share design based research reflections from a summer workshop for after school educators from 3 tribal nations. We use a Generative model of Culturally Relevant Teaching (CRT) that focuses on developing narratives and tools that inform students of cultural idioms through space and enable translations into creative architectural forms using the immersive nature of VR/AR technology. This paper reports findings from an intertribal educator workshop that uses the Spiro Mounds of Oklahoma, USA, as the context for VR/AR learning. The main research question focused on “In what ways can blended cultural learning and technology-rich immersive professional development support afterschool educator’s abilities to translate Indigenous concepts into creative design experiences?” We report preliminary findings from pre-surveys, participant observation, exit tickets, and co-design discussions with elders and educators about how to modify the activity for their unique tribal culture and afterschool setting.

II. DECOLONIZING DIGITAL LANDSCAPE THROUGH EDUCATION

Research suggests that problem based spatial design education using VR/AR can motivate and prepare students for Science, Technology, Engineering, and Mathematics (STEM) careers [2], [3]. Additionally, VR/AR will be prominent technologies in many major STEM industries demanding a new set of skills for the emerging STEM workforce. However, while there is often inequitable access to Computer-Aided Design (CAD) in public schools and indigenous communities in the United States, there are also barriers in accessing knowledge given the colonized nature of science curricula [4]. Drawing on generative design principles, our project aims to design curriculum and implement culturally responsive CAD instruction for middle school youth and educators at tribal afterschool programs. This article reports findings from an intertribal educator workshop.

Digital decolonization refers to the effort to bridge the gap in digital practices as a means of limiting inequalities that existed in the past. According to [5], “the main feature of the Web 2.0 and 3.0 eras is moving beyond Digital Information to Digital Negotiation and Digital Creation” (p.400). Marginalized groups should move from digital recipients to become active participants of the digital environment by creating and sharing of information that might be particular to their cultural heritage. With the era of web 2.0 and 3.0, there is representation of indigenous groups in the digital world, however there is still a divide in terms of access and representation [6]. To examine the divide, we would need to look through the lens of equity to examine the gap between what indigenous groups and non-indigenous people can do and what cannot be done, the difference in the access to knowledge (education) and technology in schools and home environment, and most importantly the influence of culture in education, and its
influence on the underrepresentation of Native Americans in STEM fields [7].

CRT as a specific pedagogy allows the cultural references, ideas, and experiences of students to be an important part of the learning process [8]. Presenting science in culturally relevant frameworks can increase Native American participation in STEM learning and this includes after-school science education experiences [9]. Generative models of CRT [10] focus on developing narratives that inform students of cultural idioms and translates into creative architectural forms through the use of the immersive nature of VR/AR technology. These experiential learning opportunities can allow the students to explore their cultural heritage, develop new milieus that are relevant to their generation, and develop an appreciation for technology and its capabilities. Literature informs us about some of the underutilized systemic strategies that have been documented to work with Native American students and their learning environments, such as collaborative learning, more inclusive and diverse learning environments, and using culturally relevant pedagogy, research, and evaluation processes [11]. Therefore, it is important to develop content that is culturally relevant and embodies the worldview that Native Americans embrace, through concepts that are used in daily lives and in a hands-on-situated learning background.

III. SPACE AS A GENERATIVE LEARNING CONCEPT

Space is a central characteristic of all human activity [12]. People experience space in different ways and at different levels—therefore, space plays a fundamental role in developing culture and social connections [13]. Space and its constructs are a central theme when discussing any civilization and become a visual cue for these ancient cultures. According to Hall’s theory of proxemics [14], the way individuals perceive space depends on their cultural background. Space is a function of an individual’s culture and it is possible to express cultural characteristics through these spatial metaphors.

The importance of this idea of space as a metaphor for culture is taken a step further by [15] through the concept of Genius Loci or the Spirit of Place, which is described as what makes a space specific as well as the dimensions of lived experience, interaction, and use of space [16]. The spirit - or sense - of place usually refers to what makes a space specific to the individual, such as the characteristics, memories and associations, and activities afforded by the place. Sense of place is defined as the emotional relationships and meanings attributed to the space [17]. However, while the personal and relational dimensions relate to the space, they can also apply to the place since place refers to the mental environment. This is due to the “experiences-in-place” being able to evoke significant feelings involving the perceived place. These feelings can be discussed under three categories: experiences of personal growth, memories, and feelings of safety, threat, and belonging [16]. Therefore, the idea of using space as a cultural metaphor is not new, and has been used in different domains including STEM education.

IV. METHODS & DATA COLLECTION

The project follows an iterative process of design, implementation, research/evidence, feedback, and adjustment of program components. This process is commonly referred to as Design Based Research (DBR), which is focused on improving “educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories [18].

Seven (n=7) afterschool educators from three tribal nations participated in the three-day workshop and were provided a stipend for their participation. A pre-survey was used to better understand their prior STEM teaching experiences and instructional comfort with STEM education, as well as teaching beliefs about technology. Observational data was collected and analyzed using video recordings of the workshop. Educators were asked to complete exit tickets each day to capture individual reflections about the workshop content. Finally, educators participated in a group brainstorm with the workshop hosts to identify specific tribal nation connections and synergies with existing cultural programming at the afterschool. The first day the focus was providing the educators with some background of CRT pedagogy and providing them with an introduction to Spiro Mounds, its Architecture and the cultural significance. The researchers provided information by inviting the curator for the Spiro Mounds Museum and presenting the participants with an overview of the Spiro Mounds. The discussions focused mainly on the structure of the spiro mounds and the artifacts that were entombed within the mounds. The discussion also focused on the cultural significance of the mounds to all tribes in Oklahoma, as it embodied aspects of all tribes of the Mississippian settlements.

During this first day the educators were provided with basic instruction on how to use Sketchup and explore the 3D models using VR through the Enscape plugin. Furthermore, some of the artifacts (replications of actual artifacts found in the mounds) that the curator brought were 3D scanned using a handheld 3D scanner.

The second day was focused on recreating the Spiro Mounds using Sketchup. The after school educators developed the 3D model of the Spiro Mounds using information on the structure provided by [21]. The artifacts that were 3D scanned were then included inside the 3D model of the mound.

![Fig. 1. Exterior and Structure of the Spiro Mound (rendered 3D model).](image)

During this experience, the intention was for the educators to combine the cultural aspects of the Spiro Mounds with the technical details of developing 3D models and finally experiencing these cultural artifacts through immersive VR. A culturally responsive method was utilized for the educators to construct knowledge rather than just passively take in information by developing the Spiro Mound using Sketchup. Then the educators experienced the Spiro Mound using VR, where they built their own representations and incorporated new
information upon their pre-existing knowledge of the Spiro Mounds.

The third day was utilized for the co-design of the educational modules of the after school program. In DBR, collaborative design, or co-design, is one strategy for utilizing teachers’ expertise to design, implement, and test educational outcomes, thereby strengthening teachers’ agency. This process also allowed the researchers to understand what is familiar to students in the context of that particular after school community and also allowed them to create STEM connections to already existing cultural learning activities.

V. FINDINGS AND CONCLUSIONS

To answer our main research question, we introduced generative design and CRT to our after-school educators. Our intertribal educator workshop set the stage for exploring spatial design across cultures, and codesign with CPN elders and educators.

Most of the teachers (86%) have a Bachelor’s Degree or Higher. While their years of experience in STEM ranged from 2-13 years, most (86%) felt comfortable or somewhat comfortable implementing STEM and Technology activities. Notably, of the 3 partner tribal nation afterschool programs, 2 programs devoted less than 20% of the time on STEM learning, while the other program reported more than 50% focus on STEM. Already existing STEM activities used in the afterschool programs included having lectures and guest speakers, small group and/or outdoor activities, participating in engineering design challenges, and having robotics competitions. These findings overall demonstrate how the amount of experience of the teachers, commitment to STEM education, and available resources varied across each afterschool program.

The third day of the educator workshop was focused on creating co-designed connections. The educators gave insight into the interests of the students, and the activities/projects in progress at the afterschool program. For example, it was through the educators that knowledge of the students’ bead working was learned. The idea to create a museum to showcase this work became the objective of module three.

The DBR process allowed for the afterschool modules to be modified. Initially, it was the plan to have the students learn about and create a 3D model of the Spiro Mounds. After discussion with the after school educators, it was determined this would not be a realistic goal since the Oklahoma Native American Tribe’s students had little to no experience with 3D modelling software.

We learned that an important component of generative design is to develop relationships with cultural knowledge bearers and tap into existing after school cultural activities. For several tribal nations, administrative units dealing with cultural preservation and language are not necessarily used to collaborating or working in the after school setting. In the future, we will continue to encourage educators to actively identify cultural knowledge bearers, community based problems, and other stakeholders for the hack-a-thon which is introduced in the final module.

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Work-in-Progress—Designing Evaluation Modules in the VR-based Simulation for Learners with Intellectual Disabilities

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Abstract—The purpose of this work-in-progress paper is to develop an evaluation module in the VR-based simulation for learners with intellectual disabilities. The observation screen provides feedback to learners and evaluates their personal learning achievement. The simulation is designed to view the performance of the learner, offering visual and auditory feedback. The usability evaluation for learners with intellectual disabilities was conducted using grounded theory. In terms of performance, the observation screen helped identify difficulties in the learners' spatial navigation, individual interaction, and learning tasks. The teacher can provide appropriate feedback on the learner's difficulties using the observation screen.

Keywords—virtual reality, intellectual disability, vocational training, feedback

I. INTRODUCTION

For learners with intellectual disabilities (ID), the transference of information learned to its corresponding practical application can be certainly both complex and challenging [1]. Thus, contexts in which learning takes place must reflect real-life applications as much as possible. For this reason, learners tend to undergo effective vocational education and daily life training in less restrictive spaces such as communities [2]. However, training in the community is not without its accompanying costs and risks. Moreover, the difficulty in learning cannot be controlled [3]. Therefore, virtual reality emerges as a method to reduce said costs and risks in real life. It can tailor the learning environment to the needs of ID learners, thereby providing them with a scaffold appropriate to the degree and characteristics of the disability [4]. With the support of virtual reality, various educational aspects such as daily life skills, leisure, and vocational training can be provided to learners with disabilities [5]-[7]. However, as learning may be hindered if the concept is presented in a manner that fails to challenge the learner to elicit responsive effort on their part, the learning design in virtual reality requires careful consideration [8]. In the context of disabilities, where the individual difference among the learners is high, students with ID experience great difficulties with learning, communication, and social skills than non-disabled people [9]. Thus, the virtual learning space can pose challenges of its own to such learners. For instance, it is difficult for these learners to use joysticks at the onset of participating in virtual reality learning, due to which they may experience isolation [10].

In particular, it is necessary to adequately perform the learning processes designed within the content to achieve sufficient learning. However, unlike the designed purpose of learning achievement, if a learner experiences unexpected difficulties in the process of performing a simulation task, it can be assumed that the prepared learning tasks cannot be performed, which, in turn, can lead to the discontinuation of learning. Therefore, various interface designs that can accommodate and consider the specific learning situation should be introduced[5][10]. However, this may not necessarily be the most ideal design for learners with ID because feedback does not respond systematically and quickly at the moment when the learner feels difficult. Put succinctly, the simulation needs more adaptive feedback design systematically. Yet, it is difficult to find a detailed study on how learners with ID receive support through virtual reality simulations with observation screens.

Therefore, the research problems addressed in this study areas follows:

1. To design and develop an observer control panel of vocational education simulation for intellectual disability learners.
2. To check the usability of the vocational education simulation to which the observer control panel is applied.

II. THEORETICAL BACKGROUND

A. Virtual reality design for learners with ID

The virtual reality content designed for vocational education with specific consideration for the ID learner is diverse. In the study of [5], a simulation that can manipulate coffee machine behavior and coffee manufacturing process has been employed with near-life likeness. This simulation analyzed and applied the task to the level at which ID learners could sufficiently perform. Furthermore, a reinforcement strategy considering learners' motivation and a teacher management system for learners' learning management were organized together. A study by [7] developed a vocational training simulation for students with autism and learners with ID. The training contents provided included a variety of job tasks. It was designed to provide visual
and auditory help based on the area of disability so that learners may learn effectively through all processes. Furthermore, a control panel was provided through a separate tablet so that the learner's training coach could observe the learning situation and manage it as necessary.

Taken together, the virtual reality vocational training simulation for ID learners can be summarized with the following characteristics: 1) The actual employment environment and duties were selected, 2) the tasks were subdivided and presented in consideration of the learner's intellectual ability, 3) elements to increase learners' motivation and level of participation in the learning process were provided, 4) feedback configurations were utilized to help the learner, 5) the coach is capable of managing the learner's learning situation as necessary.

B. Usability Evaluation through Grounded Theory

The majority of the methods employed to evaluate usability are carried out by experts who use pre-finished products/contents or entail the involvement of responses from questionnaires. However, in the context of ID learners, the accurate identification of usability may be challenged by the difficulties emerging from individual characteristics of ID [11]. Thus, it is important to observe closely and interpret the process wherein the user interacts with the content. Grounded Theory is used as a qualitative analysis method for analyzing in-depth information on users, behaviors, and situational information [12].

Grounded theory constructs a relationship between concepts by identifying frameworks that understand and interpret the diversity of actions observed in qualitative data [13]. Open coding, axial coding, and selective coding were presented as systematic data collection methods in the theory of evidence [14]. Open coding is used to discover prominent features such as similarities and differences through repeated comparative analysis of data. Axial coding refers to the categorization of concepts that appear in open coding based on theoretical sensitivity. Finally, selection coding refers to building a theory through explanation based on data [15].

III. METHOD

A. Design and Development of Evaluation Module

In this job training simulation, students with ID perform as convenience store staff in a virtual convenience store environment. Besides discovering the problem situation of the guest avatar in the simulation, learners should accurately identify the cause of the problem situation. Then, find the right tool (the mop), and use the tool to solve the problem. Finally, organize the tools, notify the customer that the problem is over, and check for additional problems.

The simulation was developed using Unity 3D and applied Google Firebase as the database. The simulation structure is as follows: Fig. 1.

This simulation has been designed to provide systematic feedback. Thus, learners receive support in the form of voice outputs and pop-ups by clicking on the ‘Support’ button in the upper right during the simulation. Additionally, the learner's task performance is presented from a third-person perspective so that teachers can grasp the nature of unexpected problem situations more easily. In case a problem emerges, the teacher can provide support on their own.

The primary evaluation metrics are speed and accuracy with which the task was performed in vocational training for special students. Therefore, the teacher checks the learner's performance from the learner's point of view and the observer's point of view on the monitor of the PC where the VR simulation is in progress. The teacher scores the achievement level of the target behavior as good, fair, or poor (Fig. 2). The simulation also measures the learner's performance time to assess punctuality skills. The measured performance time, the number of times support was required, and the achievement scored by the teacher are all uploaded to Firebase in real-time.

After the simulation is completed, the student takes off the VR Headset and checks the assessment results with the teacher. The assessment results are then provided in the form of a work log with the date, time of work, the number of times support was received during a task, and customer ratings (Fig. 3). This is both an evaluation and a form of feedback on learning outcomes.

B. Usability Analysis using Grounded Theory

All processes of using the virtual reality vocational education simulation were filmed on video so that participants' actions, expressions of intentions, or conversations with their mothers could be referenced. MAXQDA was used for data analysis. All the conversations in the process of data collection were transcribed, based on which a timestamp was applied to
match the contents of the transcription with the contents of the video. The analysis of the data was conducted through Grounded theory. The data coding was conducted by a researcher with 4 years of experience as a special education teacher who has observed the current study subjects for more than 2 years. In the data analysis, open coding for major features was conducted by continuously comparing and analyzing the recorded videos repeatedly. Furthermore, the concept of the code that appeared during open coding was clarified after a review by one educational engineering expert. Subsequently, axial coding was performed through the categorization of concepts extracted in the open coding process, which was presented as a model through selective coding by reflecting the context of axial coding.

IV. RESULT

Using the observation screen, it was possible to find difficulties in learners’ spatial navigation, interaction with objects, and task performance. In spatial navigation, learners showed difficulty in changing directions. More specifically, learners gave up moving because they were too close to the wall to obtain information on the direction when the view was blocked. It also showed difficulty in controlling precise positioning, especially in the process of holding the mop, which did not fit the object well. This demonstrated its difficulty in interacting with objects. The difficulty in space exploration and object manipulation made it difficult to simultaneously perform the action of moving to the destination while holding the object. With regard to the performance of the learning task, the learner recognized the process of solving the task. The system was also able to provide adequate feedback in the cognitive task area, but it was unable to provide adequate feedback in space exploration or grasping objects. Therefore, this caused the learning process to stop regardless of cognitive understanding.

However, through the observation module, the instructor found difficulties in terms of the learner’s usability. When the user showed difficulty in manipulating the object, the third-person screen was able to show the depth of the learner’s hand motion and the distance from the object more accurately than the learner’s point of view. In addition, the third-person point of view made it easy to check the learner’s location and state even when isolated from the wall. Put differently, although no systematic feedback on accessibility has been constructed, the observation module has helped in identifying usability difficulties, enabling immediate feedback.

V. DISCUSSION

The screen where learners can observe the learning situation is effective in grasping the learner’s problem situation. This makes it possible to quickly identify difficulties in learners’ spatial navigation, interaction with objects, and performance of learning tasks. However, to properly provide feedback and a positive User Experience, the following factors must be considered. First, learning support for movement and direction change should be included when designing feedback to increase VR usability. In [10] presented an interface in which the instructor’s screen touch is mirrored into the HMD in a direction that can solve the problem of one’s own direction and usability in the learner’s isolation situation. Second, the straight movement itself was not difficult when learners exhibited difficulty in exploring. However, it showed difficulty in changing direction and grabbing, grasping, and moving within VR. Straight line movement is a simple key in using joysticks, but multi-key is used to grasp and change directions. Therefore, as shown in [16], the joystick may be considered difficult for the user. Therefore, it is necessary to simplify the key components of the joystick or to get accustomed to it by providing learners with experience in advance.

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K-12 STEM Education
Abstract—Fully-immersive virtual reality (VR) can be used to display 3D data so it is possible to use different vantage points and scales to observe these data. VR provides the perception of depth that is essential to appreciate distances and positions of 3D data points. In this paper, we propose a serious game in fully immersive virtual reality related to astronomy education. It allows users to learn about the positions and types of deep sky objects that are in the Messier catalog. The present work has multiple purposes: to teach the location of Messier objects in the night sky, to learn about the main types of deep sky objects, and to raise awareness of the consequences of light pollution on the night sky as some of the Messier objects can be observed with the naked eye in dark sky locations. The usability, workload, and potential VR symptoms have been assessed with undergraduate students. The results support the conclusion that VR has a key impact on the immersion of the users in the learning activities, with a laser pointer allowing to access easily all the different functionalities. The gameplay based on visual search exploits the 3D space in VR; the hints allow users with no prior knowledge of the topic to complete the tasks. With no motion and objects located at a far distance within the environment, the VR environment does not induce any VR symptoms.

Index Terms—virtual reality, astronomy, serious game, education

I. INTRODUCTION

The delivery of STEM education has radically changed in the last decades following technological advancements, from the chalk and board to slide-based presentations. In STEM education, slide-based presentations have been implemented widely in the teaching of biology, chemistry, physics, etc., allowing dynamic presentations with multimedia content. The next generation of student-centered teaching and learning methods in STEM will include virtual reality (VR) [1]. In scientific fields where 3D data are present, students often struggle to situate, locate, and rotate objects mentally. It is the case in multiple STEM fields, including medical education [2], but also in the humanities where artworks can be presented in their original size [3]. Understanding key concepts of physics and astronomy requires the notion of reference frame, an abstract coordinate system with an origin, orientation, and scale. Many concepts in astronomy require changing ones perspective within a 3D space for understanding the motion of astronomical objects [4]. Astronomy is a key part of STEM education. It is one of the oldest natural sciences, and it studies celestial objects and phenomena. Astronomy can be divided in subfields: astrophysics, astrometry (how celestial bodies are positioned and move in space), astrogeology, and astrobiology. It can also be decomposed in relation to the technique that is employed for astronomical research, e.g., observational astronomy. Immersive learning using virtual reality is particularly adapted to scientific fields where the representation of 3D data has a key impact on the understanding of learners. It is the case of medical imaging [5] and 3D earth science data sets [6] where 3D data are used and the appreciation of depth can improve data visualization. The main asset of virtual reality is to represent objects in their real size and to observe, manipulate 3D objects where perspective can bring additional information.

VR can be used for displaying data presented on a sphere, such as the celestial sphere. The projection of a sphere on a 2D screen is an old problem that is common in map projections [7]. There are multiple ways for representing a world map, it includes the equirectangular, Mercator that was developed for navigation purposes, Miller, Gall-Peters that preserves sizes and proportions, Goode homolosine, stereographic that is most useful for maps of polar regions. There are two models for creating different map projections: by presentation of a metric property and projections created from different surfaces. The first type includes equidistant, conformal, gnomonic, equal area, and compromise projections. They account for area, shape, direction, bearing, distance, and scale. The second type includes cylindrical, conical, and azimuthal projections. A map projection is a technique to flatten a sphere’s surface into a plane so the sphere become a map, i.e., a 2D projection that can be printed or displayed on a computer screen. These different projections aim at preserving some properties such as the direction, shape locally, the area, the distances, or the shortest route. The projection transforms the longitude and latitude into polar or Cartesian coordinates. Each projection has its own set of advantages and disadvantages; fully immersive VR can bypass these constraints with a full representation of the sphere.
In this paper, we propose a new serious game in fully immersive virtual reality that aims at showing to students the positions of deep sky objects that can be seen with an amateur telescope. Contrary to typical astronomy applications that show the motion of stars or planets, in which the user is in a perspective that is not realistic, the proposed application places the user in a realistic situation in relation to the scale and position of the environment to look at the night sky. The remainder of the paper is organized as follows. First, applications related to the astronomy education are presented in Section II. Then, the proposed serious game is detailed in Section III. The results corresponding to the evaluation of the serious game are given in Section IV. Finally, the potential benefits of the proposed application are discussed in Section V.

II. RELATED WORKS

Mintz et al. proposed a virtual environment that uses a dynamic 3D model of the solar system [8]. It is based on scientific visualization techniques and can be used as an effective aide in astronomy teaching. The motion of the planets allows to highlight day and night, seasons, eclipses, and phases-topics. These concepts are typically difficult to understand at young age. A key asset of such a model is that it provides a rich learning experience while training users to deal with a 3D space with objects of different sizes, at different scales. The presentation of the physics concepts in a virtual environment helps to overcome the inherent geocentric view and shows to students the heliocentric view of the solar system.

In [4], Barnett examines how 3D models of the Solar system helped student development of conceptual understandings of different astronomical phenomena, which require a change in reference frame. In [9], they use an Oculus Rift VR headset running AAS WorldWide Telescope software to visualize 3D data. Such an application using a VR headset can be deployed in different places (e.g., festivals, classroom) to reach communities that are not able to access planetariums. The shows that are typically presented using fulldome video technology can be transferred to VR headsets [10]. This immersive environment of digital planetariums offers great opportunities for outreach and engagement of STEM audiences.

WorldWide Telescope (WWT) is a tool for astrophysical data exploration and discovery in the Big Data era [11]. WWT is an open source scientific data visualization platform managed by the American Astronomical Society. It provides a virtual sky, where it is possible to explore different all-sky surveys. It includes a Microsoft Windows application that is a main component in planetariums and international education; and a WebGL powered Web application. The Christenberry Planetarium has used WWT’s VR capabilities in public outreach to promote the latest astronomical discoveries. WWT has been used for live and recorded shows in major planetariums. Furthermore, VR has demonstrated its impact in education for understanding 3D structures in anatomy. For instance, undergraduate students using VR for cardiac anatomy learning achieved a substantial higher score than control group [12].

Mobile platforms provide a cost effective solution for XR and VR applications. In [13], they propose a VR application for mobile platforms that depicts the movement of the Solar System together with the translation of each planet and planetary gallery with various information about each planet. It also includes activities about orbits and star parallax. While it provides educational content, the gaming aspect is not highlighted. Another mobile base application for Android-based systems using virtual reality was proposed to present the solar system [14]. In [15], they recreated the traditional ball-and-stick moon phases learning activity with virtual reality. While there was no difference in terms of learning with other traditional approaches, they have shown that users prefer using the VR simulation. Astronomy is a scientific discipline that can be taught at various ages; in [16], they propose a VR application for astronomy education in primary and middle school. In [17], they proposed a framework for engagement with VR using immersion, facilitation, collaboration, and visualization as key components for the assessments. Their experiments at a science festival show that VR provides fun and enjoyable experiences, and can enhance learning and understanding of astronomical concepts. Finally, VR has been used to walk in an exploded star using NASA and other astrophysical data of the Cassiopeia A supernova remnant that have been rendered in VR and augmented reality (AR) [17]. In addition to specifically tailored learning experiences, we can mention applications that are available to a wide audience, it includes the Universe Sandbox, which includes VR functions [18].

In the different studies that have combined astronomy and VR, the number of applications provided some serious gaming approach is limited. The interaction with the environment is not a synonym of game. We can distinguish applications depending on the point of view of the user: does the VR situate the user in a realistic position? For displaying planetary motion, the scale and the position are adapted so that is it possible to experience some motions: the laws of physics are respected but the graphical content may be generated empirically (e.g., for displaying the surface of exoplanets).

III. METHODS

The proposed serious game is based on the representation of the night sky as it is presented in a dark sky location. It includes the stars and the milky way that are presented on a large sphere. The sphere is represented as an 4-level icosphere, so the texture can be mapped on the sphere without artefacts. The texture is based on the Milky Way from the GigaGalaxy Zoom project [19]. For the stars presented in the night sky, we have considered stars from the HYG database, which includes data from three catalogs: the Hipparcos Catalog, the Yale Bright Star Catalog (5th Edition), and the Gliese Catalog of Nearby Stars (3rd Edition). The Hipparcos catalog is the largest collection of high-accuracy stellar positional data, particularly parallaxes. The Yale Bright Star Catalog includes basic data on all naked-eye stars. The Gliese catalog is the most comprehensive catalog of nearby stars, and has many fainter stars that are not found in the Hipparcos Catalog.
Among these stars, we display in the VR environment only the stars with a magnitude 5.6 corresponding to what can be seen with the naked eye in a Suburban sky with a Bortle scale set to 5. For the representation of the stars in the VR environment, we use a particle system, where each star is a particle. The color of the stars are based on their temperature, and their sizes are based on their apparent magnitude, i.e. bright stars are depicted as bigger particles than faint stars.

For the evaluation of the application, we consider the Messier objects. They are a set of 110 astronomical objects, which were cataloged by the French astronomer Charles Messier [20]. The objects in this catalog include 6 diffuse nebulae, 27 Open clusters, 4 Planetary nebulae, 29 Globular clusters, 40 Galaxies, and 4 other objects (see examples in Fig. 2) [21]. The goal of Charles Messier in compiling the catalog was to help comet hunters not to be confused by his selection of objects that he thought looked like comets. Messier Catalog has become a standard guide to astronomers, in particular amateur astronomers, for a study of the sky’s best objects that can be seen with a consumer grade telescope, and that have shaped our understanding of the universe, such as the Andromeda galaxy (M31) and the Crab nebula (M1).

The position of the different Messier objects are depicted in Fig. 1. In [22], they show that the messier objects can be used as a tool for teaching astronomy where students can observe the objects through a telescope, followed with the explanation related to these objects. It also represents a social event where astronomy clubs and societies perform the Messier Marathon where participants attempt to observe all the Messier objects in just one night in March each year. Because the objects are not always visible in the night sky, each object is associated with a pre-defined location of observation (longitude and latitude) and a time and date. The fields for the representation of an object in the Messier catalog are detailed in the JSON description 1. Each deep sky object include a type, a constellation, a magnitude, a discoverer, a year, the position (right ascension (ra) and declination (dec)), and an index to its catalog, with additional information related to some other catalogs. In the presented example, the index in the New General Catalog of Nebulae and Clusters of Stars (NGC) is also given. It is worth noting that such a description allows the game to be enriched with any catalog of deep sky objects.

The proposed serious game in VR provides the same approach where the nature of the objects, their discoverer and other information are given for each target. We do not expect users to know about the night sky and to know about the position of the different deep sky objects in the sky. Contrary to other astronomy software where there are no gaming components and the user is placed as an observer, the proposed game allows users to search for objects in the night sky in the VR environment. Because users may have no prior knowledge and to avoid frustration, we propose different hints that the player can consider:

- **Hint 1**: The player gets the constellation where the object is located. The lines of the constellation are displayed in the night sky. The user has then information about the region where to search.

- **Hint 2**: The player gets a feedback in relation to the position of where the laser pointer is pointing to, and the position of the target. The color of the laser pointer changes in relation to the distance between the target and the position of the laser pointer. In addition, there is in the menu a color bar that indicates the current color of the laser pointer and its meaning in relation to its proximity with the target.

- **Hint 3**: The player gets a visual feedback in relation to the difference between the right ascension (celestial equivalent of terrestrial longitude) of the object and the position of the laser pointer.

- **Hint 4**: The player gets a visual feedback in relation to the difference between the declination (celestial equivalent of terrestrial latitude) of the object and the position of the laser pointer.

```json
Listing 1. Information for a deep sky object.

```json
{
  "DSO": {
    "Index": 8,
    "Catalog": "NGC",
    "Number": 6523,
    "Name": "Lagoon Nebula",
    "Type": "Diffuse Nebula",
    "Code": "sn",
    "Constellation": "Sagittarius",
    "Magnitude": 5.8,
    "Discoverer": "Giovanni Battista Hodierna",
    "Year": 1654,
    "Country": "Italian",
    "RA": 18.0633,
    "Dec": -24.3833
  },
  "NameCatalog": "Messier",
  "CodeCatalog": "M",
  "Date": "08/15/2021",
  "Time": "22:00:00",
  "DegreeLatitude": 40,
  "MinuteLatitude": 0,
  "SignLatitude": 1,
  "DegreeLongitude": 120,
  "MinuteLongitude": 0,
  "SignLongitude": -1
}
```
graylevel and extracted from the Digitized Sky Survey (DSS), the second image is in color and is a composition of blue, red, and near infrared images from the Second Generation DSS; the third image is in color and is a composition of images from the Wide-field Infrared Survey Explorer (WISE) using different wavelength range bands. The images were acquired by the Skyview client [23]. An example of feedback after the successful detection of an object is given in Fig. 7. At the beginning of the game, the player can sort the objects by constellation, by index in the Messier catalog, by type, or randomly. The player can also search only within a category of objects: galaxies, globular clusters, open clusters, and nebulae. During the game, the player can set the equatorial (i.e., the frame of the stars, the sidereal frame) and the azimuthal (i.e., the position of the observer on Earth) grids in the scene (see Fig. 6). These grids provide additional educational content as they represent different reference frames.

The great-circle distance, orthodromic distance, or spherical distance is the distance along a great circle. Let $\lambda_1, \phi_1$, and $\lambda_2, \phi_2$, be the geographical longitude and latitude of two points $p_1$ and $p_2$ on a sphere (see Fig. 4). We define their absolute differences as $\Delta \lambda, \Delta \phi$. The central angle between them is denoted by $\Delta \sigma$. It is given by the spherical law of cosines if one of the poles is used as an auxiliary third point on the sphere $\Delta \sigma = \arctan A/B$, where

$$A = \left(\cos \phi_2 \sin(\Delta \lambda)\right)^2$$

$$+ \left(\cos \phi_1 \sin \phi_2 - \sin \phi_1 \cos \phi_2 \cos(\Delta \lambda)\right)^2 \right)^{1/2}$$

$$B = \sin \phi_1 \sin \phi_2 + \cos \phi_1 \cos \phi_2 \cos(\Delta \lambda)$$ (1)

The serious game was implemented with Unity 2019.4.8f1, using the SteamVR plugin to allow different types of VR headsets to be used. The controls are limited to buttons within the VR environment that can be activated by the laser pointers coming out of the VR controllers and the trigger button. The user controls are presented in Fig. 5.

**A. Performance Evaluation**

We have assessed the game with 3 questionnaires: the usability, the workload, and the potential VR symptoms. The
Fig. 4. Great-circle distance: distance between \( p1 \) and \( p2 \).

Fig. 5. Controls for the laser pointer with different VR headsets (left: Valve Index, middle: Oculus Touch, right: HTC Vive).

The evaluation of the workload and system usability is presented in Tables I and II. The scores of the Virtual Reality Symptom Questionnaire are given in Table III. The values represent the mean and standard deviation across participants. The highest value for the NASA-TLX is for the mental demand (6), the lowest value for the performance (2.8) as all participants completed successfully the task, thanks to the different hints. The results reveal that there were close to no VR related symptoms during the evaluation of the game, as all the average values are close to 0. These results were expected as users were in a standing only position. The scores for the system usability and the NASA-TLX suggest that there are no issues for navigating through the questions, with a medium workload.

V. Discussion and Conclusion

We have presented a serious game in fully immersive virtual reality where users can search for famous deep sky objects in the night sky. Creating a serious game for STEM is not an easy task as the game should be entertaining for users with different levels of knowledge in relation to the covered field. The serious game does not require any prior knowledge of the locations of deep sky objects. Users can enable different types of hints and investigate at their own pace the location of these objects. While the game provides a score, depending on the number of hints that were activated by the users for each question, the proposed approach provides a direct engagement of the users into the night sky. Immersive learning using VR can place the user in a realistic situation that can be unique and difficult to get in the real world. For the observation of the night sky, first it is necessary to be in dark locations. Most of people living in urban areas are not able to see the Milky Way due to the light pollution. In large cities, it can even be difficult to distinguish constellations such as Ursa Major. With the development of urban areas, it is becoming more and more difficult to determine our place within the universe. The Milky Way is hidden from more than one-third of humanity; it includes 60% of Europeans and almost 80% of North Americans [27]. In this situation, virtual reality can show to people the effects of light pollution and give them a representation of how the night sky looks like in places with no light pollution. In the present serious game using the Messier catalog, players can see that some objects, including galaxies, globular clusters, and nebulae, are in fact objects that can be found with the naked eye. Such a learning experience raises awareness about the effects of light pollution and everything that can be seen in a dark sky location. In addition, the VR representation allows players to experience the representation of the night sky in different locations, i.e., the southern hemisphere. Accessing dark sky locations becomes difficult and prevents students to learn about astronomy outside, and VR provides a solution to this challenge.

The evaluation of the proposed game highlights its simple and yet engaging gameplay that invites the user to find the location of the different objects. Thanks to the hint related to...
Fig. 6. Left: example of hint related to the constellation; Right: view of the night sky with the azimuthal grid.

Fig. 7. Left: visual feedback for finding the target; Right: visual feedback for the successful detection of an object with images of the DSS, DSS2, and WISE surveys.

Fig. 8. Examples of questions with the user interface within the VR environment.

| TABLE II
| Usability Evaluation (1: strongly disagree - 5: strongly agree) |

<table>
<thead>
<tr>
<th>TEST</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think that I would like to use this feature frequently</td>
<td>3.7±1.57</td>
</tr>
<tr>
<td>I found the feature unnecessary complex</td>
<td>1.5±1.27</td>
</tr>
<tr>
<td>I thought the feature was easy to use</td>
<td>4.4±0.7</td>
</tr>
<tr>
<td>I think that I would need the support of a technical person to be able to use this feature</td>
<td>2.1±1.57</td>
</tr>
<tr>
<td>I found the various functions in this feature were will integrated</td>
<td>4.2±0.92</td>
</tr>
<tr>
<td>I thought there was too much inconsistency in this feature</td>
<td>1.2±0.42</td>
</tr>
<tr>
<td>I would imagine that most people would learn to use this feature very quickly</td>
<td>4.7±0.48</td>
</tr>
<tr>
<td>I found the feature very cumbersome to use</td>
<td>2.3±1.25</td>
</tr>
<tr>
<td>I felt very confident using the feature</td>
<td>3.8±1.48</td>
</tr>
<tr>
<td>I needed to learn a lot of things before I could get going with this feature</td>
<td>2.7±1.49</td>
</tr>
</tbody>
</table>
the great-circle distance, players can easily find the objects within a limited amount of time without getting blocked. VR combined with serious games can be used in different types of learning experiences. First, it can be used in an informal learning setting where learning occurs away from a structured, formal classroom environment. It is the case when users acquire a serious game primarily for the gaming components. Second, it can be used in a formal learning situation in which learners can situate and/or manipulate 3D objects related to the teaching materials. Third, VR provides a great way to enhance public engagement and to develop public outreach, despite the limitations of some VR technologies that require external sensors and powerful desktop computers. Further works will include the addition of a tutorial and videos to better explain the gameplay. It can also be enhanced with the addition of other deep sky object catalogs and additional information about these objects. Finally, the serious game remains a solo experience and the addition of an online leaderboard would help promoting the satisfaction of competence.

ACKNOWLEDGMENT

The author acknowledges the use of NASA's SkyView facility (http://skyview.gsfc.nasa.gov) located at NASA Goddard Space Flight Center for extracting all the images of deep sky objects.

REFERENCES


Abstract—Engineering education courses look into processes, equipment and people in order to prepare students to tackle problems in their careers. In manufacturing industry, it is important to use virtual manufacturing tools to analyse processes. This includes both equipment and people. Assembly operations can involve human operators. Modular arrangements of predetermined time standards MODAPTS is a predetermined motion time system method used to analyse assembly processes. Augmented reality (AR) is increasingly being used for industrial processes as well as in education. AR application have been used for maintenance training as a useful way to overly digital instructions to a trainee whilst being able to look at a real object. This is potential beneficial for education. This paper presents the evaluation of a prototype to test a predetermined time standards model using an AR application. An evaluation was carried out comparing AR-based instructions in tablet and PC monitor and paper-written instructions. The results of evaluating the prototype encourage their use as an educational tool in engineering courses.

Index Terms—augmented reality, education technology, virtual engineering, assembly assistance

I. INTRODUCTION

The ongoing COVID-19 crisis has shown how important it is to have a regional supply of goods of daily use, but also other products required in the medium term. Stable and short supply chains as well as flexible production systems are crucial for European economies - recent years have shown severe problems arising from the increasing migration of the manufacturing industry in the Asian region. Flexible and adaptable production lines offer one possibility for regionally economical productions, as these open up the possibility - not only in the event of a crisis - to be changed immediately so that urgently needed goods can be made available relatively quickly. Even in normal operation, flexibility means less dependency and thus greater resilience, which also contributes to secure jobs. Producing small lot sizes to achieve flexible, feasible production systems requires high automation ratio and fully integrated digitalization through the whole company, enabling smart manufacturing concepts, often related to the term industry 4.0. Typically, literature dealing with smart manufacturing, intelligent manufacturing, cyber physical production systems or industry 4.0 - are missing out on crucial part on the production floor - human workforce [1], [2]. Small production batches of different products demand highly skilled, well-trained personnel experiencing a high mental workload [3], [4] as it is difficult to adopt to changing task descriptions several times a day. The study of actions and movements is one of the classical examples of engineering activities aiming to improve manufacturing processes. The aim of such studies is optimising a production process, standardising tasks, and eliminating or minimising unnecessary activities. It is useful to use such activities in engineering education courses to teach a different set of skills and competences to students. Immersive technologies are used more often for industrial training and education. One of those technologies, Augmented Reality (AR) has been used for several training and education applications in maintenance, assembly and engineering [5]–[7]. Augmented reality apps for assembly can be useful for education. Nonetheless, there are other platforms that can implement such functionality. We were interested in finding out which platform could help achieve better results for learning an assembly task aimed at industrial settings.

In this project, a testing prototype was developed to investigate the advantages of different platforms for training in an assembly task. A pilot study was carried out comparing three platforms: AR on PC/monitor display, AR on handheld device and written instructions. The pilot study mixed outcomes in effort required and performance. The work was directed by the question whether an AR-based MODPTS system is reliable enough for describing motion analysis in educational settings.

The contribution of this work is twofold. First, it contributes by showing a case of predetermined time standards. Secondly, it expands the conversation of use of digital tools in education by investigating the setup of a testing rig for educating engineering students in the analysis of assembly operations. In the next section we discuss related work, followed by an introduction of the testing application. The following section discusses the study, then the results and discuss the outcomes and next steps.

II. RELATED WORK

The potential of AR for training and learning is associated with affordances of the technology. Overlaying digital information within the visual field of the user whilst being able to see the surroundings enables to associate data with
physical devices, places or processes. In the case of AR using see-through headsets, the user has their hands free for manipulating objects and can potentially receive instructions without need to change their attention to look at a display. In the case of AR using hand-held devices, the user can still see their surroundings but depending on the activity, they might be limited by holding the device.

Several methods are based on the Design for Assembly (DFA) and Predetermined Motion Time Systems (PMTS) methods. One of those methods is Modular arrangements of predetermined time standards MODAPTS. MODAPTS is extended in several models and methods to analyse assembly processes. The DFA and PMTS/MODAPTS were expanded through a time estimation method for manual assemblies aimed at being used without need to have deep knowledge of MODAPTS and DFA [8]. Other work [9] developed a model that considers physical and cognitive efforts to extend a predetermined motion time system, drawing data from operations modelled in a digital application.

There is interesting work integrating AR for training in assembly processes. In [10] the authors identified requirements for an AR training solution in boiler assembly. Among the requirements the authors list workers safety, user acceptance, viability of the training and technical setup. The work highlights several challenges. One challenge is authoring of AR instructions. The authors point out that dependence on existing content should be avoided. Their methodology sees the need to support hands-free operation in order to allow an assembly operator to use both hands. Additionally, they emphasize to avoid modifying the assembly process both in authoring and training. Another challenge refers to the complexity of setting up the authoring or training tool, emphasizing the need to be available on demand, being easy to setup and not require technical knowledge. In [11] an AR app was developed in a handheld device (tablet) as an option for guiding an assembly task. The work compares mobile-based AR and paper instructions. An interesting trend is the combination of AR and machine learning as one application where a convolutional neural network was implemented for detecting objects and compares them with reference 3D models. Despite the available literature, it is often a question in which scenarios to use technologies such as AR and for which tasks. Technology is often updated and so far, immersive technologies lack the level of standardisation found in other technologies. For example, a person can buy a computer and only needs to consider the operative system but there will be content available, and use will be similar to previous version. AR has fewer regular updates in technology, In the case of AR headsets it can be difficult to move applications between headsets from different vendors. Also with handheld devices it is necessary to see how well they perform with new libraries. Therefore it is of interest to have a way to evaluate AR applications and compare them with other platforms used in engineering.

An application was developed to provide instructions on carry out the assembly of a valve. The application was developed in Unity and Vuforia was also used for the AR version. An AR app version was developed for a tablet. Another version was developed for PC with a desktop monitor. The application has a minimal user interface (see Fig. 1). The user is presented with a text dialog. The text box provides instructions on the assembly. An important part of the prototype was selecting the preference in industry (unwanted markers on components, additional time expenditure by applying the markers) the technical challenges to overcome are also the milestones for the successful widespread use of AR in such applications and environments. There are many approaches to solve the problem of object detection from classic image recognition algorithms to modern neural networks. However, they all have difficulties such as surface finish, geometric symmetries or lighting conditions which leads to unstable visualisation and loss of tracking during SLAM depending on angle and distance to the lens [14].

III. TESTBED PROTOTYPE

Due to technical challenges that are not fully solved yet the great potential that AR holds for supporting industrial manufacturing processes is still unlocked. To display the virtual content exactly at the corresponding spatial position while moving the AR device, the real environment needs to be captured and tracked relative to the device respectively the user. The following types of tracking are used for AR applications [12], [13]:

- Marker-based tracking
- Marker-less tracking
- Model-based tracking

Marker-based tracking uses Barcodes, Quick Response-Codes (QR) or individually generated markers with clear structures and high contrast. Marker-less tracking uses GPS data, accelerometers or Simultaneous Localization and Mapping (SLAM) technology for localization and positioning. The model-based tracking method detects edge features of real objects and compares them with reference 3D models.

Since marker-less AR systems will be very likely to be the preference in industry (unwanted markers on components, additional time expenditure by applying the markers) the technical challenges to overcome are also the milestones for the successful widespread use of AR in such applications and environments. There are many approaches to solve the problem of object detection from classic image recognition algorithms to modern neural networks. However, they all have difficulties such as surface finish, geometric symmetries or lighting conditions which leads to unstable visualisation and loss of tracking during SLAM depending on angle and distance to the lens [14].
Standards model. An optimal assembly process was modelled using MODAPTS after the model proposed by Alkan [9]. The movements were analysed to separate relevant and irrelevant movements. Irrelevant movements were those made by the participant that did not relate to the assembly, for example, moving hair from their face [15]. The video application Tracker captured the movements of the participant and converted the data into values. The values were then extracted as a graph. One graph was created for each hand. Values in those resulting graphs were analysed to differentiate the movements. The processing of the graph focused on differences in relative values. The researcher also observed the participants and collected additional data for other parameters.

The complexity of the assembly is considered by the MODAPTS methodology adapted from Alkan [9] in addition to time needed for completing the task and errors during the assembly. Alkan uses an operational complexity index OCi which considers the total number of tasks and movements, the diversity of such tasks and movements, terminal, auxiliary activities and the effort to complete said activities [9]. In Alkan’s work, they define the following process to define the operational complexity index.

A process involving determining and calculating several factors is necessary to determine the operational complexity index. The process requires to define the overall goal for the operator and presenting it as a series of tasks divided in simple operational activities. Then, a MODAPTS analysis is carried out to convert operational activities into codes and time values. Here emphasis is made on the level of detail in PMTS coding. Every activity should be coded adequately considering factors and limitations in order to achieve higher accuracy. The process includes using a task effort penalty to account for physical and cognitive effort. This is presented as a penalty factor. The factor assumes that the activity is carried out by a qualified and experienced operator.

Basic operator activities are subjectively classified and assigning three values. Natural body activities are assigned a value of zero (0), an activity that requires some effort is assigned 0.5 and an activity that hinders overall work performance is assigned one (1). Alkan presents a table for effort penalties for movement, terminal and auxiliary activities. The table is extremely large so it is not included in this paper due to space limitations. A generic diversity factor accounts for reduction on complexity due to repetitive, identical or generic activities. A size factor is used to consider when a complex task is divided in several simpler and effortless sub tasks. Then a calculation is made to account for complexity in single assembly operations.

Here we have not included all the equations required to calculate the aforementioned factors. These factors are embedded in the model and in the results section we present the values obtained.

The average time to complete an action is described based on Time units (MODS). The tasks in the assembly are presented in table I:

The AR component of the application helps to provide visual instructions to the user. In order to provide accurate instructions, it is necessary to recognise the parts used in the assembly and overly digital instructions. The instructions are a combination of text and simulations. The simulations are, for example, overlaying an Allen key and showing that the user needs to tighten a screw. Object tracking methods based on video input were used for the project. The methods used in the project are part of the Vuforia Engine [16]. Two methods for object recognition are used in the application based on PTC functionality: Model Target and Model Target 360. The engine offers a Model Target generator to create model target databases. A 2D image or a 3D model can be included in the database and used for content input or output. The Model target 360 is generated through training a neural network offered by Vuforia. The application uses two cameras to record user movements during the assembly. The movements are used to analyse the assembly. The open source tool Tracker was used for identifying and following the user’s movements during the assembly. A Matlab script was developed and used to process and transfer data into the MODAPTS model.

<table>
<thead>
<tr>
<th>No</th>
<th>Task description</th>
<th>code</th>
<th>MODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Take the valve</td>
<td>E2M3G3</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Take clump</td>
<td>E2M3G3</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Put clamp onto valve</td>
<td>M3G3P5</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Put controller on clamp</td>
<td>M3P5</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Take Allen key</td>
<td>M3P1</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Screw clump tight</td>
<td>LG3C4C4C4P5</td>
<td>24</td>
</tr>
<tr>
<td>7</td>
<td>Put down Allen key</td>
<td>M3P1</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Take plug connection</td>
<td>E2M3G3</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Screw on plug connection</td>
<td>G3C4C4C4P5</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>Take open-end wrench</td>
<td>M5G3R2E2</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>Screw the plug-in connection tight</td>
<td>LG3C4P5</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>Take muffler</td>
<td>E2M3G3</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>Screw on muffler</td>
<td>G3C4C4C4C4P5</td>
<td>24</td>
</tr>
<tr>
<td>14</td>
<td>Tighten muffler</td>
<td>LG3C4P5</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>Put down open-end wrench</td>
<td>M3P1</td>
<td>4</td>
</tr>
</tbody>
</table>

IV. EVALUATION

The prototype was evaluated through a pilot study. 20 participants were recruited from the student’s population at the institution. The participants had no previous training experience on the task. Each participant was exposed to one of five conditions: AR instructions on a tablet using either Model Target or Model Target 360 technique, instructions on a PC monitor using either Model Target or Model Target 360 technique or hard copy instructions (written on paper).

A. Setup

The test place was setup on a desk. A monitor is placed in front of the user. There is a top camera perpendicular to the hands of the user. There is a second camera placed to the left, parallel to the user (Fig. 2). The participants wore markers on their wrists. The participants were asked to place both their
hands on the table at the beginning of the test in order to set a reference coordinate system for the cameras.

Three spanners and a set of Allen keys were placed to the left on the table (figure 2). The assembly consists of five parts. The parts were placed to the left of the participant at the beginning of the test. The parts are: 1) valve SMC VHS30-F03 with dimensions 60x30x80mm. 2) Regulator 3) connection element (spacer with bracket) SMC AC-Y000 with dimensions 20x50x60mm 4) a pneumatic silencer SMC AN200 with dimensions 20x20x80mm 5) straight push-in fitting SANG-A IQSG3814 with dimensions 20x20x35mm. At the end of the assembly, it should look as shown in Fig. 3. The parts can be attached in several ways, meaning that it is possible they could be incorrectly assembled. This is a reason why the model needs to consider errors in the assembly.

B. Testing modalities

The participants experienced one of five possible testing conditions

- Testing condition 1 PC Monitor instructions. Participants sat in front of a monitor with an overhead camera (perpendicular see Fig. 4)) and a camera to the left at hands level (parallel). The app uses the Model target technique.
- Testing condition 2 PC Monitor instructions. Same setup as in condition 1 but the app uses Model Target 360 technique (see Fig. 5).
- Testing condition 3 Tablet instructions. Participants sat at a table with an overhead camera (perpendicular) and a camera to the left at hands level (parallel). They were given a handheld display (tablet) see Fig. 6). The app uses the Model target technique.
- Testing condition 4 Tablet instructions. Same setup as in condition 3 but the app uses Model Target 360 technique.
- Testing condition 5 Hard copy instructions. Participants sat at a table with an overhead camera (perpendicular) and a camera to the left at hands level (parallel). The participants received written instructions to carry out the assembly.

C. Task

The participant selects a part and places it under the camera. The application shows what assembly must be used. The participants will confirm that has completed that step and press a button to move to the next step of the assembly. The measurements include duration of the assembly, number of mistakes, workload and complexity of the system [15]. No questions were allowed during the assembly. The participants followed a think aloud protocol during the assembly. It must be noted that there are several ways in which the assembly is possible.
Time to carry out the assembly and number of errors were two main metrics measured during the study. Each step in the assembly ended when the participant grabbed a new component according to instructions. If the participant selected the wrong part, the time on that step would still be counted until the correct part was grabbed. The assembly based on paper instructions took on average longer than the other conditions. The outcome of the Model target method on both tablet and PC presented the shortest assembly times (Fig. 7).

Participants would manipulate the paper instructions or the tablet, which could potentially influence their performance. However, the average time taken for the tasks are not that different between the PC and tablet setups with the same object recognition method. There is a greater difference with the time taken using written instructions.

Possible errors were classified in two categories. Grave errors such as incorrect use of the tools. Critical errors are actions which result in a malfunction or non-usability during the assembly. A limit of 20 maximum critical errors was established for each condition for all participants, meaning that each participant was restricted to 5 critical errors. The assembly carried out using paper instructions resulted in the highest number of errors with 45% of possible errors. The condition with the target Method on PC had the lowest number of errors with 2 errors (Table II).

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>NUMBER OF CRITICAL ERRORS IN ALL CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valve</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Instruction</td>
<td>Tablet (MT)</td>
</tr>
<tr>
<td>Valve</td>
<td>0</td>
</tr>
<tr>
<td>Connection</td>
<td>3</td>
</tr>
<tr>
<td>Regulator</td>
<td>3</td>
</tr>
<tr>
<td>straight</td>
<td></td>
</tr>
<tr>
<td>push-in</td>
<td>1</td>
</tr>
<tr>
<td>pneumatic</td>
<td></td>
</tr>
<tr>
<td>silencer</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
</tr>
</tbody>
</table>

The differences in number of critical errors between methods on tablet and PC are greater than the difference seen in time of assembly.

The different types of subjective loads (physical, cognitive) were collected using NASA task Load Index (TLX) [17]. The values for all load values are presented in table III. Each test group had 5 participants and they experienced only one condition each.

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>TOTAL LOAD VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instruc-</td>
<td>Tablet</td>
</tr>
<tr>
<td>tion</td>
<td>(MT)</td>
</tr>
<tr>
<td>Test group 1</td>
<td>59.66</td>
</tr>
<tr>
<td>Test group 2</td>
<td>38.33</td>
</tr>
<tr>
<td>Test group 3</td>
<td>44.00</td>
</tr>
<tr>
<td>Test group 4</td>
<td>47.00</td>
</tr>
<tr>
<td>Average load</td>
<td>47.25</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>9.02</td>
</tr>
</tbody>
</table>

The load does seem to be correlated to the method as the variation in values for the Model Target and Model Target
360 methods change in different ways. The Model Target on tablet had the lowest average load (38.66) followed by the same method on PC (42.25) whilst the highest values were for the Model target 360 methods (47.41 in Tablet and 50.66 in PC).

V. DISCUSSION

The main objective in this work is to be able to evaluate AR for instruction into industrial processes. The testing rig provides a guide to evaluate a time estimation method. The combination with object and movement tracking based on video is valuable towards a concept of virtual engineering. It is valuable to encourage students to test cutting edge technologies and methods such as those used in AR. At the time this work was carried out, the Model target 360 method was not commercially available. As such, this work also served as a way to test this technology before its commercial introduction.

It was expected to see a difference between the use of paper-written instructions and the instructions on devices. It was most surprising that the difference in performance between tablet and PC was not higher. Potentially this should be examined on the light of AR application design. One important aspect is that the implemented AR methods allowed to see instructions within the same visual field as where the assembly was being carried out. The participant still had to change viewpoint when grabbing other parts during the assembly as well as manipulate the tablet. The results were mixed when looking at errors and there is much variability, suggesting there might be another variable to investigate. The outcome of the test suggests that AR has potential as a reliable method to describe motion analysis in an educational setting.

A. Educational Focus and Pedagogy

Digital tools are an important part of our courses. Each engineering discipline uses nowadays key software applications. Often, educational institutions integrate a particular software into their curriculum because it is widely adopted in industry. Exposing students to such tools during their education can help them in their future careers in industry.

Simulation is important in some of the courses we teach at our department. Virtual manufacturing and virtual engineering are more common approaches in modern engineering practices. Therefore, it is important for us to teach our students to understand how to use virtual technologies for engineering. More important is that they can understand what happens in the applications so they are not just black boxes, throwing values without understanding their source.

A reason to explore Alkan’s method is that it is associated with virtual manufacturing. Accounting for complexity in the process is difficult. Therefore the implementation of the camera rigs to capture user’s movement can be a valuable tool for the educator to explain the complexity of Motion Time systems.

B. Limitations

The participants were assigned to one condition each. A between-subjects statistical design could have given us further insight into the collected data. Such analysis is still pending. The participants did not receive training before carrying out the task. It could be argued that this contravenes some of the preconditions on the model used for motion time.

VI. CONCLUSIONS AND FUTURE WORK

MODAPTS are useful but complex models to get insight into assembly activities. AR is an adequate technology to implement MODAPTS in evaluation and educational settings. It is certainly interesting to investigate further AR in combination with the models.

Our strategy aims to include more virtual engineering systems to offer students alternative educational experiences.

We intend to explore other scenarios featuring additional industrial processes associated with mechatronics. In future tests we plan to use cases like this to train students in statistical design.

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REFERENCES


Developing and Evaluating a Multiplayer Game Mode in a Programming Learning Environment

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Abstract—Serious games have an already well-known positive impact on students’ motivation and their learning experience. In computer science education a majority of games and approaches exist, that provide engaging environments for students. On the one hand, these can be games related to learning algorithmic thinking but on the other hand, games to learn coding. Besides single-player games, there are also multiplayer games where players compete against each other or collaboratively work on programming tasks. However, many existing multiplayer games offer pre-defined levels where teachers have limited flexibility and individuality for their students. Additionally, many existing game environments use competitive over collaborative approaches. In our project, we extended an existing game by a multiplayer mode where players work together on coding tasks. The game elements support many coding-related concepts but also computational skills such as sequencing, conditionals, loops, and also advanced topics such as concurrency or dependencies using meaningful levels and tasks. However, we conducted an evaluation including 41 participants in three workshops: two in-class activities with secondary school students and an online activity with computer science students. Within these workshops, the students collaboratively worked on coding tasks within the game environment. Thereby, we observed the communication between the students while working on the tasks. Additionally, we evaluated the students’ attitudes towards collaborative learning. We found out that the in-game chat is barely used while in-class activities, especially when the tasks require only low coordination between players. We also found out, that students learn from each other and are more motivated when working together. With our approach, we want to provide educators with a flexible game environment where students can collaboratively improve their coding skills while solving engaging tasks.

Index Terms—game-based learning, coding, collaborative learning

I. INTRODUCTION

In educational and professional settings a large number of collaborative approaches for coding exists such as programming workshops, Hackathons, or pair programming. These methods can increase the skills, creativity, productivity, and diversity of development teams. Specifically, collaborative programming is beneficial for beginners but also for experts to share experience and get insights about other perspectives. Working together has a long and important tradition in human culture. When working collaboratively people are more interested in solving tasks, achieving a better performance, and are more persistent in challenging tasks [1]. Social aspects such as motivation, or common goals are also relevant in computer games. First multiplayer games appeared already in the 1970s, as arcade games were played on arcade machines. The way people play computer games with each other has changed significantly over the past decades. The evolution of multiplayer goes from playing simultaneously on the same computer or console via a split-screen, or asynchronous in a hot seat mode to games over networks where each player has their own device. In multiplayer games, a basic distinction is made between competitive (two or more players compete against each other) and cooperative (two or more players aim to reach a goal together) [2].

In addition to the entertainment factor, computer games are also used in education as game-based learning. Various serious games in many fields try to engage and promote students in the corresponding topics. Similar to entertaining games, a large number of multiplayer games exist in the area of education as well. Even though cooperative methods tend to have a greater effect on learning achievements [3] and the motivation [4], a large number of tools exist that follow a competitive approach. Many authors point out the promising opportunities of collaborative educational games [5], not only to teach subject-related topics but also to increase the player’s social skills.

In this research, we introduce a collaborative learning approach for programming tasks and challenges in a game-based environment. Therefore, an existing game was extended by a multiplayer game mode. Prior research showed that there is a need for different educational contexts within the environment such as in-person or online modes. Therefore, we focused on a simple interaction between players in the system. To gain a better understanding of the game-based approach we conducted an evaluation with three groups. The following research objectives were defined in the scope of this study:

- How do students communicate in teams while collaboratively solving a programming task in the multiplayer game mode?
- What are the opportunities and challenges related to the player’s interactions within the game?
- How does a multiplayer game affect the student’s attitude towards collaborative learning?
The structure of all evaluations was equal, but the group of participants was different. Two evaluations took place as supervised workshops in school classes (3rd and 7th grade) and one was an unsupervised online study with computer science students. This research aims to evaluate a game-based learning approach and show its possibilities in education. Within this project, a central contribution is the design and implementation of the multiplayer game mode for the existing sCool environment. Additionally, we want to illustrate possibilities for an engaging approach to learn programming collaboratively.

This paper is structured as follows: Chapter 2 gives an overview of engaging collaborative learning approaches and tools. In Chapter 3 the sCool game environment is presented. Chapter 4 covers the three evaluations that were conducted within the project and in chapter 5 the results are presented and discussed. Finally, chapter 6 concludes the entire project.

II. BACKGROUND AND RELATED WORK

Learning to program is a complex process for beginners. It requires learning not just a language but also specific ways of thinking. Over the last decades, many different educational approaches have been developed to help novices. These aspects of programming learning are covered extensively in literature [6], [7]. The related research covers pedagogical models, discussions about programming languages for beginners, engaging tools and learning environments, and approaches of content delivery.

One central theory in the context of collaborative learning is the social cognitive theory [8]. According to Bandura people learn based on their own experiences and by observing the experience of other persons. When other people are observed a person tends to reproduce the learned behaviour. This type of collaborative learning is also relevant in introductory courses for programming [9]. When learning to program collaborative learning also indicates several advantages covering increased motivation, a better understanding of content knowledge, and improving soft skills. There are different approaches for collaborative programming learning such as peer review, pair programming or group activities [6]. These approaches also include the usage of engaging technologies such as serious games. Therefore, tools such as LightBot or Robocode are applied in education. These games are generally intended to be single-player games. Students can collaboratively work together on-site on tasks within the games in a pair programming setting [10].

There are also games where the game mechanic is dedicated to a multiplayer setting. An educational game where two players collaboratively work on a problem is Pyrus [11]. The system’s web interface displays a problem and provides users with an editor to submit code. The game is round-based which means that each player has a turn where he or she can contribute to the solution. The evaluation showed that the participants spent most of the time on planning and organizing than on coding. Furthermore, the players fail on effective collaboration, since they are not familiar with the process of pair programming.

An important element in computer-supported collaborative learning is the communication between team members. Fast-paced communication technology such as chats promotes instant communication. Related to this aspect an explicit goal is vital to have a clear aim for all team members [12]. Text messages in a chat could have an impact on programming tasks, since both use text. Therefore, an audio support using a microphone can be used instead [13]. Another key aspect in collaborative learning environments is a well-structured educational concept. Educators should provide students with clear goals, appropriate resources and feedback [9].

Games such as CodeWars are intended to be competitive games where players work on programming tasks simultaneously. While solving the tasks there is no interaction between the users. A similar platform is CodinGame where players are challenged to solve tasks. Again, there is no interaction between players during the tasks, but the platform provides an asynchronous communication where players can discuss solutions after a challenge [14].

Over the last years the number of research in the field of immersive learning environments in computer science education has increased. Pirker et al. [15] conducted a literature survey which gives an overview of various immersive approaches in computer science education. They also name different advantages related to immersive learning such as meaningful visualization to make complex topics (such as algorithms) more understandable, or social experiences related to collaboratively learning to program. One immersive video game is FunPlogs [16] where players create and solve puzzle-like programming tasks. The game consists of two scenes, a building and a scripting scene. Within the building scene students are collaboratively creating levels together, where one person is using a Desktop view and the other person is wearing a VR device.

Another game-based approach related to programming is the serious game sCool [17]. The game’s purpose is to engage students in coding and to increase their computational thinking skills. sCool consists of a web platform where educators can manage courses and players and the game itself. The web tool provides teachers with many features such as defining tasks, managing players, creating game maps, preparing in-game questionnaires, or doing learning analytics. All data from the web tool is transmitted to the video game, which provides a flexible and individual learning experience. The game is divided into a concept-learning part and a practical part. The concept-learning part introduces basic concepts of coding and computer science. Within the practical part, the players have to apply these concepts in coding tasks using the Python programming language. Since this game did not provide a dedicated multiplayer mode so far, the next chapter describes its design and development.
III. sCool Multiplayer Game Mode

While sCool provided the player with different gaming possibilities for the single-player mode, there was no way to play and solve puzzles together. Therefore, we designed and developed a multiplayer mode for the practical programming part of the game - also known as robot missions. Here, players are given the task to navigate a robot through a map and reach a certain goal while avoiding obstacles. This has to be achieved by writing code in the Python programming language [17]. Based on previous experiences and insights of the literature survey, the following requirements have been defined to provide a multiplayer mode:

- Integrate game elements to provide collaboration possibilities
- Allow educators to create multiplayer maps
- Provide real-time communication for players
- Creating and joining lobbies

A. Collaborative Game Elements

To encourage collaboration between players, new elements have been included in the existing game. With these new elements, it is possible for course designers to create challenges in which players rely on each other to advance in the level.

Doors and Triggers: For the first mechanic, a simple door was created. To open this door, a trigger has to be activated. This trigger is represented as a platform that can be located on an empty field on the map and must be activated by moving over it. The door and trigger have the same color as well as a line between them, to better understand the connection of these elements (see Fig. 1). This feature is a great asset for multiplayer and can also be used in single-player mode. In the online custom map creator, doors and triggers can be placed individually. When placing either of them, a number indicating the index will also show up. Doors and triggers with the same index belong together (see Fig. 2).

Wait and Signal: For the second collaboration element, the concept of threads in computer science was taken into account. Just like threads, the robots are able to work through their tasks concurrently. There might be a point where one thread has to be sure that another thread has completed a certain task, before moving on. A thread can therefore wait for a certain signal before resuming work. The same behaviour has been implemented for the robot missions. Players are able to wait for a certain signal until they resume their execution. Right now, there are two use cases for this: A certain path might lead both robots to get to the same field at the same time. This would lead to an undesired crash and a reset. One player would have to wait while the other can safely pass and then send a signal to wake the other up. The second use case would be to use it in combination with the door and trigger. These elements can be placed on the map in such a way, that requires one player to wait until the other robot activates the trigger and sends a signal that it is safe to move on (see Fig. 1).

The existing web interface allows educators to create individual maps by placing all available game elements on a 2D grid. The number of players is implicitly defined by the number of robots that are placed on the map.

![Fig. 1. This map shows the field for a two-player level. This mission requires coordination between the two players to activate the triggers to open doors.](image1)

![Fig. 2. Example for a map creation in the teacher’s web app.](image2)

B. Communication

Communication and interaction between players are vital parts of a collaborative multiplayer environment. The design of the gameplay requires communication between players to discuss strategies to solve the given puzzle. These strategies cover plans about dividing the tasks within a map, deciding on routes to avoid crashes, or which signals to use to share resources. Furthermore, communication can be used to ask for help and give guidance at a certain level. Players are also able to just chat with course colleagues using plain text messages. While all of these actions can be achieved through one channel, we decided to provide different channels. The first includes the whole course. Every player within a course can use it and will receive messages sent through it. The other channel is lobby-specific. Only players within a mission lobby can send and receive messages. A more private situation like this may encourage players to communicate with their partners in the lobby instead of all the participants in the course.

C. Architecture and Functionality

Fig. 3 shows the system’s architecture with all relevant components. On the one side, there is the game client.
Each course has its own endpoint and consists of several missions. For each mission, users are able to create lobbies on demand. A lobby holds information on current players, their code, and spectators. A user may choose to join as a player controlling a robot or as a spectator, simply watching others and being able to chat with them. When a player is done writing code for a mission, the code will be run locally and checked for errors. If there are no errors, the code is sent to the server and broadcast to other players and spectators in the same lobby, after having received all code snippets. This will then trigger the game to execute the code of each robot and start the movement.

All of the communication functionality for multiplayer mode was done with different message types such as joining or leaving lobbies, code updates, or regular chat messages. This was realized with a so-called Publisher-Subscriber pattern. Here, the incoming messages from the server (publisher) are distributed to all the components (subscribers), which are interested in getting updates about these messages. As an example, when a player joins a lobby the chat component will display a message, while the component for the robot mission will initialize the robot. All of these actions happen independent of each other. Integrating new features and/or new message types may also be done without interfering with the current functionality.

**D. Exploring Possible Learning Experiences**

sCool’s multiplayer mode opens up additional learning expenses. Using the web tool’s map generator, the missions can have a high level of freedom. The game elements are expanded by interactable elements such as triggers, portals, or coins but also non-interactable objects such as doors or boxes. Certain learning objectives can be realized quite easily through appropriate level design. By adding elements such as doors and triggers, or portals, the players can be encouraged to highly collaborate to solve a level. They have to coordinate themselves and their team members as well. This also requires a good understanding of the programming environment and increases computational thinking skills (see Fig. 4).

Fig. 1 illustrates a possible level design where collaboration between both players is absolutely required to reach the goal. Each player has to use the trigger (floor plate) to open the door and let the other player pass. Additionally, they have to coordinate about the correct timing, since pushing the trigger depends on an open door. Therefore, the players can apply the wait/signal concept. The idea of this feature is to illustrate synchronization between players.

**IV. Evaluation**

To evaluate the multiplayer game mode we conducted three evaluations. Two evaluations took place within a school class and the third as an online activity due to the COVID-19 pandemic situation with computer science students at the university. We were interested in evaluating the interaction and communication between the players and the student’s attitude towards collaborative learning of the game type.
A. Participants and Recruiting

Overall 41 people participated in this study. To receive a wide range of opinions the same evaluation was conducted with three different groups: a 3rd-grade secondary school (group A), a 7th-grade secondary school (group B) and university students studying computer science (group C).

With reference to diverse feedback, the project team attached importance to the selection of the participant groups. For the in-class activities, two partner schools of the research group were invited to participate in the study. One of the school classes (group A) is from a rural area, while the other class is an urban school (group B). The recruiting of the participants for the online study (group C) happened within the scope of a computer science introductory class. An email was sent to all students of the course and 9 have agreed to participate in the study.

Group A consisted of 19 students (4 female, 15 male) with an age range between 12 and 15 (M=13.36, Sd=0.76). In group B 13 students (7 female, 6 male) attended the evaluation, aging between 17 and 19 (M=17.61, Sd=0.77). Group C consisted of 9 students (all male) in the field of computer science (Bachelor, Master, and PhD students). They were between 21 and 32 years old (M=26.77, Sd=3.38).

B. Materials and Methods

At the end of the evaluation, the participants were asked to fill out a survey with 24 items in total. The answers were collected using an in-game questionnaire that is integrated into the game’s user interface. This approach allows asking questions without interrupting the player by changing the system.

The survey consisted of four parts: i) personal information (age and gender), ii) collaborative learning, iii) system interaction, and iv) general feedback. The questions related to collaborative learning are a modified version of Driver’s questionnaire [18] including 11 questions (see Table I). The items’ overall reliability was assessed by calculating Cronbach’s alpha (α=0.79). Thus, the value indicates a satisfactory internal consistency. The questions related to the system interaction are six statements on a Likert scale ranging from 1 (strongly agree) to 5 (strongly disagree). Due to the specific classroom situation of this study, the six questions of this questionnaire have been created by the authors to receive insights about the student’s interaction with each other. When testing for internal consistency for this questionnaire the Cronbach’s alpha has a value of α=0.6. Finally, the participants could answer three open-ended questions as general feedback covering aspects they perceived as positive and negative and give room for suggestions.

When starting the sCool video game the participants were informed that their data will be collected and analyzed for a scientific purpose. The players can decide if they want to confirm. In case they refuse the data collection and analysis they can play the game without any restrictions. Besides the participant’s age and gender, no personal information was collected. For this reason, it is not possible to link an answer to a participant which means all data is anonymous. One person of the project team who was not involved in the data collection was responsible for the data analysis to keep this process as objective as possible. The data was analyzed using the R programming environment.

C. Procedure

Even though the mode (in-class and online) of the workshops slightly differed from each other, the procedure was the same for all of them. All interventions took a total time of maximum 50 minutes. First, all participants received an introduction about the evaluation and the game. In both in-class activities, this explanation was held by a member of the project team. At the online workshop, the participants received all necessary information via a YouTube playlist (see Appendix) that was prepared by the project team again.

After the software installation, all remaining activities had to be done in the game which took about 40 minutes. After starting the game all participants had to go through the onboarding level to make themselves familiar with the user interface and the gameplay. Afterward, nine levels were provided: four basic levels with less collaborative purpose, two intermediate missions that required collaboration between the players and finally three advanced levels where a comprehensive coordination between the players was required. Besides the task numbers and categories Table II contains a list of all game elements that have been enabled for the specific levels. The column Intensity of Interaction defines to what extent interaction between the players was necessary to solve a task. The range is from None, which means that no interaction is necessary, over Little and Medium which means the players have to slightly coordinate their actions (within a few messages) to High which hardly requires a comprehensive strategy and cooperation to solve a task. All levels were designed for two players. The game mechanism allows to create a new game lobby or join one. As soon as two players are present in a lobby the game starts. The players are not aware of their partners in a game and get randomly assigned to a person to force them to mainly use the game chat for communication.

The players were asked to play at least the four basic and two intermediate levels. Afterward, the participants filled out the questionnaire about interaction and collaboration that was integrated into the game to encourage students to complete the questionnaire without being distracted by a change of platform.

V. FINDINGS AND DISCUSSION

A. Collaboration

The aim of this study was to let teams of two players work collaboratively on programming tasks. Three different groups of levels were offered, whereas the necessity for coordination between the players is increasing. The response of question C1 illustrates that communication was hardly required for the levels (M=2.41, Sd=1.22).

Obviously, the majority of the participants enjoyed the multiplayer mode, since they mainly agreed, that this is more
motivating than working alone (M=1.86, Sd=0.77). In the open-ended questions, 23 out of 41 participants (56%) additionally mentioned that they consider the multiplayer mode to be motivating and promising: "[I liked] the possibility to exchange within the chat [and] that I had to trust the other blindly if he did not answer in the chat. That was exciting!" (group A). When observing the suggestions for improvements participants mentioned, that waiting for partners might take a while: "you have to wait till the partner also executes the code" (group A).

When it comes to collaboratively working on a problem, there is a noticeable correlation (d=0.75, p=0.000) between variables C1 ("I communicated often with my partners") and C2 ("I always felt like being a team with my partners"). This indicates that participants that regularly communicated with each other during a mission felt stronger as part of the team. Another noticeable correlation (d=0.70, p=0.000) is between the items C2 and C9 ("I believe that I know my partners better now") which also emphasized on the positive effect of communicating within a team. The feeling of being part of a team (C5) has also a strong positive correlation (d=0.61, p=0.003) with fun when exchanging solutions in a team (C4).

When looking at feedback regarding the improvements, the responses from the school interventions (groups A and B) mainly suggest including game elements such as skins, items, or enemies. The results from the online evaluation (group C) compromises usability features (hide chat or faster onboarding level) and additional functionality (speed mode, voice chat, or code completion).

B. Chat Interaction

During all three evaluations, 370 messages were sent within the sCool in-game chat. The participants of groups A and B were located in the same room since it was planned as an in-class activity. The instructors told them that they can use the chat, but also communicate within the classroom. The game is structured in a way that players got randomly assigned to another partner in the next round since players do not see which player is in which game. This makes in-class interaction more inconvenient. In both groups the players used the chat mainly for entertaining purposes: 130 messages were sent in total and most of the conversation was not related to game activities. Since the communication in group C was mainly limited to an online mode it was used more often. The correlation (d=0.73, p=0.000) between the items C1 and I3 ("The communication via the chat was easy") also shows that participants are more likely to communicate with their partners via chat when they are able to handle the chat better. Overall 240 messages were transmitted in this group. The different usage of the chat also shows when comparing the mean values of question I2 ("I also communicated with my partners by talking") for each group. Due to the in-class setting of groups

### Table I

<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>I mostly used the chat for communicating with others.</td>
<td>3.05</td>
<td>1.43</td>
</tr>
<tr>
<td>I2</td>
<td>I also communicated with my partners by talking.</td>
<td>2.14</td>
<td>1.36</td>
</tr>
<tr>
<td>I3</td>
<td>The communication via the chat was easy.</td>
<td>2.27</td>
<td>0.83</td>
</tr>
<tr>
<td>I4</td>
<td>It was easy to discuss possible solutions via the chat.</td>
<td>2.77</td>
<td>0.92</td>
</tr>
<tr>
<td>I5</td>
<td>The handling of the chat was easy.</td>
<td>2.73</td>
<td>0.94</td>
</tr>
<tr>
<td>I6</td>
<td>It was fun being in a group with people, I would usually not be together.</td>
<td>2.14</td>
<td>1.08</td>
</tr>
<tr>
<td>C1</td>
<td>I communicated often with my partners.</td>
<td>2.41</td>
<td>1.22</td>
</tr>
<tr>
<td>C2</td>
<td>I always felt like being a team with my partners.</td>
<td>2.36</td>
<td>1.18</td>
</tr>
<tr>
<td>C3</td>
<td>I often discussed possible solutions with my partners.</td>
<td>3.00</td>
<td>1.31</td>
</tr>
<tr>
<td>C4</td>
<td>Exchanging possible solutions with my partners was fun.</td>
<td>2.23</td>
<td>1.02</td>
</tr>
<tr>
<td>C5</td>
<td>I had the impression that the players of a course saw themselves as a team.</td>
<td>2.82</td>
<td>1.14</td>
</tr>
<tr>
<td>C6</td>
<td>The discussions I had with my partners was important for understanding the solutions.</td>
<td>2.64</td>
<td>1.22</td>
</tr>
<tr>
<td>C7</td>
<td>I learned a lot from others during the game.</td>
<td>2.73</td>
<td>1.20</td>
</tr>
<tr>
<td>C8</td>
<td>I see a benefit in what I have learned.</td>
<td>2.59</td>
<td>1.01</td>
</tr>
<tr>
<td>C9</td>
<td>I believe that I know my partners better now.</td>
<td>3.41</td>
<td>1.26</td>
</tr>
<tr>
<td>C10</td>
<td>Solving tasks in a collaborative way is more motivating than solving tasks alone.</td>
<td>1.86</td>
<td>0.77</td>
</tr>
<tr>
<td>C11</td>
<td>Generally, I prefer to solve tasks alone.</td>
<td>2.91</td>
<td>1.06</td>
</tr>
</tbody>
</table>

### Table II

<table>
<thead>
<tr>
<th>Task</th>
<th>Category</th>
<th>Game Elements</th>
<th>Intensity of Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Basic</td>
<td>Boxes, Coins, Disks</td>
<td>None</td>
</tr>
<tr>
<td>#2</td>
<td>Basic</td>
<td>Boxes, Coins, Disks, Portals</td>
<td>Little</td>
</tr>
<tr>
<td>#3</td>
<td>Basic</td>
<td>Boxes, Coins, Disks</td>
<td>None</td>
</tr>
<tr>
<td>#4</td>
<td>Basic</td>
<td>Boxes, Doors/Triggers, Disks</td>
<td>Little</td>
</tr>
<tr>
<td>#5</td>
<td>Intermediate</td>
<td>Boxes, Disks, Wait/Signal</td>
<td>Medium</td>
</tr>
<tr>
<td>#6</td>
<td>Intermediate</td>
<td>Boxes, Disks, Wait/Signal, Doors/Triggers, Portals</td>
<td>High</td>
</tr>
<tr>
<td>#7</td>
<td>Advanced</td>
<td>Boxes, Coins, Disks, Wait/Signal, Doors/Triggers, Portals</td>
<td>High</td>
</tr>
<tr>
<td>#8</td>
<td>Advanced</td>
<td>Boxes, Coins, Disks, Wait/Signal, Doors/Triggers, Portals</td>
<td>High</td>
</tr>
<tr>
<td>#9</td>
<td>Advanced</td>
<td>Boxes, Coins, Disks, Wait/Signal, Doors/Triggers, Portals</td>
<td>High</td>
</tr>
</tbody>
</table>
A (M=2.57, Sd=1.55) and B (M=1.54, Sd=0.52) a lot of interaction took place in class, while in group C (M=3.00, Sd=1.73) more interaction took place using the chat. But the results of group C also shows that there was probably an additional channel for communication such as two fellow students working on the task together. The following chat snippet shows an exemplary conversation between two players:

- Player A: "You go first, and I will wait."
- Player A: "And you are sending me a signal then?"
- Player B: "I try..."
- Player A: "Which signal name? ESP? :D"
- Player B: "Amen"
- Player B: "alright"
- Player A: "Nice :D"
- Player B: "well done :D"

When observing the suggestions for improvements some participants mentioned, that their partners did not respond on chat messages: "that the probability of getting an answer from my team partner in the chat was 50/50" (group B).

One aspect related to chat and interaction is the approach that students are randomly assigned to other players. The idea was to shuffle team members to have diversity in the group constellations. Players should benefit from various opinions and solutions. Question 16 was related to the students’ acceptability about random groups. They respond that it was fun for them to play with people they would usually not work together (M=2.14, Sd=1.08). Remarkably, the online group, in particular, noted that they sometimes had difficulties with the operation of the chat window, as it sometimes overlaps the game. Since approximately 65% (240 out of 370 messages) of the total chat messages came from Group C, there is more feedback from this group related to the chat. Although the chat was noted almost equally positively and negatively, some of the participants indicated in the feedback that they would like to see a voice chat. Since the coding activities are already text-based a chat might have a negative impact on the collaboration. Silvia et al. [10] made similar observations and suggest microphone support as well.

The design of the levels hardly influences the need for communication. The first half of the levels were mainly intended to have no direct need for communication, and the second half required more coordination of the participants.

### VI. Conclusion and Future Work

In this paper, we have introduced a multiplayer mode for the serious game sCool. The game mode’s objective is to combine the advantages of collaborative multiplayer gaming with an engaging learning environment to increase the students’ engagement and skills in programming. Furthermore, we have conducted evaluations with 41 participants in three groups, two in-class activities with school students and one online activity with computer science students. The results showed that the collaborative learning approach of the game is motivating. The in-game interaction between the players, especially in class settings, shows room for improvement. Due to the game mechanics and the duration of each level a dedicated voice communication seems to be inappropriate.

#### A. Limitations

The selection of the participants was based on a diverse group of people, to receive various feedback. Each group consisted of a number between 9 and 19 participants, whereby the mode of the intervention was also different (in-class and online activity). In this way, it is not possible to make significant assumptions related to group-specific features such as performance, interaction, etc. Therefore, we plan to run further evaluations with a larger population of each group and similar conditions. This allows having a study design where comparisons between groups can be measured to gain further insights into the learning experience of the groups.

#### B. Future Work

In a future version of the game, we will also consider the participants’ feedback for an improved game. The chat interaction will be optimized to have on the one side a lightweight user interface and on the other side more expressive interaction for instance arrows to point to specific areas within the game. We will also include further game elements that emphasize collaborative learning such as pressure plates, or additional signals.

The focus of this evaluation was to evaluate the novel game mode regarding interaction and the participants’ attitude towards collaborative learning. In the next iteration, we plan to run evaluations that go beyond the scope of single workshops, to investigate long-term effects. This extended study design should give further insights into the students’ performance related to the collaborative game mode.

### APPENDIX

#### ADDITIONAL RESOURCES

The participants of the online study were provided with the following YouTube playlist to get all the necessary instructions: https://youtube.com/playlist?list=PLgkLPu4Kf-pmVnElLiHkYZ13XKf3O1UD

### REFERENCES


From Users to Creators: Motivations, Implementation, and Impacts of Augmented and Virtual Reality in Science and Engineering Projects in K-12 Education

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Abstract—Current research on immersive technologies has widely described their application in K-12 settings, with evidence of their goals, approaches, and potential to enhance learning. However, there is a dearth of studies describing those technologies being used as authoring tools by students. This paper investigates how K-12 students apply virtual and augmented reality technologies as tools for designing experiments and solutions for their science and engineering projects. Study 1 analyzed 12 projects presented at a FEBRACE national science fair between 2015 and 2020 and Study 2 investigated, via an online questionnaire, the motivations and influences from students who worked on those projects. Results include the context in which the projects were developed, motivation for using virtual and augmented reality technologies, fields in which they were applied, and types of software and hardware used. Findings inform how future research can build on those experiences to integrate immersive technologies in K-12 education.

Index terms—virtual reality, augmented reality, authoring tool, k-12 education, STEM

I. INTRODUCTION

Immersive technologies can provide a rich and interactive environment that allows users to experience and explore a variety of simulations. Immersive virtual reality (VR) has shown significant results when applied to situations that in person would be dangerous, impossible, or expensive [1]. Immersive VR and augmented reality (AR) enable users to interact with the digital content more naturally than other media, enhancing their exploration behavior. Due to their affordances, there has been increasing interest in using these and other types of extended reality (XR) technologies for learning and education [2], [3].

There is already an extensive body of research demonstrating the potential of AR and VR technologies to support and to diversify learning experiences in K-12 Education (e.g. [4], [5]). As AR and VR extend the sensorial environment of learners by mediating reality via technology, they allow new possibilities of interaction with concepts that are abstract or non-accessible in traditional media [6]. Although they surely provide meaningful learning experiences with technology, their use in K-12 educational settings do not necessarily fit the current expectations of how students can use computational environments as authoring tools to express their hypotheses and ideas [7]. In addition, there is little documentation on the research on K-12 students not only using ready-made AR and VR applications, but also designing projects that benefit from those technologies.

However, as we present in this paper, projects presented by K-12 students in science fairs in Brazil provide concrete examples of immersive technologies being used to support scientific inquiry or to solve real-world problems. Building on those examples, we investigate how K-12 students apply AR and VR technologies as tools for designing experiments and solutions, their motivations and influences on and of using AR and VR as authoring tools.

II. RELATED WORK

Various studies, including recent literature reviews, have described the potential and impact of immersive technologies in K-12 educational settings. After systematically reviewing 21 studies targeting primary and secondary education, Pellis and colleagues [8] suggested that mixed reality (MR) technologies are usually associated with the learning of science to bring abstract concepts to life. Similarly, Mass et al. [4] identified five common themes among 29 reviewed studies: students reporting a positive attitude towards learning after interacting with those technologies, increased motivation to learn, increased engagement in learning activities, improvement in learning outcomes, and the development of 21st century skills.

Additional reviews investigated the application of more specific XR technologies to K-12 educational settings and reported similar results. For example, Queiroz and colleagues [9] identified that studies targeting the use of VR HMDs on K-12 education generally reported positive learning outcomes in students’ performance, especially when associated with the development of specific skills. Targeting K-12 students’ science
learning and programming skills, Metcalf and colleagues investigated the cognitive and affective outcomes of a blended immersive and computational modeling tool with elementary students [10]. They developed and investigated the impacts of a 3rd-grade curriculum that blends a 3D virtual ecosystem, a 2D visual programming and a modeling environment. They found that it was effective in learning ecosystem science content and practice.

Due to the high costs of technology and content development, most studies investigating VR on K-12 education used experiences developed by experts. Concerning studies using AR, there is a concentration of studies focusing on higher education, with few studies targeting vocational education [11]. However, with the recent significant reduction in equipment and development costs, AR and VR technology has been increasingly adopted in domestic settings (in 2021, more than 10 million VR headsets were sold and 90% of the smartphones were AR ready [12], [13]). Also, with accessible and free development tools available and free tutorials online, people have been able to develop immersive experiences from home. Ashtari and colleagues [14], in their study focusing on AR and VR developers, found that accessible tools and learning materials are crucial to development in both formal and informal creations.

However, there is a dearth of research reporting the use of immersive technologies as authoring tools in K-12 educational settings [14], [15]. For instance, Vert and Andone [16] propose a set of criteria for educators to choose among VR authoring tools, from those that enable collaboration among authors to those that integrate 3D models libraries, targeting higher education settings. Likewise, Nebeling and Speicher [17] classify existing authoring in AR and VR, based on the levels of fidelity, skills and resources required, and identify two issues to make authoring more accessible: creating high quality content and models, and programming interactions among those entities. Although the authors propose two new tools to address these issues, no actual experience with novice learners is reported.

III. STUDIES OVERVIEW

This investigation encompasses two studies with a mixed methods design. Study 1 is a descriptive content analysis of projects submitted to FEBRACE (acronym in Portuguese for Brazilian Science and Engineering Fair) from 2015 to 2020. Study 2 is survey research in which quantitative and qualitative data were collected by an online survey distributed to team members of the projects in Study 1.

FEBRACE is a major outreach program from the Universidade de São Paulo, Brazil, launched in 2003 to promote scientific culture and entrepreneurship in Science, Technology and Innovation, in K-12 educational settings. Besides supporting local science fairs and providing professional development for teachers throughout the country, FEBRACE holds the largest nationwide science fair in Brazil.

In order to join the annual fair, teams, up to three students, submit their science and engineering projects for evaluation by the judging committee (composed by professors, researchers and professionals). Each submission includes a paper or report and a five-minute video presentation. Once selected, students present their project in a synchronous event and undergo an additional round of evaluation and feedback. Outstanding projects are then selected to join ISEF, the International Science and Engineering Fair. students and teachers from more than 1,200 cities from all states have already joined thFEBRACE, with an average of 2,300 projects submitted by year between 2015 and 2020 (range included in this study).

IV. STUDY 1

A. Methods

Data collection and analysis encompassed two phases: (1) identifying projects that applied AR and VR technologies from projects submitted to FEBRACE, (2) collecting and analyzing data from these projects’ reports.

We adapted protocols from the systematic literature review (SLR) [18] to implement phases 1 and 2, since they required clear guidelines to analyze data from students’ reports. Here, the research question that guided the review was “What do K-12 students do when they build science and engineering projects with AR and VR tools?”, and the data sources were yearly FEBRACE proceedings, which contain the title, keywords and abstract for projects presented, made publicly available in the official science fair website [19]. The search strings “augmented reality” and “virtual reality” were used to locate projects at FEBRACE proceedings for further analysis. The search included 2041 projects from 2015 to 2020, from which a total of 12 projects were identified. Only projects that mentioned the development of XR experiences in the abstract were included. All the 12 projects passed the inclusion criteria for analysis.

In addition, the FEBRACE organizing committee provided the reports from the 12 projects; the reports were submitted by students before presenting at the fair, in a double-column format, varying from three to eight pages. The authors applied the following evaluation criteria: setting in which the project was developed (public, private and/or vocational school); kind of immersive technology used in the project (VR, AR, or both); theme in which the project was developed, as well as core scientific ideas explored in the project; software and hardware used in the project.

B. Results

Table I presents a summary of the 12 projects found in the analysis, including: year presented; a description; the school type (“school”), if private (priv), public (pub), vocational (voc); and application area (“area”), that is, the field with which the project mostly relates to. Additional data is provided on an online repository (https://bit.ly/ilrn2022-users-creators).

Projects’ descriptions show that AR technologies were the most common among projects, included in 9 projects. In addition, proportion of public schools (66.7%) follow average numbers in FEBRACE (e.g., 72% in 2020), with significant number of vocational schools (10). Finally, projects surrounded two major areas: using AR and VR technologies to facilitate learning of specific concepts, particularly from STEM fields, and applying AR and VR technologies to advance research and practice in health care.

Fig. 1 presents the different types of software and hardware related to AR and VR used in the projects. Unity and Blender
were the most common software used on the projects, even though they usually require advanced computing knowledge; besides, Vuforia showed to be a promising environment for K-12 students to develop AR applications. Among the hardware, the predominance of smartphones indicates their potential to make AR and VR technologies more accessible. Finally, it is worth mentioning that five XR headsets were identified, all from different models, which suggests their availability in specific settings were essential to the use of those technologies.

### TABLE I. SUMMARY OF PROJECTS SELECTED IN THE STUDY

<table>
<thead>
<tr>
<th>N</th>
<th>Year</th>
<th>Description</th>
<th>School</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2015</td>
<td>Using an interactive screen with AR to help events increase their social media engagement.</td>
<td>pub, voc</td>
<td>Marketing</td>
</tr>
<tr>
<td>2</td>
<td>2016</td>
<td>Developing a tool with AR and image processing to assist nurses perform venipuncture.</td>
<td>priv, voc</td>
<td>Healthcare, medical procedures</td>
</tr>
<tr>
<td>3</td>
<td>2017</td>
<td>Developing an AR tool to support the learning of topography as students interact with sand tables.</td>
<td>pub, voc</td>
<td>Education, learning of topography</td>
</tr>
<tr>
<td>4</td>
<td>2017</td>
<td>Designing a mobile app with AR to provide interactive visualizations of a cellular structure.</td>
<td>pub, voc</td>
<td>Education, learning of cytology</td>
</tr>
<tr>
<td>5</td>
<td>2018</td>
<td>Designing a mobile app with AR to provide interactive visualizations of cellular division.</td>
<td>priv</td>
<td>Education, learning of cellular division</td>
</tr>
<tr>
<td>6</td>
<td>2018</td>
<td>Using a sensory device as an AR tool to provide navigation independence to people with visual impairments. Designing a VR environment to run their solution.</td>
<td>pub, voc</td>
<td>Healthcare, visual impairment</td>
</tr>
<tr>
<td>7</td>
<td>2018</td>
<td>Performing mirror therapy using AR integrated with smartphone cameras.</td>
<td>pub, voc</td>
<td>Healthcare, medical treatments</td>
</tr>
<tr>
<td>8</td>
<td>2018</td>
<td>Developing VR and AR resources to support the learning of construction engineering.</td>
<td>pub, voc</td>
<td>Education, learning of construction engineering</td>
</tr>
<tr>
<td>9</td>
<td>2019</td>
<td>Designing a VR environment to support therapy for phobia treatments.</td>
<td>priv</td>
<td>Healthcare, medical treatments</td>
</tr>
<tr>
<td>10</td>
<td>2019</td>
<td>Designing an app with an AR to provide extended visualizations of chemical reactions.</td>
<td>pub, voc</td>
<td>Education, learning of chemical reactions</td>
</tr>
<tr>
<td>11</td>
<td>2020</td>
<td>Designing VR immersions in the Amazon Forest to foster students' interest.</td>
<td>priv, voc</td>
<td>Education, learning of ecosystems</td>
</tr>
<tr>
<td>12</td>
<td>2020</td>
<td>Designing a game with VR to simulate an expedition to the outer space.</td>
<td>pub, voc</td>
<td>Education, learning of astronomy</td>
</tr>
</tbody>
</table>

V. STUDY 2

A. Methods

To expand the research from Study 1, Study 2 investigated “What are the motivations, requirements and challenges for using XR (AR and VR) as an authoring tool for learning?” We designed a questionnaire with demographics, open-ended and Likert-scale questions. We invited participants from the projects we analyzed in Study 1 to answer the online survey. All the questions are available on an online repository (https://bit.ly/1ln2022-users-creators) and their respective variables investigated are presented as follows:

- **Previous experience (PE):** two 5-point Likert scale questions on how often they had interacted with and developed content using AR or VR technologies.
- **Choosing the technology (CT):** one 5-point Likert scale question on when students decided to use AR or VR in their projects.

![Fig. 1. AR and VR hardware and software.](image)

- **Access to resources (AcR):** three 5-point Likert scale questions on the importance of different resources (devices, experts, tutorials) to the development of tools with VR or AR.
- **Programming skills (PS):** two 5-point Likert scale questions on the impact of programming skills on the project design.
- **Learning transfer (LT):** three 5-point Likert scale questions on to what extent the knowledge gained in developing the project to the science fair was transferred to other contexts.

Additionally, eight open-ended questions investigated participants’ (a) motivation for using AR and VR, (b) authoring tools choice criteria, (c) consulted instructional materials, (d) development process, (e) programming languages, (f) challenges, (g) lessons learned, (h) general AR and VR use after the project conclusion.

The questionnaire showed to be an appropriate approach, given the total number of students (29) and its potential to provide comparable straightforward information [20]. However, by the time of the publication, we had responses from 6 participants (4 male, 2 female) from 4 projects. We assume the major challenge to hear from them was the long period of time since they joined FEBRACE (up to six years).

B. Results

Table II presents the results for the Likert-scale questions, with responses ranging from 1 to 5 according to the scale used in each item (e.g., “1” can refer to “never”, “not at all” or “strongly disagree”, depending on the question). Although any conclusions are limited to the small sample of responses, there were strong consensus in some of the items, such as no prior experience with creating artifacts with AR or VR before the project, and the importance of having access to tutorials.

We next present a summary of content analysis of answers related to each variable investigated by open-ended questions.
• (a) Motivation for using AR and VR: the answers emphasized the AR and VR affordances in visualization and prototyping (e.g., “[we] realized that some students had extreme difficulty in visualizing microscopic levels of chemistry, which can be facilitated with VR/AR”).

• (b) Authoring tools choice criteria: access to hardware and software was listed as an important aspect in selecting the authoring tools (e.g., “…we had several hardware available at the institution lab, which facilitated the project development”).

• (c) Instructional materials: online tutorials were listed by all the participants as crucial to learning how to use the authoring tools and develop the project.

• (d) Development process: all the respondents reported that the main AR and VR assets were developed from scratch, particularly specific 3D models.

**TABLE II. RESULTS FROM LIKERT-SCALE QUESTIONS**

<table>
<thead>
<tr>
<th>Variables</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE: interacting with AR or VR</td>
<td>50%</td>
<td>17%</td>
<td>17%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>PE: creating with AR or VR</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT: problem-driven design</td>
<td>17%</td>
<td>50%</td>
<td></td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>AcR: importance of devices</td>
<td></td>
<td>17%</td>
<td>83%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AcR: importance of experts</td>
<td>17%</td>
<td>50%</td>
<td></td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>AcR: importance of tutorials</td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS: requiring new skills</td>
<td></td>
<td></td>
<td></td>
<td>67%</td>
<td>33%</td>
</tr>
<tr>
<td>PS: difficulty to use</td>
<td>33%</td>
<td>50%</td>
<td></td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>LT: relevance in other contexts</td>
<td></td>
<td></td>
<td>50%</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>LT: using the tool after fair</td>
<td>17%</td>
<td>67%</td>
<td>17%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT: new tools with AR or VR</td>
<td>17%</td>
<td>50%</td>
<td>17%</td>
<td>17%</td>
<td></td>
</tr>
</tbody>
</table>

* never / not at all; strongly disagree; rarely / slightly / disagree; sometimes / somewhat / neutral; frequently / moderately / agree; always / extremely / strongly agree.

• (e) Programming languages: participants listed C as the main programming language required from them to learn, together getting familiar with Unity commands.

• (f) Challenges: participants pointed out a variety of challenges during the design process, such as: finding free resources available, learning how to use Unity, and making sure their creations were based on the correct representation of scientific ideas.

• (g) Lessons learned: in addition to learning technical skills, participants also highlighted the importance of understanding the potential of AR and VR in other fields, particularly in education (e.g., “by using AR in our project, we could notice it will be a great ally to teaching and learning in the near future”).

• (h) General AR and VR use after the project conclusion: one-third of the respondents did not use AR and VR after presenting their project; one-third kept working on their projects for a while and one-third designed additional projects with AR and VR.

**VI. GENERAL DISCUSSION**

Two complementary studies were run to investigate how K-12 students use AR and VR as authoring tools in their projects for a science fair, their context of use, motivations, challenges and learning outcomes. In Study 1, we found that most projects used AR rather than VR technologies. Qualitative data from Study 2 indicated that this choice was influenced by the accessibility of the technology, since both hardware (smartphones) and software (development apps) for AR development are more accessible than VR ones.

Interestingly, Study 1 indicated that most projects (10 out of 12) were developed in vocational schools. Bacca and colleagues [11] systematically reviewed studies using AR technologies for education and found that only 3.1% of the studies were carried out in vocational schools. In Brazil, around 9% of high school students take their regular high school courses integrated with a vocational track, for specific technical skills or jobs [21]. Our finding suggests that vocational schools make AR and VR more accessible to students when compared with regular schools, probably as a strategy to help them gain familiarity with emerging technologies relevant to job market. Previous studies show that a considerable percentage of professional AR and VR developers did not have a formal training in design methods before landing on the job [14]. This finding indicates an opportunity in terms of research and practice, which could leverage the vocational preparation to the job market. In that sense, a literature review targeting AR in Vocational Education suggested that AR could serve as a bridge between vocational and mainstream education [22]. Also, the authors pointed out the potential of AR in developing skills required for the future workforce that go beyond programming and include constant adaptability and autonomous learning.

In Study 1, several projects targeted health care and marketing issues, indicating that the students looked for problems outside the mainstream K-12 education, contributing to transferring the K12 education knowledge to professional environments. Also, in Study 2, most respondents reported learning outcomes from the project were relevant in other contexts, and four of them kept working on their projects or developed additional projects using AR and VR. These findings are aligned with the literature about the potentials of AR and VR in K-12 education [11], [22], and bring examples of learning transfer from authoring AR and VR in K-12 education, particularly at vocational schools.

Concerning motivations in developing AR and VR, our findings are aligned with previous studies targeting AR and VR developers [14] and show that the main motivations related to the AR and VR affordances in visualization, prototyping and the innovation aspects of these technologies. In addition, students used AR and VR to develop projects that strongly resonate with core ideas in Science Education. This result corroborates findings from Queiroz and colleagues [9], which identified most applications of immersive VR in K-12 settings targeting learning experiences in STEM.
Study 1 indicated that requiring programming and modeling skills did not hinder students to choose sophisticated tools to design AR and VR projects, such as Unity and Blender, and Study 2 pointed out the importance of developing cost-free technologies to foster their use. Also, all participants in Study 2 reported developing main AR and VR-related components from scratch, which aligns with previous studies reporting the lack of user-friendly authoring tools that support the development of educational experiences [23]. These findings are also evident in our participants’ report that C (a complex programming language) was the most used language to develop the projects, indicating the need for specific programming skills in AR and VR authoring.

In Study 2, we found that all the participants reported access to free tutorials and videos as key to support the use of authoring tools in AR and VR. This finding corroborates Ashtari and colleagues’ study [14] in which AR and VR creators reported to heavily rely on these types of instructional materials. Those results suggest that developing accessible online resources might be an effective strategy to promote the design of AR and VR in K-12 settings.

Moreover, although accessibility and cost seem typical aspects to consider when deciding the technology to support XR projects development, this is not well documented in the literature. Ashtari and colleagues [14] reported technical aspects and project specificities as the main elements driving software and hardware decisions in AR and VR projects. Aligned with Ashtari and colleagues [14], participants from our study also mentioned technical difficulties in the project as drivers of tools’ choice. Still, the main elements considered in choosing the authoring tool and hardware were cost and accessibility. This finding suggests that probably because K-12 students usually rely on the parents/caregivers’ finances, the costs assume a central role in the decision-making process.

VII. LIMITATIONS

The main limitations of this work include the specific context in which the study was conducted, since science fairs do not necessarily represent the aspects of a regular K-12 educational setting. Hence, the results illustrate the potential of what students can achieve when access to emerging technologies and opportunities for true scientific inquiry are provided. Additionally, the number of projects analyzed (12) represent less than 1% of the projects presented at FEBRACE during the time range of this study. Besides indicating that AR and VR technologies are far from being popular in K-12 settings, the small sample of projects make it difficult to identify consistent patterns or trends on their characteristics. Finally, the low number of responses in Study 2 limits any claims based on that data; instead, they should serve as an initial step for further research in the field.

VIII. CONCLUSION AND FUTURE DIRECTIONS

Current research on immersive technologies has widely described their application in K-12 educational settings, with evidence of their multiple goals, approaches and potential to enhance learning. This paper contributes to the field of AR and VR in K-12 education by providing concrete examples of how students have been using those technologies as authoring tools to their science and engineering projects. Those examples were detailed in terms of their key features, motivations, challenges and outcomes. Moreover, this study can inform future research and practice on how to promote a different role for students when they interact with immersive technologies, from users to creators.

Next steps for this study include extending the search for upcoming years of FEBRACE, trying out different strategies to engage more participants with the questionnaire, and conducting interviews with participants to gather more nuanced information in their design process with AR and VR. Besides, preliminary findings suggest different opportunities for research, such as what K-12 students learn as they create tools with AR and VR, and which resources and strategies can be designed to promote a broader use of those technologies in K-12 education.

ACKNOWLEDGMENT

We thank students and teachers who developed the projects which this study is based on, particularly those who shared additional thoughts via the questionnaire. We also thank the FEBRACE organizing committee for their support, giving access to project team members and their reports.

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Framework for Scalable Content Development in Hands-On Virtual and Mixed Reality Science Labs

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Abstract—Authentic hands-on laboratory research is essential for undergraduate STEM education. Yet the tactile authenticity required to impact affective, cognitive, or psychomotor learning outcomes associated with laboratory training remains underexplored. Virtual and mixed reality (VR/MR) have enabled increasingly realistic hands-on STEM training experiences. However, they still lack authenticity with regard to user manipulation of fully functional and realistic laboratory tools, analysis of realistic (i.e. user-acquired) noisy data, and the application of critical thinking skills to draw conclusions from such noisy (and possibly faulty) data. Here we present efforts to develop such an approach while also providing faculty content experts tools for code-free customization of VR/MR training experiences via structured spreadsheets. This approach enables nuanced real-time user feedback on laboratory skills such as proper pipetting or sterile technique which are otherwise difficult to provide. It also offers complete safety from chemical, biological, and radiological hazards and is more cost-effective than a traditional lab. This Hands-On Virtual-Reality (HOVR) Lab platform is uniquely enabling and will be valuable in the physical and life sciences for both research and instructional applications.

Index terms—Mixed-reality, virtual-reality, STEM education, science labs, optical tracking, multi-disciplinary uses of XR

I. INTRODUCTION

Active learning is well-suited to meet the wide range of learning needs of modern STEM learners [1]. It reinforces the concepts that students passively absorb from lectures or textbooks by promoting the higher-level critical thinking skills (i.e. application, evaluation, analysis, integration, and ultimately creation of knowledge) that are central to actually “doing” science. In this context, one-on-one mentored research experiences are the ultimate active learning experience because they are fully authentic and span the full range of higher-level critical thinking skills including the creation and presentation of new knowledge. Students appreciate this, and are highly engaged, motivated, and impacted as a result. Unfortunately, resource limitations make it difficult to provide all students with one-on-one mentored research experiences.

Less resource-intensive alternatives, such as course-based undergraduate research experiences (CUREs) have proven to be a useful lower-cost alternative or complement to one-on-one mentorship [2]. Here we present preliminary data for another alternative which can be scaffolded with both CUREs and one-on-one research mentorship to make achieving desired learning outcomes more scalable and cost-effective. Our novel approach uses virtual and mixed-reality (VR/MR) technology, 3D printing, and high-precision motion tracking of hand-held laboratory tools to enable a highly authentic yet tightly tracked, regulated, and safe STEM laboratory training environment.

In this system, students can practice lab procedures by interacting with virtual content using either VR controllers or optically tracked but otherwise completely authentic hand-held physical lab tools. Student manipulation of these physical lab tools, the acquisition of raw data using them, and the processing and analysis of this raw data is tracked in real-time with millisecond temporal resolution and sub-millimeter spatial resolution. Importantly, complete programmatic control over the signal, noise, and calibration state of all the instruments and
tools in the virtual environment together with the high-resolution tracking of user interactions described above enables the provision of real-time feedback not only on whether users are collecting data correctly, but also on whether they are analyzing and drawing appropriate conclusions from this data. This approach is cheaper, safer, easier to implement, and can provide more detailed feedback than traditional face-to-face laboratory instruction. With institutional support and investment, students can use this approach to conduct STEM lab training activities at their own pace and on their own schedules — while still gaining fully authentic hands-on exposure to scientific instruments, tools, and methods.

II. RELATED WORK

Many STEM virtual lab simulations use low-immersion web-based 2D displays and highly inauthentic user interaction (UI) mechanisms (e.g. computer keyboards and mice) [3]–[5]. The relatively few high-immersion (i.e. 3D) STEM virtual learning systems that do exist are generally fully VR with three or six degree-of-freedom (3dof or 6dof) universal hand-held controllers mediating UIs with all objects in the digital environment [6]–[8]. The generality of these controllers unfortunately, makes them ill-suited to serve as authentic surrogates for all actual hand-held lab tools. Because AR systems overlay digital content over the real world, they are similarly limited by their dependence on actual physical instruments that are not subject to programmatic control. In addition, generating authentic hands-on STEM lab experiences in such systems requires tracking real-life lab tools with computer vision methods — which are both expensive and limited with respect to tracking resolution. Finally, in such systems the reagents used must be real (a safety concern) and detectable by the computer vision cameras employed (a significant challenge). Together these limitations make AR less well suited for STEM laboratory training applications. No existing platform offers the essential tactile/kinesthetic force feedback and level of authenticity required for college-level physical and life science laboratory instruction.

To meet this need, we have developed the Hands-on Virtual Reality Lab (HOVR Lab) mixed reality system. We have applied it here to chemistry and biochemistry lab training situations and outline a discipline independent framework for scalable content development that will enable rapid creation of customized training experiences for diverse student populations by faculty content experts with little to no coding experience.

III. HANDS-ON VIRTUAL REALITY LAB SYSTEM DESCRIPTION

The HOVR LAB mixed reality system consists of three major components. First, it employs a dual-mode lab tool UI framework which enables fluid and customizable switching between VR-mode (i.e. controller-mediated) and MR-mode (i.e. physical lab tool-mediated) control of each lab tool that is deemed critical to psychomotor skills acquisition. Second, it employs a scalable Unity3D back-end software system which 1). detects the 3D poses of all VR controllers and physical lab tools being manipulated during data acquisition as well as any other standard user interactions, 2). outputs simulated raw data to the user via virtual instruments in the lab environment, and 3). assesses the user’s performance in recording, analyzing, and interpreting this data. Third, the HOVR Labs system has a faculty content-developer front-end consisting of a customizable

![Fig. 1. The Hands-on Virtual Reality Lab system front-end design for student users. The figure shows the lab bench, lab tools (used to manipulate samples), and lab instruments (used to output recordable raw or processed data). Students view the virtual lab bench via a head-mount display (HMD) and interact with the virtual content using either VR controllers or optically-tracked hand-held physical lab tools (see below).](image1)

![Fig. 2. Physical lab tools are optically tracked using 5-point IR retroreflective bead marker sets mounted onto lab tools in a non-perturbative manner via 3D printed adapters. The adapters are designed to minimize marker occlusion and interference with lab tool use.](image2)
Lab “tools” are visible on the shelf and on the lab bench. These include pipettes, beakers, tip racks, reagent bottles, and many other hand-held objects. Students use the lab tools to transfer reagents (which are never touched and thus completely virtual) and perform chemistry experiments by following the step-by-step instructions defined by the faculty content developer in the Lab Module Generator and presented to the student user on the display. The precision and accuracy of each lab tool can be controlled programatically but is also dependent on the user’s (proper or improper) manipulation of the lab tool. Lab “instruments” are defined as lab tools that also serve as sources or sinks of raw or processed data that the user can/must eventually record in their lab notebook. Examples of lab instruments include a scale, a desktop computer running an instance of Microsoft Excel, and a calculator.

<table>
<thead>
<tr>
<th>Objective #</th>
<th>Task Descriptor</th>
<th>Objective Type</th>
<th>Objective Level</th>
<th>Tool</th>
<th>Tool Type</th>
<th>Variable</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Dispense 500ml of water from the ultrapure water dispenser into a 1L Beaker.</td>
<td>Physical</td>
<td>Introductory</td>
<td>1L Beaker</td>
<td>Container</td>
<td>Total_Volume (ml)</td>
<td>500</td>
</tr>
<tr>
<td>1</td>
<td>Place the weighing boat onto the scale.</td>
<td>Use-Scale</td>
<td>Introductory</td>
<td>Scale</td>
<td>Instrument</td>
<td>Contained_Tools</td>
<td>Weighing Boat</td>
</tr>
<tr>
<td>2</td>
<td>Now tare the scale.</td>
<td>Use-Scale</td>
<td>Introductory</td>
<td>Scale</td>
<td>Instrument</td>
<td>Displayed_Mass (g)</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>Pick up the P20 pipette and set it to 20.0 ml using the &quot;Set Pipette&quot; menu on your left hand's wrist.</td>
<td>Use-Pipette</td>
<td>Introductory</td>
<td>P20 Pipette</td>
<td>Pipette</td>
<td>Set_Volume (ml)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Fig. 3. Example of a section of a Lab Module Generator spreadsheet. Each row defines one snapshot of the virtual world during the lab procedure where the selected variable on the selected lab tool has a particular target value. The task description, logical criteria to be met, and feedback are parsed into the Unity3D simulation software on start-up. When students submit results, the corresponding tool and target value of its variable will be used to check if the student performed the task correctly. Data validation logic is programmed in the Excel which allows the chemistry and bio-chemistry content developers to efficiently make a lesson plan by selecting from a predefined list of task types, lab tools, and variables (Only a small part of the Excel is shown in the above picture due to limited space).

The overall lab experience is broken down into a set of “milestones” each originating from a separate row of the Lab Module Generator spreadsheet. Each milestone defines one or more conditions that must be met in order for the student to progress through the lab experience. At each milestone, the student user reads the instructions on the display, performs the specified task, indicates their readiness to be assessed on their performance of the task, receives positive or negative feedback, and then either proceeds to the next milestone or is invited to either re-attempt the task or – if necessary - re-acquire their data. Throughout the experience, the student user records raw or analyzed data into a virtual lab notebook at milestones pre-specified in the Lab Module Generator spreadsheet. Acquired and recorded datapoints can be used in subsequent data analysis milestones in order to assess the user’s analysis of their data. Data entry into the notebook is done using menus that are specific for the data required for that milestone (e.g. a numeric keypad, multiple choice selections from pre-defined options defined within the Lab Module Generator spreadsheet by the faculty content developer, etc.). In some milestones, data analysis is done using Microsoft Excel running on the GPU computer that is also running the experience.

Each lab tool, instrument, or derivative “datapoint” has associated with it an accuracy (i.e. systematic error), a precision (i.e. standard error), a measurement type (i.e. mass, length, volume, temperature, etc.), and a unit of measure (e.g. liter for volume measurements). Instrumental errors are propagated to saved raw datapoints and ultimately to processed data using standard numerical error propagation methods in order to define the acceptable tolerances for any raw or processed values submitted by the student for assessment in a given milestone.

As a simple example, a student might be told to measure 250 mL of water using a 1 L beaker. To complete this task, the student would grab a virtual 1L beaker using a VR controller (in VR mode) or a physical 1L beaker (in MR-mode); add water from the water dispenser; read the water level using the gradations on the virtual 1L beaker rendered in their HMD; place the 1L beaker onto a “submission area” for assessment; and then say “submit” or “ready” to indicate they are ready to be assessed. The software would then: check how much water is in the beaker; determine whether this value is within the tolerance limits required given the precision of the 1L beaker; and then display the appropriate feedback (e.g. “nice work” or “try again and be sure to look out for…”) as defined in the Lab Module Generator spreadsheet. If incorrect, the student would be invited to repeat this milestone until the correct volume of water is submitted in the 1L beaker.

B. Dual-Mode Lab Tool User Interaction Design Elements

There are many motion tracking solutions which could be used for mixed reality applications. However, the precise tracking of multiple scientific lab tools and instruments simultaneously in real-time without interference with lab tool function is a significant challenge. Notably, some lab tools must be tracked with greater precision than others in order to enable proper functionality. For example, the top of a pipetman requires sub-millimeter tracking resolution relative to the shaft in order to enable precise tracking of liquid transfers, while the transfers made using a beaker can be tracked well enough even with a tracking resolution of ±1 cm.

We explored various optical tracking solutions which meet the above requirements for the totality of lab tools we sought to use in our system (~30 which need to be simultaneously tracked). Currently, we use SteamVR tracking to track the HMD (and the user’s perspective of the VR environment) and the VR controllers. For tracking lab tools in MR-mode, we currently use...
Optitrack Motive passive tracking of IR-retroreflective markers mounted onto custom-made 3D-printed adapters. Most lab tools are simple and require only 6dof tracking (e.g. beakers or reagent bottles) and thus only a single rigid body marker set. However, some lab tools (e.g. pipette man) have multiple mobile elements and thus require additional markers which can report on the additional internal degrees of freedom (e.g. the top and tip ejector of the pipette). Fig. 2 illustrates examples of our patent-pending lab tool optical tracking solution in which passive tracking markers are designed and mounted onto a pipette (8dof lab tool) and a beaker (6dof lab tool).

One potential complication of our approach in MR-mode is that in order to avoid having a physical lab bench cluttered with physical lab tools containing adapters, students need to be able to use a single optically tracked physical lab tool to manipulate all virtual instances of that class of lab tool. To resolve this issue, we designed a specialized UI system which we termed the handler-activator-activated tool system. In this system, instead of having three different physical pipettman for the 20 microliter, 200 microliter, and 1000 microliter pipettes used in a traditional biochemistry lab, we have only one physical pipettman which can control any instance of all three pipettes. When in VR-mode, the VR controllers are used as a completely generic “handler” which picks up, drops off, and manipulates all lab tools regardless of their class. In contrast, when MR-mode is activated for a particular class of lab tool, a single tracked physical lab tool “handler” is used to manipulate all virtual instances of that class of lab tool. In MR-mode, the physical lab tool “handlers” have a distinctive grey color. Students can load colored and functional instances of lab tools (i.e. “activated tools”) onto their handlers by moving the handler onto lab tool “activators” located at fixed points on the benchtop or on the lab shelf. The activated lab tools contain the scripts that provide functionality. Students can release instances of activated lab tools onto the lab bench using special gestures such as tapping the handler onto the benchtop. This approach enables user interaction with numerous instances of virtual lab tools using a small number of tracked physical lab tool handlers and thus reduces table clutter and improves tracking performance.

C. Scalable Content Development via Structured Spreadsheets

A major barrier to the broader dissemination of VR/MR STEM learning experiences is the high cost of developing, testing, and iteratively optimizing such experiences for different target student populations. To address this issue, we designed our system to be scalable and easily customizable by chemistry and biochemistry content experts that have limited programming experience. For this purpose we designed a highly structured spreadsheet which functions as middleware to help chemistry and biochemistry content experts define and iteratively refine the logical milestones or steps that students should pass through during their VR/MR experience. Drop down lists and data validation logic ensure adherence to the formatting and syntax requirements of our back-end software which reads the formatted Lab Module Generator spreadsheet and actually creates the VR/MR lab experience. Fig. 3 shows example rows/milestones of such a Lab Module Generator. In this example, the student is first tasked with getting 500mL of water using a 1 Liter beaker (row/objective/milestone 1). Next, they are asked to place a weighting boat onto the scale. Next, they must tare/zero the scale. Finally, they must set a P20 pipette to pick up 20 microliters. Roughly 100 rows and about 20 columns are required to define a standard pipette calibration lab experience in which the user pipette is either randomly miscalibrated or not and the user must carry out experiments to determine whether and by how much the pipette is miscalibrated.

Milestones or objectives can be any one of a few pre-defined types. “Physical” submissions involve the placement of a lab tool on a “submission area” to check the value of one of its many variables (e.g. total volume, solute type/concentration, pH, etc.). For example, in milestone/objective 0 from Fig. 3, the “total volume” variable of a 1L beaker is checked to see if it is within a pre-specified tolerance from 500 mL (the “target value”). “Data acquisition” milestones require the user to record a “datapoint” into their lab notebook. “Data analysis” milestones require the user to use the raw datapoints acquired and recorded in previous milestones to calculate parameters (e.g. average, standard deviation, percent systematic error, etc.) which are checked against target values in order to assess the student’s data analysis skills. “Conclusion” milestones require the user to examine the analyzed data and draw logical conclusions which are then also assessed using Boolean logical operators that are implemented at the level of the Lab Module Generator spreadsheet by the content developer. This system supports expansion of the number and types of lab tools, variables, calculations, and Boolean logical operations available to content developers. By having content developers select from predefined milestone types, lab tools, variables, etc. they can create or modify lab experiences quickly, efficiently, and at low cost (i.e. without having to write or modify the source code).

IV. ASSESSMENTS AND PILOT STUDY DATA

In Fall of 2021, we tested a simple pipette calibration HOVR Lab module in two upper-division biochemistry lab courses containing a total of about 25 students. In this module, a pipette is randomly miscalibrated and the user is asked to acquire and analyze data in order to determine whether and by how much it is miscalibrated. Our pilot study focused primarily on assessing the usability of the system. However, we also assessed the importance of the tactile authenticity of lab tool manipulation on cognitive, affective, and psychomotor skills acquisition. Our mixed-methods study was based on previous studies which have also explored the impact of physical versus virtual lab experiences in other STEM fields [9], [10]. We used a pre-mid-post design with two interventions for our pilot studies. Students were randomly assigned into control or experimental groups in which the sequence of the two interventions (VR-mode version or an MR-mode version of the module) was altered. At the beginning and end of the study we used the Chemical Concepts Inventory [11] to gauge students’ incoming (pre) and outgoing (post) general understanding of chemistry. The Meaningful Learning in the Laboratory Instrument [12] was used to assess the expected and perceived cognitive and affective impact of the students’ traditional laboratory class as well as each of the two interventions from our study. Targeted cognitive assessments directly related to the subject matter covered in the pipette calibration module were also used immediately before and after each intervention. These consisted of both multiple choice
questions identified by faculty content experts as well as standardized and validated multiple choice items taken from American Chemical Society Exams [13] and aligned to the Anchoring Concepts Content Map [14]. In addition, we also assessed the impact of the VR/MR experience on students’ intrinsic motivation and self-efficacy using other established inventories [15], [16]. Finally, to assess student user experience (UX) with the VR/MR environment in the VR and MR-modes of the module, we employed a previously-validated UX in immersive virtual environments instrument [17].

Briefly, the qualitative results of our various assessments on the pipette calibration module indicate the following: 1) the system was particularly uncomfortable for students with glasses; 2) the large majority of students enjoyed both the VR and MR interventions and considered them valuable and innovative learning experiences; 3) our initial version of the module – which involved calibrating three different pipettes at two different volumes- was too long and needed to be shortened in order to ensure that students would be able to complete the VR/MR activity within a reasonable timeframe; 4) the excel spreadsheet-based method for iterative refinement of each module/experience makes iterative refinement of the VR/MR experience very easy; and 5) students found the feedback on their data analysis and calculations to be very helpful. A detailed and more quantitative analysis of our preliminary pilot test results as well as the results of our ongoing larger-scale trials is currently in progress.

V. DISCUSSION AND FUTURE WORK

VR and MR systems are very likely to play a valuable role in the future of science laboratory education. While they may never fully replace traditional wet lab experiments, they will almost certainly bridge critical learning gaps by providing detailed and real-time feedback on performance metrics which often escape instructors in traditional settings. MR systems are far less expensive to purchase, maintain, and implement when compared to traditional wet labs and they also offer reduced safety concerns/liability, greater freedom for students to learn on their own time, improved engagement, greater focus, and more opportunities to make mistakes and learn in a less stressful and more game-like environment.

In this paper, we present a novel framework for scalable and cost-effective development of fully customizable VR/MR science labs across the physical and life sciences. We briefly introduce the general methods we use for enabling MR-mode tracking of physical lab tools. We apply our approach to the simplest (yet arguably most important) of chemistry/biochemistry lab procedures – pipette calibration. We demonstrate proof-of-principle and examine the feasibility of our general approach and present preliminary results from a pilot user study examining efficacy and impact on both cognitive and affective outcomes in the fields of chemistry and biochemistry.

In the future, we hope to target more advanced concepts/procedures and more detailed characterization of the impact of authentic hands-on (i.e. MR-mode) versus inauthentic controller-based (VR-mode) lab tool UI on student psychomotor skills acquisition, conceptual understanding, and affective outcomes (self-efficacy and intrinsic motivation). The complete technical details (including the tracking performance metrics of our system) will be published in a more technical journal. Our system empowers content developers to tailor their students’ HOVR lab experience without having to code, and we are very hopeful that more faculty will be able to harness the power of spatial computing to enhance teaching and learning at the bench using this approach.

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SAVR – Design and Evaluation of an Immersive Virtual Reality Serious Game on Hazard Perception in Technical and Vocational Education

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Abstract—Technical and vocational secondary school students take internships in enterprises as part of their training. As such, they are often confronted with hazardous situations, such as contact with chemical substances, operating specialist machinery or in potentially dangerous working conditions. Students therefore need to be prepared in the school setting, prior to their internship experience. To address this challenge an immersive virtual reality serious game was developed. Students’ perceptions of the effectiveness of the game were assessed using a survey. Targeted variables were presence, design, interest and usefulness. Students positively evaluated all measures, suggesting an immersive virtual reality serious game is a useful instrument in teaching hazard perception in technical and vocational secondary education.

Index terms—serious game, hazard perception, secondary education, design research, safety education

I. INTRODUCTION

Immersive virtual reality (iVR) is increasingly being used in educational settings as VR headsets have become more affordable and user friendly [1]. Several authors point to the affordances of iVR for learning, such as authentic learning environments, visualizing what is otherwise invisible and creating learning experiences which are in real-life not possible, too expensive or too dangerous [1]-[4]. Providing students with authentic learning experiences which would be too dangerous in real life, was the main incentive for the design of the SAVR project. Previous research has shown iVR to be an effective tool for teaching safety procedures in an interactive and engaging way [5]-[8] and outperforming more traditional or 2D-approaches [9], [10]. Although these safety trainings often are designed as serious games, results from research on iVR serious games are not consistent [11], [12]. Building on the existing literature, we designed an immersive virtual reality serious game to teach hazard perception to students in technical and vocational secondary education in Flanders. Hazard perception, sometimes called hazard identification [13], refers to one’s ability to perceive situations as dangerous, including the perceived level of risk [14].

II. METHODOLOGY

We adopted the methodological framework of Educational Design Research as developed by McKenney and Reeves [15]. This approach consists of three main stages: analysis and exploration; design and construction; evaluation and reflection.

Both students and teachers from five Flemish technical and vocational secondary schools, were engaged during the development of SAVR in an approach of collaborative design and co-creation. An informed consent prior to the start of the whole SAVR project was obtained by all students, parents, teachers and the principal.

A. Analysis and Exploration

In this first stage, we conducted separate interviews and focus group interviews with all stakeholders from the project team who were involved with safety education. They were asked for their current needs, what regulations they had to adhere to, how the SAVR game should be integrated into their current courses and so on. These interviews included 15 teachers, 28 students, 7 members of three organizations concerned with developing curriculum materials for safety education in Flanders, 2 persons from 2 organizations monitoring safety procedures at work and 2 pedagogical advisory board members.
All interviews were held online using Microsoft Teams due to Covid-19 safety regulations and were recorded. The recordings were downloaded as MP4-files and converted to MP3-files for further analysis.

B. Design and Construction

Based on the existing materials and outcomes of the interviews a first prototype was developed. This prototype was then tested for usability by all stakeholders. They were all provided with one or more Meta Quest 2 iVR headsets. Prior to the testing phase a member of the developer agency organized an online webinar explaining how to operate the virtual reality headset and how to port the software to the device. The developer agency used their own management software to be able to push updates to the device and to live monitor the testing sessions. The first prototype was then tested by all stakeholders while being observed by the developer agency and the research team. All observations were written down via an observation protocol and discussed in an online meeting with all members of the developer agency and the research team. The findings were then categorized in codes, such as usability, software bug, playfulness... which gave rise to suggestions for the next prototype. The design suggestions were first presented to the project team as a whole and confirmed or adapted according to needs and desires which were identified in the first stage of analysis and exploration. Over a timespan of five months, a total of four prototypes were designed, developed and tested in an iterative approach (see Fig. 1): results from observations of each formative test session were used to improve the design of the next prototype.

Fig. 1. Process display of a design study, adapted from McKenney, 2001.

C. Evaluation and Reflection

Finally, the last version was tested (Fig. 2). 51 students from 5 schools in vocational and technical secondary education in Flanders participated in the summative testing of the application.

48 students were male, 3 were female; and their age ranged between 14 and 18. Following safety regulations by the iVR headset manufacturer Meta [16], iVR players under the age of 13 were excluded from this study. Most students (76,5%) had quite a lot of gaming experience, but only a minority (31,4%) had experience with immersive virtual reality.

The participants tested the full version of the game, which takes approximately 14 minutes. Then, they were asked to complete an online questionnaire using Qualtrics survey software, starting with some demographic elements such as age, gender, prior VR experience and prior gaming experience. Part two of the survey consisted of 26 items on a 7-point Likert scale. Presence was measured using 8 items from the Presence Questionnaire of Schubert, Friedman and Regenbrecht [17]: 4 items on spatial presence and 4 items on involvement. Next, usability was measured using 4 items from the design scale of Web Based Learning Tools survey [18]. We were also interested in whether the game had an effect on students' motivation for safety education, so we added 7 items measuring interest/enjoyment and 7 items on value/usefulness, both from the Intrinsic Motivation Inventory by Deci and Ryan [19].

III. RESULTS

A. Analysis and Exploration

Results from the focus group interviews with students indicate current safety education practices lack authenticity. Often students are referred to books on safety regulations, which they have to study on their own. Sometimes a visit to a conference on safety is organized. The main problem for students, is the lack of real-life experiences, due to the limitations within formal education. They expected the immersive virtual reality learning experience to tackle that gap and to provide for ample training opportunities. Teachers expressed a similar concern, but also asked for a learning experience which would be easy to use in their classes, which could be integrated in their existing course materials and is curriculum aligned. This was also expressed by the pedagogical advisory members. Furthermore, teachers indicated a lack of educational materials on safety, aimed at secondary education. Most safety education materials address a professional market or are in most cases focused on safety instructions when operating specific machinery. Teachers and pedagogical advisory members asked for training hazard perception as an attitude. This was confirmed by the organizations concerned...
with developing these materials. The SAVR project tries to address the gaps identified by the several stakeholders.

The development of SAVR was partially funded through the InnoVET program by the Flemish Department of Education, stimulating innovation in Vocational Education and Training (VET) [20]. Only a small budget was provided, limiting the development of the game. Hence, several design decisions had to be taken.

B. Design and Construction

First, we provide a short overview of the game design of SAVR. The game starts with a tutorial to get students familiar with how to interact with the virtual environment. They learn how to move by teleporting and how to take photographs. This is explained in a prerecorded 2D-video by a member of the research team dressed as a construction site manager. Students are asked to perform a last-minute risk analysis as a rationale for the game. The tutorial is set in a container at the virtual construction site. Next, students move over to the site itself where 23 construction workers are engaged in welding, drilling, climbing scaffolds... Students need to find the hazardous working situations and take a photograph of it. When such a danger is spotted correctly, short audio feedback is provided and the dangerous situation is corrected. When students spot a situation which is not hazardous, they are told there is no danger in that situation. Students get a maximum of 15 pictures to find 10 hazards within a total of 23 construction situations. Both the number of photos taken and identified hazards are always shown to the students on the virtual smartphone. The game ends when 15 pictures are taken. Finally, students are teleported back to each hazardous situation in the game automatically. The construction site manager then shows the students whether they had identified the hazard, why the situation can be seen as dangerous and how it should be done properly.

As ease of use was one of the major concerns of teachers, we chose to develop for a standalone VR setup. Meta Quest 2 served as our best option, as it fitted within the constraints of the budget and Meta Quest 2 also allowed for running other educational applications which are available within education and training in Flanders.

Standalone VR setups, such as Meta Quest 2, are limited in GPU-power. Therefore, graphic detail must be reduced in order to maintain performance and limit motion sickness resulting from latency issues.

Another concession resulting from the limited budget, was the design choice of downsizing the amount of interactivity. Instead of having machines operated by the players themselves and testing whether safety procedures were taken into account, virtual avatars and a virtual construction site were created. The avatars perform all operating actions on this site, sometimes in a safe way, sometimes not. Players have to take a picture of dangerous working conditions with a virtual smart device. This design choice was in line with teachers’ emphasis on detecting hazardous situations rather than training specific operations procedures.

All stakeholders expressed the desire for ample training opportunities. First, we defined a list of 23 hazardous situations which students had to be able to detect. As was explicitly expressed by all stakeholders during the analysis phase, these situations align with the curriculum standards, meeting several learning goals of students’ hazard perception training. The situations were then designed in both a safe and an unsafe version. All 23 situations were then saved in a repository of which the SAVR game randomly chooses 10 situations which are presented in an unsafe condition. The remaining 13 situations are carried out in a safe way by the virtual avatars. This randomization allows for multiple learning opportunities, as each time different hazards have to be found.

Observing students during the prototype testing sessions brought forth some new design elements. Students initially took as many photos as they could, shooting almost everything there was to see. As a result, they eventually succeeded in finding all hazardous situations, but mainly by coincidence. Therefore, we limited the number of photos they could take to 15. This is indicated by a symbol on their smart device, next to a symbol showing how many hazards they have already found (Fig. 3).

Another design element resulting from observation was that students took a wide-angle picture, once again being lucky to have the hazard on the picture. In the final prototype a picture was therefore only valid when students were close enough to the hazardous situation, excluding the factor of luck.

Due to an initial lack of system feedback, some users kept on taking photos from different angles to be sure the system registered the photo taken correctly. To address this, the hazard is now automatically corrected into the safe version when a user captures the hazardous situation, accompanied by short audio feedback by the virtual trainer. Doing so, a combination of both system feedback and content-related feedback is established.

Observations also made clear that after the initial tutorial on how to interact with the virtual environment, not every student was able to teleport or to take a picture in a fluent way. As such,
it seemed the tutorial did not present enough learning opportunities, resulting in the game being too complex for first time SAVR players. To tackle this issue, we chose to add a validation element to the tutorial. Users must perform the actions, needed for the training itself later on, three times, each within a timing of 5 seconds. When users were not successful in doing this, they needed to restart the first exercise. In doing so, users got familiar enough with the control instruments, allowing them to fully focus on the training content on hazard perception instead of thinking about which controller button to use.

Although the range of teleporting was already limited, some users were disoriented after transporting to another location in the tutorial scene. To mitigate this effect, users were automatically turned into the direction of the next hazard or the virtual construction site manager.

C. Evaluation and Reflection

We first tested the unidimensionality of the instrument via exploratory factor analysis using SPSS28. All items had satisfactory factor loadings. Next, Cronbach’s alpha was calculated for each scale to test reliability. To test the effect of SAVR we calculated the means and standard deviation. All items were scored on a 7-point Likert scale. Results are presented in Table 1.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Cronbach’s Alpha</th>
<th>Means</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial presence (IPQ)</td>
<td>.526</td>
<td>5.47</td>
<td>.844</td>
</tr>
<tr>
<td>Involvement (IPQ)</td>
<td>.690</td>
<td>4.47</td>
<td>1.27</td>
</tr>
<tr>
<td>Design (WBLT)</td>
<td>.774</td>
<td>5.95</td>
<td>.853</td>
</tr>
<tr>
<td>Interest/enjoyment (IMI)</td>
<td>.912</td>
<td>5.75</td>
<td>.937</td>
</tr>
<tr>
<td>Value/usefulness (IMI)</td>
<td>.935</td>
<td>5.48</td>
<td>1.052</td>
</tr>
</tbody>
</table>

Next, we looked for significant differences in variance between groups. Due to the skewed distribution for gender (only 3 females, less than 5%), the effect of gender was not further investigated. For age, we made a distinction between students from different grades. In Flanders, Belgium, secondary education is divided in 3 grades. Students in year 3 and 4 belong to grade 2, year 5 and 6 belong to the third grade. Scores for each scale were calculated using Mann-Whitney U tests. Comparison for design (WBLT) proved to be significant in favor for the second grade (mean rank 29.72) over the third grade (mean rank 21.09) with a p-value of .037 and an effect size of -.291 which is considered to be low to medium. A similar significant difference was found for interest/enjoyment (IMI) with a mean rank of 31.90 for the second grade and 18.23 for the third grade at a p-level of .001. This time the effect size was medium to large (r = -.46). We also investigated the effect of gaming experience and created three groups: few, moderate, a lot. This time we used Kruskal-Wallis test as we had three groups. Comparison of groups showed no significant difference for any measure. The final effect under investigation was prior experience with virtual reality. Again, three groups were created and Kruskal-Wallis tests were run. No significant differences could be found.

IV. Discussion

In this study we designed, developed and tested an immersive virtual reality serious game on hazard perception, called SAVR. This game was developed to be used in courses on safety in the second and third grade of technical and vocational secondary schools in Flanders.

Results from the interviews during the analysis stage indicated a need for such materials as all stakeholders expressed the lack of authentic learning experiences. One of the affordances of immersive virtual reality is that it can recreate such authentic, real-life environments, due to its immersion, presence and interactivity [21], [22]. Test results for spatial presence and involvement indicate students felt highly immersed in SAVR. They also valued the iVR game in terms of interest/enjoyment and value/usefulness, indicating SAVR is a useful instrument for safety education on hazard perception in vocational and technical secondary schools.

We could not retrieve any difference of significance between subgroups, apart from the grade. Students from the second grade scored both Design [18] and interest/enjoyment [19] significantly higher than students from the third grade. A plausible explanation could be that older students had already more iVR experience, hence are more critical about new iVR experiences. However, no correlation could be found between age or grade and prior iVR experience. Our results apparently suggest that SAVR is more fit for younger students. A sound explanation cannot be provided for and should be investigated in more detail in future studies.

We were successful in attaining both goals of our project. First, we developed a useful tool to teach hazard perception in technical and vocational secondary education. The game is now used in several schools in Flanders and the Netherlands. The second goal of Educational Design Research [15] is adding to the theory, in this case on hazard perception. Some design guidelines were identified, such as randomization of hazards, taking photographs as a test base and avoiding the factor of coincidence via iVR interaction settings. This adds to the understanding of how immersive virtual reality games can help to teach hazard perception in technical and vocational secondary education. Especially within the constraints of limited budget, concerns of ease of use in a classroom and demands for sustainability in terms of ample learning opportunities.

Although successful, this study was also confronted with some limitations. First of all, the results should be interpreted carefully and not be generalized as our sample was limited to 51 students. Secondly, this paper includes only students’ perceptions. Analysis of teachers’ and other stakeholders’ perspectives would complement our findings. Next, design guidelines were identified during observations. They cannot yet be taken for granted and need to be validated in future studies involving larger groups and in quantitative research designs. We were also not able to test whether SAVR has a real-life impact, i.e., whether students will show a transfer of attitude of hazard perception to real working conditions.

V. Conclusion

To address the lack of authentic learning experiences on hazard perception in technical and vocational secondary
schools, we designed, developed and tested an immersive virtual reality serious game. Test results indicate SAVR can be considered as a useful instrument to be used for safety education. In line with the methodological framework of Educational Design Research our work has both practical and theoretical implications.

ACKNOWLEDGMENTS

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An Interactive Chess-Puzzle-Simulation for Computer Science Education

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Abstract—The hype around the series “The Queen’s Gambit” led to a boom in playing chess. The game enhances strategic thinking, stimulates intellectual creativity, and improves problem-solving. These skills are increasingly in demand and also essential in the field of computer science (CS). Traditional teaching approaches are often insufficient to teach CS concepts. Interactive and digital experiences can be used to create an exciting, engaging, and realistic learning environment. In this paper, we explore the potential of a chess-based learning approach to increase motivation in CS. The application includes an interactive chess-puzzle simulation to teach the concept of state machines using a chessboard as an input field. We present a study with 35 students for evaluating the students’ motivation, emotions, and workload with a focus on the learning experience. The results indicate a positive impact on the learning process and engage students in learning computer science.

Index Terms—computer science education, learning, e-learning, chess game

I. INTRODUCTION

During the pandemic, chess has turned into a trendy game. Inspired by the streaming series The Queen’s Gambit, millions of people have become fascinated by chess, a 1500 years old board game. Its unbeaten tactical level of deepness makes it a fantastic game and a very interesting and engaging sport. Online chess games and e-sport events around chess are becoming more and more popular. The famous chess website Chess.com has added a few new bots related to the series characters to benefit from the series’ popularity. Since 2020, the site has counted millions of new registrations [1]. It shows that the hype around the series and chess can be used to motivate people to play and get involved with the topic. Everyone can handle the movements of the pieces, but becoming a master is challenging. Chess enhances strategic thinking, stimulates intellectual creativity, and improves problem-solving [2]. These skills are also essential in the field of computer science (CS). The hype around chess could be a powerful tool to explore CS topics. State machines are a common method for realising a control concept by using states and state transitions [3]. Traditional learning methods often struggle to teach problem-solving and conceptual understanding [4]. Providing embedded pedagogical activities have been shown to be an effective technique in comparison to traditional methods [5]. Such additional tools can be used to support students to strengthen their conceptual understanding. In this paper, we introduce an interactive chess-puzzle-simulation to motivate and support students in learning state machines. The main research objectives are:

- Exploring how chess affects the learners’ motivation and emotions in learning.
- Identifying the workload of different chess scenarios while learning conceptual aspects.
- Discussing advantages and disadvantages of chess-based learning tools for CS education.

Contribution: In this paper, we present a study with 35 students, discussing a chess-based learning approach for CS education. The focus is on the students’ motivation and on identifying and discussing the benefits and challenges of chess-puzzles in learning with CS students and none CS students.

II. BACKGROUND AND RELATED WORK

Chess has become an evergreen when it comes to improving skills and learning. It can be a valuable extension for learning while having fun [6]. Chess not only affects the evaluation of social emotion, but it also increases the skills in problem-solving as well as the cognitive abilities of frequently chess-playing children [2]. Reading competence is probably not the first skill that comes to mind regarding chess. Nevertheless, mid-elementary school students improved their reading skills when they participated in the chess program compared to students who did not [7]. Chess program members surpassed non-chess program members in the mathematics and reading part of the Pennsylvania System of School Achievements (PSSA) test [8]. Chess can also improve concentration, creativity, as well as self-esteem [9]. In addition, chess has some positive impact on planning tasks that require the ability to think ahead. Unterrainer et al. [10] showed that chess players performed better in the Tower of London planning task than non-chess players. Even more, the gap between these two groups grew with the increased difficulty level. Rosholm et al. [11] integrated chess-based lessons in mathematics classes, which showed an increased learning outcome in the understanding of mathematical concepts. Moreover, chess promotes certain social abilities like cognitive flexibility as well as negotiation.
skills which can be used to support high-functioning autistic children [12]. However, Sala and Gorbet [13] consider that
the effects of chess on academic and cognitive abilities are not well-proven. They claim that chess seems to have only a
small positive impact and mentioned that further research is
required.

A variety of concepts and methods have already been de-
veloped to improve educational instructions in the field of CS.
Papastergiou [14] has shown that digital gaming concepts in-
crease the motivation in learning computer memory concepts.
Interactive simulations, visualizations as well as gamified
learning environments can be used to support teaching [15].
Regarding CS topics, simulation environments reduce the com-
plexity by making concepts more tangible [16], [17]. Slabý
and Ševčíková [18] integrated small chess tasks into a discrete
mathematics course to increase learners’ motivation. Students
had to figure out the solution for the knight tour problem
of a reduced chessboard by finding the Hamiltonian circle or
Hamiltonian path. Gusev [19] integrated chess programming
into different CS classes to teach structured and well-designed
software development. Programming assignments were based
on chess engines where students had to modify and extend
them. The author showed that such an approach can be useful
in teaching programming if students are sufficiently motivated.
While various studies already have shown the positive effect
of digital game-based learning approaches in increasing the
motivation [14], [20], we want to use the hype around chess
to increase students’ motivation in learning CS concepts.

III. LEARNING APPLICATION

As a starting point, we used a virtual laboratory environment
with different interactive and engaging learning methods to
motivate students for computer science. The environment
provides an immersive 3D lab experience and makes learning
more enjoyable. Users can navigate through a laboratory
hub and are able to explore a variety of simulations and
experiments. The framework is implemented in Unity and
supports various platforms such as desktop or web-based
applications for a high level of availability. When selecting an
experiment, the user is transferred into a separate scene. Within
this scene, users can manipulate the experiment behavior
by adjusting specific parameters. Integrated simulations and
learning activities can be launched at any time and as often
as liked to support exploration without being penalized for
mistakes [21].

A. Chess-Puzzle Setup

The goal of the chess puzzle simulation is to convey and
consolidate knowledge regarding state machines in a simple
manner. Users should get involved in the topic by solving
different chess puzzles. Figure 1 shows the chessboard with
the loaded scenario. Each scenario contains a puzzle with
different pieces. The main task is to capture all enemy pieces
on the board. In the edit mode, users can add new states and
rules by defining the state transition (current state and next
state), the move option, and the input field. The surrounding
in the rule set has to match the current position during play
mode to be executed. Figure 2 demonstrates the surrounding
encoding for a specific 3x3 neighborhood. The combined rule
set defines the users’ figure behavior. The added rules are
shown in the state-transition table and can be modified by
the user. When switching to the play mode, the state machine
starts and moves all figures step by step. The first state is
predetermined as “start” and the last state as “end”. If a puzzle
is finished correctly, the user is informed through the dialog
area that the scenario is successfully finished. The user always
has the possibility to change freely between the edit and play
mode. The movements of the enemy pieces are predefined and
leads always to the same positions. This means two different
instances of the simulation also end up in the same position.

![Fig. 1. Chess-puzzle-simulation view.](image1)

![Fig. 2. Board situation/surrounding encoding.](image2)

IV. EVALUATION

The aim of the study was to investigate the impact of playing
chess on the students’ motivation and emotions while learning
conceptual aspects. We conducted a user study with 35 stu-
dents using an interactive chess-puzzle-simulation integrated
into a virtual learning environment. The research focus of
the study was on: (1) user-experience and engagement, (2)
learning experience, and (3) workload.

A. Material and Setup

For conducting the study, participants were asked to start
the simulation in the browser. The users were separated from
each other and worked individually on the different tasks. Each
A participant received a document with the study instructions and the task descriptions. To link the individual questionnaires, we assigned users an anonymous ID.

B. Method and Procedure

The study was set up as an online survey where the users worked individually using the provided guidelines. It included a pre-questionnaire, the tasks in the learning application, the workload questionnaires, and a post-questionnaire. At first, we asked all participants to complete the pre-questionnaire to get personal information and previous experience in e-learning, computer usage, state machines, and programming rated from from 1 (low) to 5 (high). After completing the pre-questionnaire, they got a detailed introduction into the learning application how to move and interact. We explained to them how to create new states, state-transitions and how to manipulate them. If users were not familiar with state machines or chess, we provided a short video explanation and the basic chess movements, as well as a short tutorial example. During the experiment, participants had to perform the following tasks:

1) Start the chess-puzzle simulation and familiarize yourself with the tool.
2) Load the tutorial scenario and try to solve it.
3) Load the scenarios and solve the puzzles one by one.

For each scenario, configure the state machine in such a way that your figure capture all enemy pieces.

If users were unable to solve the task within 15 minutes, they were instructed to stop the scenario and move on with the next task. After each scenario, participants rated their workload on a Likert scale between 1 (low) and 10 (high). We used the NASA Task Load Index (NASA-TLX) [22] to assess the cognitive workload and the task effectiveness. At the end, the participants were asked to fill out the post-questionnaire in which they had to answer open-ended questions about their overall experience, 16 questions on a Likert scale between 1 (fully disagree) and 7 (fully agree) about their motivation and learning experience, and 10 questions regarding usability. To evaluate the system usability and the users’ emotions while interacting and learning with the learning application, we used the System Usability Scale (SUS) [23] and the Computer Emotion Scale (CES) [24].

![Chess-puzzle scenarios](image)

**Fig. 3.** Chess-puzzle scenarios.

C. Participants

For recruiting participants, we contacted 35 students (27 male, 8 female) from different fields of study and universities via social media channels. The participants were aged between 20 and 32 (AVG=24, SD=2.4). 21 of them had a background in computer science. We asked each participant to rate their previous experience with computers, video games, programming and state machines on a Likert scale from 1 (low) to 5 (high). Most participants rated themselves as experienced with computers (AVG=3.6, SD=1.3) and video games (AVG=3.3, SD=1.4). Only a few rated themselves as an expert in the field of state machines (AVG=2.2, SD=1.2). The experience with programming was rated as moderate (AVG=3.1, SD=1.5).

V. Results

In the following section, we present the results with a focus on motivation, learning experience, and cognitive workload. Additionally, we investigate the system acceptance and the emotions during the learning process. To identify the benefits and weaknesses, users were asked about their preferences and dissatisfaction during the experiment. We focus on the differences between CS students (A) and non-CS students (B).

A. Usability and User Emotions

Participants rated their overall impression from 1 (not at all) to 5 (very much). In general, users rated the chess-puzzle simulation as interesting and enjoyable (A: AVG=3.50, SD=0.95; B: AVG=2.9, SD=1.6). To assess happiness, sadness, anger, and anxiety while interacting with the system, we used the Computer Emotion Scale. Table I shows the result of the combined CES items for group A and B. The rating of emotions referring to happiness (e.g. satisfied, excited, curious) was quite moderate. Non-CS students rated happiness much lower than CS students. The emotions of sadness, anger, and anxiety were rated as low, while non-CS students felt more often frustrated and helpless. There was also a significant difference in the frustration level (A: AVG=1.20, SD=0.70; B: AVG=1.77, SD=0.83); wilcox-test: p = 0.03. The system usability was evaluated with the SUS questionnaire. Group A rated the usability with a score of 64.13 which indicates marginal usability. In comparison, group B scored the usability slightly higher with 69.23. However, non-CS students found that they need support to use the system. They differed most significantly on the fact that they still have a lot to learn before they can work with the system (A: AVG=1.6, SD=0.94; B: AVG=3.0, SD=1.2); wilcox-test: p = 0.0015.

<table>
<thead>
<tr>
<th>Table I</th>
<th>Results of the Computer Emotion Scale on a Likert Scale between 0 (Never) and 3 (Always)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS Students</td>
</tr>
<tr>
<td></td>
<td>AVG</td>
</tr>
<tr>
<td>Happiness</td>
<td>1.50</td>
</tr>
<tr>
<td>Sadness</td>
<td>0.75</td>
</tr>
<tr>
<td>Anger</td>
<td>0.65</td>
</tr>
<tr>
<td>Anxiety</td>
<td>0.15</td>
</tr>
</tbody>
</table>


B. Learning Experience and Motivation

To evaluate the learning experience and motivation, we asked the participants to rate their experience between 1 (not agree) and 7 (fully agree). Table II gives an overview of the students’ experience towards their learning process. In general, most users were motivated to learn with the tool as they perceived it as an interesting, engaging, and useful tool to supplement regular learning. CS students rated it a good idea to use it for learning. Both groups agreed that they learned something when solving the chess puzzles (A: AVG=4.0, SD=1.7; B: AVG=4.6, SD=1.3). CS students also mentioned that a chess-based learning approach could be a good supplement to regular learning while non-CS students found it less useful. CS students found the application interesting, engaging, and fun. In contrast, non-CS students were less engaged and had a reduced sense of fun. There was also significant difference in improving the understanding (A: A VG=4.8, SD=1.7; B: AVG=4.6, SD=1.3). CS students also mentioned that a chess-based learning approach could be a good supplement to regular learning while non-CS students found it less useful. CS students found the application interesting, engaging, and fun. In contrast, non-CS students were less engaged and had a reduced sense of fun. There was also significant difference in improving the understanding (A: A VG=4.8, SD=1.7; B: AVG=3.0, SD=1.6); Wilcox-test: p = 0.008. Nevertheless, most users were inspired to learn more about state machines.

<table>
<thead>
<tr>
<th></th>
<th>CS Students</th>
<th>Non-CS Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to learn with it</td>
<td>4.8</td>
<td>3.5</td>
</tr>
<tr>
<td>It is a good idea to use it for learning</td>
<td>5.6</td>
<td>3.6</td>
</tr>
<tr>
<td>It is a good supplement to regular learning</td>
<td>5.6</td>
<td>4.0</td>
</tr>
<tr>
<td>I learned something</td>
<td>4.0</td>
<td>4.6</td>
</tr>
<tr>
<td>It makes the content more interesting</td>
<td>5.2</td>
<td>3.8</td>
</tr>
<tr>
<td>It makes the content easier to understand</td>
<td>4.8</td>
<td>3.0</td>
</tr>
<tr>
<td>It makes learning more engaging</td>
<td>5.4</td>
<td>3.9</td>
</tr>
<tr>
<td>It makes learning more fun</td>
<td>5.5</td>
<td>3.9</td>
</tr>
<tr>
<td>It makes learning more interesting</td>
<td>5.3</td>
<td>3.9</td>
</tr>
<tr>
<td>I would like to learn with it at home</td>
<td>4.6</td>
<td>3.6</td>
</tr>
<tr>
<td>I would like to learn with it in the classroom</td>
<td>5.1</td>
<td>3.0</td>
</tr>
<tr>
<td>The experience inspired me to learn more about state machines</td>
<td>4.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Learning was more motivating than with ordinary exercises</td>
<td>5.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Seeing the chess-puzzle simulation on the computer was engaging</td>
<td>5.4</td>
<td>4.4</td>
</tr>
</tbody>
</table>

C. Workload

Users had to perform three different chess puzzles with varying difficulty levels. The scenarios differ in the number of pieces, the positions, and the possible movements (see Figure 3). After each puzzle scenario, we asked them to rate their workload between 1 (low) and 10 (high). To measure the overall performance, effort, and mental and physical demand, we used the NASA-TLX questionnaire. The success rate for the first scenario was 0.95 for CS students and 0.43 for non-CS students. The second scenario was solved by 74% of CS students and 15% of non-CS students. Most students had troubles to solve the third one (A: 0.47; B: 0.14). Figure 4 illustrates the cognitive workload for the different scenarios for group A and B. It shows an increased cognitive workload for CS students, whereas non-CS students had a consistent workload level for the second and third scenario. There was only a significant difference in the overall performance (A: AVG=5.9, SD=2.7; B: AVG=3.8, SD=3.1); Wilcox-test: p = 0.008 and the frustration level (A: AVG=5.2, SD=2.7; B: AVG=7.2, SD=2.6); Wilcox-test: p = 0.002.

D. General Comments

To get general feedback from the users, we asked them what they like and what they did not like. Almost all users commented that they liked the idea of learning by applying it to chess. The users highlighted the visualizations of the chess puzzles and mentioned that they like the concept of finding solutions by themselves. Only one user had a negative attitude towards chess. Some users had troubles with the graphical interface and suggested an onboarding system.

VI. DISCUSSION

In this study, we tried to investigate the effect of a chess-based learning approach on the learners’ motivation and emotions during the learning process. We attempted to identify the cognitive workload in learning when playing chess with CS students and non-CS students. Gusev [19] has already pointed out that chess can be useful in computer science classes, as long as students are motivated. Indeed, our results indicate that chess can be a valuable tool to increase motivation in learning computer science. Applying chess in the context of CS, inspired users to learn more. This is in line with previous studies showing the potential of chess games in motivating students in learning discrete mathematics and optimization methods [18]. The results show that even non-CS students were able to familiarize themselves with an unknown CS concept. The chess-puzzle game helped them to get easier in touch with the topic. Even those who could not solve the scenarios described that they learned something. For non-CS students, such a problem-solving approach could be a motivation driver to arouse interest in CS topics. Solving problems instead of just memorizing facts and methods can increase the constructive work for CS and non-CS students. Moreover, the visualization and animations of the chessboard.
supported students in their understanding. While computer-supported techniques are an effective method in learning CS content [17], chess can increase motivation by connecting CS with a playful and challenging task. Students agreed that the chess puzzle would be a good supplement to regular learning. This matches with the thoughts of Alnoukari et al. [16] who also see simulations as an important tool to make observations of computer science aspects easier. However, non-CS students often felt helpless and frustrated when solving the chess puzzles. The results showed a significant difference in the overall performance and the frustration level. Chess tasks should be adapted to the users’ skills in order to keep the frustration low. To support students without prior knowledge, the system should be intuitive and easy to use. Embedded explanations for a guided experience can promote understanding while playing.

A. Limitations

The study was designed as a first investigation to find out how chess affects learners’ motivation and emotions during the learning process in CSE. The main limitation of this study was the small sample size of 35 participants. A larger and more diverse sample size would help to obtain more meaningful and general conclusions. Also, the age range of 20-32 leads to the limitation that it cannot be generalized to other age ranges. The learning effects were determined by self-evaluations and do not indicate the learning outcome and long-term effects. Also, the background knowledge as well as chess skills of the participants differed. While CS students already heard about state machines, non-CS students had to familiarize themselves with the topic to solve the tasks. One participant dropped out and did not answer all questions in the post-questionnaire.

VII. CONCLUSION

In conclusion, the participants indicated that they felt more motivated and believed that the chess puzzle made the topic more engaging and encouraged them to acquire more knowledge. The different scenarios have shown to be a good motivation driver through challenging tasks. The results showed that the workload has to be adapted to the users’ skills. Even though the usability was rated as OK, there is still place for improvements to reduce the frustration level. User criticized a lack of explanations and asked for assistance while performing the tasks. Addressing these usability issues would be essential to create a higher system acceptance. Therefore, the learning activities have to be more attractive and adapted to the users’ skills in order to keep the frustration low. It would be essential to create a higher system acceptance.

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Work-in-Progress—Microscopic Immersion: Dive into the Subcellular Journey

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Abstract—Immersive learning has currently been incorporated into cell biology learning settings. It is preferable to provide a realistic experience for efficacious learning. This work-in-progress study aims to build the learning materials to envision the subcellular world of cells through raw electron microscopic data of plant cells. Transmission electron microscopic observation and three-dimensional reconstruction were performed after material preparation. The author hopes that learning materials in this work-in-progress study will provide learners with immersive experiences by allowing them to explore organelles within cells by seeing and touching.

Index Terms—cell biology, immersive virtual reality, plant cells, K-12 students, STEAM education

I. INTRODUCTION

Since the beginning of the 21st century, advanced technologies in cell biology have underpinned the diversification of learning tools and materials. For instance, hands-on and multitouch tabletops, including immersive learning, have been incorporated into cell biology learning settings [1], [2]. The pedagogical efficacy of fostering creativity based on scientific thinking may be achieved through science, technology, engineering, arts, and mathematics (STEAM) education worldwide [3]. Regarding STEAM education in cell biology, the author successfully expressed three-dimensional (3D) printed cells with emerged transparent multicolored as learning materials [4]–[6].

The author, a cell biology instructor, has explored strategies to demonstrate the structure and function of cells for students. It is preferable to provide a realistic experience for efficient learning, which virtual reality (VR) technology accomplishes by delivering an exciting, immersive learning experience. As mentioned above, learning materials for immersive learning, which employ contents based on raw microscopic data, has been emerging [1], [2]. This work-in-progress study aims to develop learning materials that allow to envision the subcellular world of cells through raw electron microscopic data from plant cells for immersive learning. Here, the author describes how the learning materials are built for adventure of diving into the subcellular world to learn the structure and function of cells.

II. PROCEDURE

A. Outline of the Angiosperm Plants Cells

*Arabidopsis thaliana*, an angiosperm plant with various organs and cells, provides the microworld with diverse biological phenomena. The cell is the smallest unit of an organism, and all living cells comprise a variety of microstructures called organelles, each with its own function. In subcellular world, many biological reactions occur...
within/through organelles, such as the nucleus, the Golgi apparatus, mitochondria, and plastids. Since the studies on (angiosperm) plant cells are fewer than animal cells [1], [2], this work-in-progress study’s main aim was to build the learning materials for *Arabidopsis thaliana*.

**B. Material Preparation**

First, entire leaves of *Arabidopsis thaliana* were chemically fixed with 4% glutaraldehyde/4% paraformaldehyde in 20 mM sodium cacodylate buffer (pH 7.2) for 16 h at 4°C, then chemically fixing with 2% osmium tetroxide for 16 h at 4°C. The fixed leaves were gradually dehydrated using an ethanol series before embedded in Spurr resin. Subsequently, they were sectioned ultrathin (70 nm), collected on copper grids (75 mesh) with support films, and stained in 4% uranyl acetate and 0.4% lead citrate. Consequently, organelles were observed and photographed with a transmission electron microscope (JEM1200EXS) (Fig. 1). This microscopic observation resembles an immersive experience.

**C. 3D Reconstruction**

A kind of organelles was observed and traced using software (Adobe Photoshop CS6) (Fig. 2). Each structure was distinctly layered. These were aligned and segmented when the objective structure was extracted. These 3D reconstruction data are being developed as learning materials for immersive learning with Unity, a 3D real-time development platform so that learners can experience the subcellular microworld by wearing a head-mounted display (HMD).

**III. RESULTS AND DISCUSSION**

This work-in-progress study aims to build the learning materials to envision the subcellular world of cells through raw electron microscopic data of plant cells for immersive learning. It would ensure that learners can experience 3D reconstructed data acquired from electron microscopic observation by wearing an HMD (Fig. 3). From this perspective, the learning material can offer a realistic experience and microscopic observation resembling an immersive experience so that the problem of the limitation of experimental instructions for students would be resolved. The author hopes that learning materials in this work-in-progress study will provide learners with immersive experiences by allowing them to explore organelles within cells by seeing and touching. More sophisticated VR or augmented reality technology and programming skills are required to perform it. Moreover, the survey of learning efficacy and comfort should be analyzed for enhancing learner experience.

**REFERENCES**


Work-in-Progress—Factors that Lead to Successful Technology Programs in Schools

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Abstract—Digital Literacy (formerly ICT Capability) is one of the seven general capabilities outlined in the Australia curriculum designed to equip young people with the knowledge, skills, behaviours, and dispositions to live and work in the twenty-first century. Whilst opinion commonly supports the premise that there is a need to prepare our children for a digital world, successfully deploying such programs in schools has been fragmented. In this paper we explore some common factors that lead to a program being successful and identify key areas that require deeper investigation and adoption into practice. This work-in-progress paper will be exploring technology as an educational affordance across curriculum areas rather than a specific subject area. This content will provide a foundation for what factors have been proven to be important in a technology program and where further development is required.

Index terms—STEM learning, digital literacy, digital pedagogy, education technology

I. INTRODUCTION

Aside from being considered a subject area, the use of technology as a tool to enhance curriculum has been recognised to be a valuable resource to many educators and spans across the key learning areas [1]. However, the adoption of any change or evolution in such structured institutions can be incredibly challenging for all stakeholders [2]. Depending on the planning and execution, the implementation of rolling our technology into schools can often be disruptive and could at times be argued to even reduce the quality of teaching and learning when done incorrectly.

Some research suggests that a structured approach can be a key factor of success in a technology program [3]. This structure could include key components such as vision, measurement, team, resources, and professional learning. Having a structured program consistently emerges as a common factor among successful technology programs in schools [4].

The aim of this paper is to provide guidance on some of the common factors that lead to a successful technology program within an educational setting. This will form part of a larger body of research which will have a specific focus on student technology leaders. It is the purpose of this research to contribute to the existing field of study around technology programs within secondary schools. The expected outcome of this research will be to explore the factors that contribute to success and specifically demonstrate that the investment of student targeted learning can help enable technology leaders within the student base. These students can then go on to support the use of technology within the learning environment for their classroom and peers.

II. THE FACTORS OF SUCCESS

Technology has irreversibly changed the way that we live and work. There is however a lack of understanding around the outcomes that are required for the real-world post schooling, both for the purposes of employment and social uses of technology [5]. It is widely agreed that there is demand for students who are emerging from schooling to have problem solving and collaboration skills in the areas of science, technology, engineering and mathematics [6]. This reinforces the fact that education has a role to play in filling this gap and genuinely preparing students for the world beyond school.

A. The Device and Student Model

The experience of a technology program is vastly different depending on the integration level and the student-to-device ratio for the chosen model. Stone [7] explored various studies that were completed around the device environment of such programs, comparing the nature and effectiveness of many students sharing a device and that of a 1:1 device environment. The broad consensus was that a 1:1 device environment was commonly accepted as best practice, however there was little commonality about what made a program successful. While there is adequate research to point to the effectiveness of a 1:1 model, not all supporting evidence points to this as the determining factor of success.

Research has reiterated the importance of collaboration and human element interaction in a project that measured the effectiveness of digital texts on devices in isolation or with secondary participants [8]. This highlights the fact that the device alone is not the key to success, the implementation and use case must also be a priority. In some cases, shared devices or a secondary participant can have a positive impact.

B. Professional Learning

Scherff [9] in her work calls into question the love/hate relationship many educators have with technology. Although technology is almost always positioned to make a task easier, it often has the reverse effect. This causes the simple tasks that
have otherwise long since been mastered, to become a new challenge that can be quite unwelcomed by educators. Whilst much of this research was compiled through her lived experience as an educator, a valuable point was made that one of key factors to success included thorough and robust professional learning [11]. The requirement for professional learning is a staple across all disciplines regardless of the subject matter.

C. Financial Investment

One of the most common evaluations performed all over the world every day is the concept of the cost benefit analysis. There is a cost of any teaching technique in schools or any set of materials, and technology is no different [10]. Having noted that financial investment is required to implement technology, it then must also be considered as a factor to the success of any program to be implemented.

Arias [11] conducted research on technology exposure and outcomes in both developing countries and developed countries and also contrasted private and public schools. Not surprisingly, the research found that the higher the level of financial support, the greater the exposure to technology. This exposure was then linked to familiarity and digital literacy and again, those students who experienced more exposure to technology held a higher level of proficiency in it. This does not, however, draw direct conclusions to the success of a program, only that budget is a factor if a program is to involve technology.

D. The Human Factor

Not all investment is financial in nature. Another, arguably more important investment in programs such as these is the less measurable investment of student/teacher time and energy. A common theme in research around technology in schools is the importance of the actual people involved in leading the programs. Given the amount of change and knowledge to be absorbed, a group of people collectively managing a program makes it more likely to succeed [12]. Dexter [12] focused on the individual expertise and ability to share focus points by having a team rather than an individual journeying alone, however a team also creates contingency in leadership should a member leave the organisation or otherwise disengage. Whilst this article shares views on leadership and educators, there are other key personnel required when it comes to a subject matter as complex as technology can be.

Schools tend to be collaborative learning environments, with teachers all coming together to deliver what they do best to foster continual improvement. This theory is congruent with building out a technology team. Phillips [13] assessed the team dynamic of learning with technology and highlighted three critical skillset requirements – Technological Knowledge, Pedagogical Knowledge and Content Knowledge. This content framework has come to be known as the Technological Pedagogical Content Knowledge (TPACK) model [14]. This work reinforces not only the role that having the right people play, but also the combination of expertise required in order to build a successful team. It is worth noting that the human cost must also be considered when assessing the relationship to cost and outcome. The investment in time out of an employee’s day is still a cost to the institution.

E. Student Learning and Literacy

It could be argued that the ultimate measure of a successful technology program is the outcome of higher student literacy in those fields. Studies on student digital literacy have been performed in relation to their respective educators. Clark and Zhang [15] measured student technology outcomes across educators with respect to the background and qualifications of those educators. Their analysis showed that educators with a STEM or Technology background, on average, generated better student outcomes in digital literacy than those without. With that connection that teachers with a stronger background create improved student literacy, questions could then be asked whether students with better digital literacy would be more capable of supporting their classroom peers.

F. Affecting Change with Interventions

From an interpretivist perspective, a more flexible and personal approach is taken when executing the structure [16]. The epistemological approach of this project is constructionism based on a constructivist learning theory [17]. This approach denotes that learning consists of building knowledge structures, which is especially felicitous where the learning is engaged in building an artefact [17]. Planned future research in this area aims not to showcase the value of technology, rather it endeavours to pursue activities whereby technology is selected based on being best fit to assist in solving problems adopting the ‘pedagogy before technology’ approach [18].

Cobb, DiSessa, Lehrer and Schauble [19] explain that design-based research (DBR) is a series of approaches with the intention of producing new theories and practices that account for impactful learning and teachings. This lends itself well to be applied to the Australia Curriculum where a ‘design thinking’ approach is encouraged across technologies curriculum in general [20]. The respective steps involved in design thinking can be seen as illustrated in (Fig. 1)

![Fig. 1. The phases of design thinking.](image)

DBR tends to surface diverse epistemological challenges with methodologies typically involving a variety of tools and techniques [21]. DBR through its evolution has become a practical research methodology in education acting as the bridge between theory and practice [21]. For these reasons this research project will be performed through a DBR methodology with the iterative approach of the research reflecting the natural setting of classroom learning.

III. BUILDING BETTER PROGRAMS

The review of the common factors that lead to success highlight the dynamics that contribute to successful outcomes in
technology programs. These points are justified through peer reviewed research which form a widely accepted knowledge base. There are, however, some challenges to work through in this space.

One of the key challenges in looking at a theory-based approach is the potential to overlook the industry practices and even real-life factors that exist. These are often the extension activities, undocumented challenges, or even softer requirements that lead to a program’s success. Examples of the factors above and beyond the theory in this paper are leadership principles, such as having a clear vision or fostering community support for the program. When these additional factors are taken into consideration, it provides a more complete picture of what a technology program model should look like. Where vision is central, softer human-based factors are orbiting closest to the vision and more action-based factors radiate outward, all playing an important role as shown in Fig. 2.

**Fig. 2. Summarised factors of success.**

**IV. CONCLUSIONS AND FUTURE WORK**

By examining current studies there is strong empirical evidence that there are fundamental benefits to adopting a structured approach when implementing a technology program in educational settings. The literature further identifies specific factors when formulating such a structure, with some areas of execution having a higher impact on the success rate than others. One of those high ranking factors is the quality of the educator, which can be developed through sound professional learning practices.

The future development of this study will explore these success factors with a particular focus on the professional learning elements. This will include the upskilling of students using classroom-based interventions under a DBR approach to investigate whether this will be an additional factor to consider when deploying a successful technology program.

**REFERENCES**


Work-in-Progress—Exploring Model Based Automated Response Systems to Enhance Student Outcomes

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Abstract—The advancement of Artificial Intelligence (AI) has sparked great excitement and expectation of its use in education. Integral to that is the idea of an Automated Response System (ARS). Huge strides have been made in the adaptation of ARS in education, although a suitable theoretical framing has yet to be explored, especially in the context of designing an ARS. A previous proposal to use the Community of Inquiry (CoI) model was presented, but a case could be made that the link between the perception, attitudes and outcomes could be much better explored as part of the design. Hence, a different approach involving the technology acceptance model (TAM) model is explored in this paper toward its use to design an ARS to help statistics students better meet a more holistic learning outcome.

Index terms—automated response system, educational technology, student engagement, higher education

I. INTRODUCTION

Advancements in Artificial Intelligence (AI) have created new ways of teaching and learning, supported by enhanced monitoring and student assistance. One of the key aspects of these AI systems are that of Automated Response Systems (ARS). However, these systems, whilst commercially adopted, has not been widely adapted in education [1] despite its promise. Thus, it would be useful to explore how ARS could be reframed to enhance these ‘teacherbots.’

A proposal was presented in an ASCILITE 2021 conference on a framework for designing ARSes. This proposal was based on the Community of Inquiry (CoI) model [2]. It posits that CoI model is a suitable model due to its ability to explain the different dimensions (or presences) that make up the educational experience in an online learning environment. As such, since ARSes are likely to be deployed in an online learning environment, it should be considered as a foundational model that underpins how ARSes are to be designed due to the obvious suitability.

This paper aims to propose an alternative framework that helps in the design of these systems by answering the question: ‘How do we use the TAM framework to design an ARS system that aims to enhance meeting holistic student?’ This will serve as a further exploration and answer to the initial proposal presented at the ASCILITE conference, albeit with the same larger overall aim of finding out which features of an ARS would need to have in order to help student meet holistic student outcomes.

II. RATIONALE

ARSes present new and exciting ways of teaching and supporting students. However, not much research has gone into this area of research. Most AR research over the past 20 years have focused more clearly on the systems and user experience aspects of these technologies, as opposed to the pedagogical aspects of it [3].

A comprehensive analysis of published literature in reputable journals over the past twenty years has also led to a similar conclusion, with only one study [4] based on a vigorously tested theoretical foundation. Overall, the studies generally utilised theoretical foundations that were not fully compatible and thus it is important that a suitable theoretical framing be identified that can help design an ARS that looks at enhancing students meeting holistic student outcomes.

Hence, it is important to explore more theoretical models for a more comprehensive view of what models could be considered in as a framework to shape the design of ARSes.

III. LITERATURE

A quick view of existing literature indicate that whilst most studies are not theoretically grounded [3], [4], two models seem to have a larger influence on some of the conceptual work around the study. The two models of the community of inquiry (CoI) model and the technology acceptance model (TAM) are most represented in the literature reviews conducted [1]. By way of background therefore, the below literature review provides some details of how these models work.

A. Community of Inquiry (CoI) Model

Given the prevalence of the CoI model in the literature, a good starting point would be to explore the Community of Inquiry (CoI) model [6]. The CoI model was created with online learning experiences in mind [7], and framed within the three key dimensions of social, cognitive, and teacher
presence and the interaction of each dimension with each other.

Each dimension is complemented with a 4-phase model of practical inquiry, namely triggering event, exploration, integration, and resolution. Current applications of CoI in online learning have seen the further development of many features that are now considered commonplace in most online courses, such as talk channels, course content catered for online teaching and feedback channels [8].

In the 2021 proposal, the CoI guided the exploration of features through each dimension (also called presences in the model) and the interaction between dimensions. Features such as collaborative learning support was highlighted due to the interplay between cognitive and social presences, showing the CoI model to be a useful model on which features to consider that an ARS can incorporate that would enhance the learning experience.

However, the CoI model is not without its criticisms. The authors put the lack of initial success of the CoI down to issues with the implementation of the model, rather than with the model. Later discussions and critiques of the CoI model has also challenged the model. The completeness of the model and its exclusion of other factors have presented a conceptual challenge [9], as well as the applicability of the model with motivation and engagement [5].

B. Technology Acceptance Model (TAM)

The other model that is commonly used is the technology acceptance model (TAM) due to its seminary role in understanding behaviour in relation to technology [10]. Created by Davies (1989) to better explain how technology is accepted and adopted by users, the TAM is defined primarily by the two main factors of perceived ease of use and the perceived usefulness (Figure 1)

![Fig.1. Technology Acceptance Model by Davies (1989).](image)

In an online learning environment, the acceptance and attitudes towards the technology play a significant role in effective learning and more specifically, in the area of self-directed learning [12]. TAM has also been used as a basis to show the structural relationship between technology acceptance and other aspects of learning, such as self-regulated learning, self-efficacy and even learning anxiety [12].

When applied at the University of Auckland in Davis and Wong’s (2007) study, student perceptions of the design of the CECIL system (e.g., flow and playfulness etc) are stronger predictors of usage intention. However, the TAM has not been as effective at predicting earning outcomes as the exploration of the TAM-learning relationships have yet to find significant results [13].

As with the CoI model, the TAM is not without its criticisms. The TAM view external factors as dependent variables, rather than as a means of finding out which factors affect acceptance [10]. The TAM also relies heavily on the behavioural intent to adopt, which is both difficult to measure and sometimes may not have any relevance due to possible compulsion. Although the usage of the ARS may not be voluntary, attitudes towards it and the subsequent learning experience should still be explored.

To address some of these criticisms, the UTAUT was birthed. Born from the TAM, but understanding the social and societal context, the Unified Theory of Acceptance and Use of Technology (UTAUT) was created by Venkata et al. [14] to better explain the various factors that influence user behaviour. It also highlighted and drew stronger links between the relationships of the attitudes of the user and the intended outcomes, explain about 77% of user adoption and 55% of variances of user behaviour[15].

Nevertheless, despite the presence of the UTAUT in the space, a clear direct link between the TAM or the UTAUT and learning is still unidentified, but studies have indicated that TAM forms the foundation of understanding the relationship between the technology and student outcomes [10].

IV. DISCUSSION

As a framework for designing ARS features, the CoI model supports the exploration of potential/existing features that contribute to the overall holistic student outcomes. Despite its support for exploration, it is hard to measure the impact of ARS on meeting the overall holistic student outcomes as it does not consider the relationship between the technology and the outcomes. Additionally, what the educational experience translates to is also not well explored. Additionally, real-world applications of the CoI model had lower levels of success than predicted, although this is attributed to implantation issues, rather than weakness in the model itself.

In addition, any framework should also consider holistic student outcomes as the intended outcome. There is an argument to be made that holistic student outcomes should be examined more as learning happens more than just that of student meeting pre-defined learning objectives. Studies examine the impact of learning technologies on student outcomes is both limited and outdated [16], [17], and there needs to be a more holistic view of student outcomes when designing the technology. Most of the studies focus on the problem and the nature of the problem itself or on the probing of new technological boundaries [18]. Thus, the framework should allow for the design of an educational technology that has a more holistic learning outcome in mind.

In this regard, the TAM might be considered to draw the relationship between intention, attitude and outcomes better. This allows a more causal manner of designing an ARS with the intended user behaviour in mind. By extending the attitudes and perceptions of certain technological tools, TAM will be able to frame the key technological features
considering how it will affect the attitude towards the technology, which in turn explains the possible behavioural outcomes. This, rather deterministic view, has been used frequently in other information science studies to great effect, showing its potential in an application in a similar technological space.

Furthermore, although the TAM is a primarily a model set within the information science space, the TAM is also suitable in the design of educational ARSes as the relationship between TAM and learning have been well documented and could be extended by including other external variables, and the application of TAM in multiple studies also shows its flexibility and applicability in different contexts [19].

So, by exploring the two most commonly used models, we have arrived at the juncture where there are two models (CoI and TAM) that both seemingly work and can contribute immensely to the design of ARSes in an educational context. Future work might consider how one or both of the models might be adopted and implemented but should be informed by a systematic literature review.

V. SUMMARY

In summary, the TAM is a useful framework that can be used to explore the design of an ARS. It gives enough consideration to the relationships between the technology and the attitudes, which remaining cognisant of behavioural outcomes. Whilst it is not without its weaknesses, it is well worth considering as a framework when designing ARSes that help student meet their student outcomes.

Yet it’s clear that further exploration and investigation of other models will have to be conducted and continued, due to the weaknesses of each model. all whilst being informed by systematic reviews of how these models are being used. This continued exploration will strengthen the case for the design of a framework that is pedagogically and theoretically sound. A future study may be able to better express the results of this exploration.

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Work-in-Progress—Extended Reality Pilots for Hybrid Learning: a New NUFlex for Northeastern University

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Abstract—The COVID-19 pandemic forced Northeastern University (NU) to pivot to virtual in Spring 2020 and spurred innovations in hybrid learning called NUFlex that were implemented starting in Fall 2020. However, for many courses and topics taught at NU standard hybrid learning is insufficient to create the ideal pedagogical experience for both students and instructors. Extended reality technologies such as augmented, mixed, and virtual reality can be leveraged to make the NU Flex experience more dynamic and immersive. We are developing best practices and pilots that blend XR technologies with course activities through iterative improvement while collecting student reflections, work samples, and survey data, that we present in this Work-in-Progress. We hope that these technologies can be scaled into other courses in the future.

Index Terms—extended reality, mixed reality, hybrid learning, STEM education, asynchronous learning

I. INTRODUCTION

The COVID-19 pandemic created a scenario where students were unable to attend classes in person due to social distancing and classroom capacity limitations at Northeastern University (NU). Beginning in Fall of 2020 NU implemented a hybrid learning model in all classrooms called NU Flex. Density requirements for students meant that on any given day 30%-50% of students would not be able to attend class in person. The attendance of students was managed by a web interface through the learning management software Canvas. Travel restrictions meant that many students were unable to return to campus and could be in a different time zone. NU Flex as implemented meant that every classroom has cameras and microphones to extend the classroom to Zoom. While this was effective for some courses it posed serious problems for many studios, labs, and skills-based courses where collaboration and use of equipment is required. Extended Reality (XR) technologies can be used in hybrid learning to augment the basic model of live classroom video. XR technology includes virtual (VR), mixed (MR), and augmented reality (AR).

The primary XR equipment used in the pilots is the Microsoft HoloLens 2 which is an MR head mounted display that maps the physical environment and projects images into like viewing 3D information [1]. Recently there has been increasing interest in the use of XR in higher education [2] but it remains difficult and expensive to implement. The technology is still being explored so educational theory is still being applied to finding the best practices of XR [3]. This project attempts to address this issue by starting with small scale pilots that have been designed to be implemented into a range of courses.

COVID-19 has lead to more research in XR teaching modalities with the goal of looking at performance and engagement [4]. How to study learning using XR is still being defined with many possible approaches. The pilots will be tested using methods of comparison with current practices in 2D [5]. There is still very few research studies aimed at studio and art teaching while there is more robust findings for STEM and engineering education [6].

The guided flow of Makerspace Training.
lenses. The lenses containing holographic projections are positioned in front of the user’s eyes, which creates the effect of a 3-dimensional hologram.

II. LEARNING PILOTS

These pilots are being implemented into courses currently running and are meant to be a week in duration. They were chosen to fill specific pedagogical needs around course activities.

A. Mixed Reality Makerspace Training

Even after COVID-19 related density requirements were lifted there are still advantages to creating MR training for makerspaces. These include asynchronous training times, analytics and authentication, and remote training. Currently, training is performed using a web-based training presentation and assistance from a technician. The MR training allows more in-depth and real-time training focus and flexibility for the technician to administer and evaluate the training. This pilot will allow students to be trained on 3D printers without a technician on site and will also allow them to refresh their skills at any time by simple rerunning the training. As seen in Fig.1., the flow of this training will start on Canvas with information about Computer Aided Design (CAD) and then proceed in the makerspace with a HoloLens 2.

![Fig. 2: Students wearing the HoloLens 2 to view a digital drawing subject in Observational Drawing.](image)

B. Mixed Reality Remote Drawing Studio

During class, students are required to develop their drawing skills by observing combinations of physical objects that are placed under a controlled light source. Being absent from class, remote learners do not have access to this aspect of an observational drawing course, which puts them at a disadvantage. Another advantage of the MR training is for guided practice outside of the studio in a controlled space. This pilot allows finer scaffolding of drawing skills for students to gradually increase the drawing subject difficulty so learners can advance at their own pace without losing momentum. The “Remote Studio” idea makes use of the HoloLens’s ability to create 3-dimensional holographic projections for the user. In this case, students would be given a HoloLens that is pre-loaded with a series of drawing exercises that rely upon 3D models. With various 3D modeling applications, the lighting conditions and object combinations would be identical to those presented in the classroom. Additionally, the students would be able to repeat various timed drawing exercises and unique drawing scenarios with the goal of getting more practice with techniques presented in the studio class. Student testing this pilot can be seen in Fig. 2.

C. Expert View for Skill-based Learning

There is a long tradition of teaching specific skills and methods in the practice of observational drawings. Teaching techniques like comparative measuring and how to achieve proper perspective have been limited to asking students to observe the use of the techniques from behind or over the shoulder of the instructor. Furthermore, observing the use of the techniques is supplemented with verbal explanations that can be elusive initially. With advancements in technology and spatial computing, students can see the use of these complicated techniques from the perspective of the instructor. Essentially, instructors now have the means to show students what is being observed, how a technique is being used, and specific scenarios where the technique can be modified by using the Microsoft HoloLens 2 in conjunction with Microsoft Remote Assist.

For Expert View, this capability of the HoloLens 2 to project a hologram is combined with Microsoft Remote Assist, which enables an onlooker to see from the perspective of the wearer. Ideally, a drawing instructor would wear a HoloLens 2 and draw a subject using traditional observation techniques that are typically challenging to explain and challenging for learners to envision. As the instructor uses the technique, his or her perspective will be streamed or recorded for the students to see.

When the student wears the HoloLens 2 the instructor can review and observe the students’ application of skills in real-time or asynchronously, which is not possible with traditional instruction. This unique learning space where the instructor can assess student learning from the perspective of the student.

D. Remote Critique

This is another pilot that uses the Remote Assist software on the HoloLens 2 which the student wears during a critique of their work. By using the Remote Assist software, the instructor and classmates can comment and discuss in real time while seeing the piece. Another possible configuration is that the instructor wears the headset, and the creator of the work uses the software to discuss the critique. Once the critique video has been captured a social video app can be used to add asynchronous feedback and discussion.

In Observation Drawing students learn to develop a drawing practice. A key component to this is learning how to critique the work of others and how to receive feedback about their own work. In the current NUFlex environment this means taking a lot of pictures of the work and sending them to be critiqued by others on a screen. Instruction with a class-wide camera on the faculty member at the front of the room is not conducive for learning so a better solution is that the student can view from the view of the instructor.

E. Live Virtual Reality Course Streaming

This pilot is the most straightforward, students will be able to join courses taught in a makerspace or art studio in VR. Currently students can join these classes by video on their
A. Mixed Reality Makerspace Training

Data collection has begun for this pilot with 10 students given the HoloLens 2 to familiarize themselves with MR and then asked to complete the training via either the web-based or MR training program. Current results show that students have found the MR training effective with a follow-up quiz has shown both training methods to be able to teach training topics. The most mentioned feature of MR training was the ability to advance the training without using their hands and that it was simple to move the training forward or back compared to pausing a video training. The weakest element of the training has been identified as a small field of view sometimes occluding MR visuals for the training. The Data collection will continue until n = 40.

B. Mixed Reality Remote Drawing Studio

A total of 9 students have used the HoloLens 2 to draw holographic forms in basic drawing exercises that would otherwise be completed through observation of physical objects. The students were then asked to apply the skills that are cultivated using the HoloLens 2 to the traditional observational drawing practice of replicating a “still life” to the best of their ability. Initial results show learning experiences presented through use of the HoloLens 2 closely mirror those presented in a traditional in-person studio setting. Due to the novelty of the HoloLens 2 and the overall experience, students showed willingness to repeat the drawing exercises presented in the device. The level of engagement is particularly notable because repetition is historically the best method for cultivating observational drawing skills. The narrow field of view and the quality of the holographic models presented by the HoloLens 2 were raised as issues by participants. Furthermore, some participants had trouble getting accustomed to the use of gestures and gaze as input channels for the HoloLens 2.

V. Future Work Plan

Currently pilots A, B, C, and D are ongoing and collecting data. Each of the pilots will have a small study of 10-20 students performed in April. Once those are completed data analysis will commence.

The goal of this project is to create best practices for implementing these pilots into other courses at a larger scale at NU. The project team has begun outreach to evaluate other faculty and courses that would fit the goals of the pilots.

ACKNOWLEDGMENT

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VI. References


Work-in-Progress—Unity between the Two Worlds: Microscopic Data-Based Immersive Experience

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Abstract—Since the 21st century, advanced technologies have prompted the divergence of learning materials. Recently, learning materials for immersive learning, adopting contents based on raw microscopic data, are emerging. As such, technologic advancement of microscopy has been emerging, as well as that of learning materials. This work-in-progress study describes the approach to envision the structure and function of organelles in plant cells based on more precise raw microscopic data as learning material for students.

Index terms—immersive virtual reality, pollen tube, microscopes

I. INTRODUCTION

Since the 21st century, advanced technologies have prompted the divergence of learning materials. For instance, interactive systems with multitouch tabletops and leap motion have been installed in diverse learning settings. This approach has been supported as strategies to gain the number of personnel for science, technology, engineering, and mathematics, who can problem-solve sustainability issues and drive innovation across the world. Therefore, it is pivotal how the learning materials and environments are offered to enhance efficacy in fostering scientific thinking and creativity [1].

To trigger student interest, it is crucial to provide an efficacious and a realistic experience. The author, a plant cell biologist, used various approaches for observing the architecture and function of organelles within cells without using raw cells; however, preparing and handling raw cells due to their small size and frangibility was difficult. Hence, microscopes are required to explore the microworld within cells (Fig. 1). Recently, learning materials for immersive learning, adopting contents based on raw microscopic data, are on a rise [2], [3]. For an efficacious and realistic experience, it is worth to combine virtual reality (VR) with raw data afforded by microscopic observation. Employing the VR technology ensures the possibility to yield a realistic experience in a virtual space while simultaneously providing efficacious approaches for learning cell biology. The author has developed the learning materials to envision the subcellular plant cell structure through three-dimensional (3D) reconstruction using an advanced 3D printer [4]–[6] and an immersive VR approach [7].

Technological advancements in microscopy and learning materials have taken place. Peculiarly, correlative light and electron microscopy (CLEM) is a method that enables obtaining microscopic data from simultaneous observations, combining light or fluorescence microscopic observations with those of the transmission electron microscope, and merging the correlation between the obtained images, i.e., unity of the two worlds between fluorescence microscopic images and electron microscopic images [8], [9] (Fig. 2). This method correspondingly unveils both the subcellular localization and ultrastructure of organelles. This work-in-progress study aims to describe the immersive VR approach to envision the structure and function of organelles in plant cells based on more precise raw microscopic data as learning materials for students.

II. DESIGN AND DEVELOPMENT

A. Plant Cell Outline

Several cell types in organs and tissues comprise plants, which afford the diverse biological phenomena. The cell is the minimal unit that composes organisms on Earth, whereas various organelles with diverse functions make up raw cells. In raw cells, a range of biological reactions occurs between organelles, such as the nucleus and mitochondria. This work-in-progress study focuses on the mitochondrial behavior of the pollen tube in Arabidopsis thaliana, an angiosperm as the internal structure of the pollen tube is easier to observe under light or fluorescent microscopes than that of the pollen due to the complex cell wall structure. Mitochondrial behavior alters with the increasing or decreasing pollen number or size during development so that it is suitable for the aim of this work-in-progress study to develop the learning materials combining microscopy with immersive VR technology.

![Microscope Resolving Power](image)

Fig. 1 Microscope for exploring the microworld
B. Material Preparation

Arabidopsis seeds were cultured on ½ Murashige–Skoog medium supplemented with 1.5% sucrose and 0.8% agar, then seedlings were transferred onto soil. All plants were grown under a 16–8 h light-dark cycle at a constant temperature of 22°C for a month. Mitochondria in the pollen were labeled with green fluorescent protein (GFP) using a gene recombinant technique. Arabidopsis pollens were cultured on pollen tube germination medium (0.01% H3BO3, 5 mM CaCl2, 5 mM KCl, 1 mM MgSO4) supplemented with 10% sucrose and 1.5% low-melting agarose. Two sperm cells and several mitochondria could be observed using fluorescence microscopy (Fig. 2). The nuclei and mitochondria were stained using 4',6-diamidino-2-phenylindole (DAPI) and GFP, respectively, due to the identified position of the mitochondria. Light and fluorescent microscopic observation and image acquisition of the pollen tubes were performed under the BX51 automated fluorescent microscope. Subsequently, entire pollen tubes were chemically fixed with 4% glutaraldehyde/4% paraformaldehyde for 16 h at 4°C, then chemically fixed with 2% osmium tetroxide for 16 h at 4°C. The fixed leaves were dehydrated stepwise with ethanol series before being embedded in Spurr resin. Then, they were sectioned thin (1 mm) and ultrathin (70 nm), respectively. Thin sections were prepared on glass slides. Ultrathin sections were collected on copper grids (75-mesh) with support films and stained in 4% uranyl acetate and 0.4% lead citrate. Thin and ultrathin sections were observed under an automated fluorescent microscope and a transmission electron microscope, respectively.

III. RESULTS

A. CLEM Observation

The fluorescent and transmission electron microscopic images were superposed. Fluorescent microscopic images showed mitochondrial localization, and transmission electron microscopic images showed the mitochondrial ultrastructure in detail. These data confirmed alterations in mitochondrial behavior, including number, size, and internal structure during pollen development.

B. 3D Reconstruction

Mitochondrial images captured using the transmission electron microscope were analyzed using Adobe Photoshop CS6, an image processing software (Fig. 2). The structure of the cristae was rugged and complex. These were aligned and segmented when the objective structure was extracted. Such 3D reconstruction data was developed as learning materials with immersive VR technology with Unity.

IV. DISCUSSION

This work-in-progress study demonstrates the process of developing an immersive VR approach as a learning material for students to better help them understand the structure and function of mitochondria in Arabidopsis pollen tubes based on raw microscopic data. Integration of obtaining raw data and developing learning materials is a complex process. To bridge the gap, the author attempts to deploy the immersive VR technology for more precise subcellular mitochondrial reconstruction. Building contents for immersive learning about pollen tube cells as learning materials is currently ongoing properly. Once this method is established, various XFP-labeled organelles (such as GFP-, red fluorescent protein [RFP]-, or yellow fluorescent protein [YFP]-labeled organelles) could become available for immersive learning. Organelles in organs and tissues, such as the endoplasmic reticulum, Golgi apparatus, plastids, and plasma membrane, require treatment with fluorescent dyes, such as DAPI, or gene recombinant technique for microscopic observation of double-labeled organelles. To this end, the author hopes to complete the development of this interactive system for efficacious immersive learning in plant cell biology. In the future, students would have the opportunity to experience this learning material as an immersive hands-on program with the help of an appropriate toolkit in diverse learning settings.

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Work-In-Progress—Developing Materials Science Experiments Using Augmented Reality: How Much Reality is Needed?

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Abstract—This work-in-progress paper presents two Augmented Reality applications for teaching fractography. The first application has little connection with reality, whereas the second application has a strong anchoring and dependency with reality: students need to have prepared physical lab samples to trigger the display of virtual elements on their phone. Student feedback reveals a tension with the teacher’s view on how much reality is needed. Where the teacher sees the use of physical samples to assess laboratory skills, many students view Augmented Reality as a learning complement on the theoretical rather than the experimental aspects of fractography.

Index Terms—Augmented reality, materials science, experimental skills, fractography, samples, reality

I. INTRODUCTION

3D simulations and virtual laboratories are effective for teaching STEM subjects, especially when students struggle with understanding phenomena that are difficult to conceptualise without visualising them or interacting with them. Contrarily to Immersive Virtual Reality (VR), where users are completely disconnected from their physical environment, Augmented Reality (AR) preserves a connection with the physical world: it overlays virtual elements on top of a mediated view of the user’s physical environment, typically provided by a smartphone or a tablet. The user points the device’s camera at a physical object to trigger the appearance of virtual elements, which are contextually useful. Researchers have shown that AR-based learning activities not only improve knowledge construction and retention, but also engage learners in high flow experience levels [1], [2], and allow students to learn in a variety of ways, mixing didactic, experiential and kinaesthetic learning [3]. It has also been found that an AR system can make learners integrate real objects and multimedia elements with positive emotions so that the mental load is reduced, and that the sense of immediacy is increased [4].

The purpose of this work-in-progress paper is to contribute to the discussion on “how much reality is needed” for AR to be an effective learning tool in STEM experiments. We present two AR applications for teaching fractography (a difficult topic in Materials’ Science), with different degrees of connection with the physical world, and for which we have collected student feedback. It is worth mentioning that students continue to consider chemistry and materials science among the most difficult STEM subjects, as they need to develop mental models of the microscopic interactions between atoms and molecules that explain the macroscopic observations. AR has been used with some success to teach molecular and sub-cellular processes, helping students appreciate how the structure of molecules often dictate their function [5], [6].

II. AUGMENTED REALITY FOR TEACHING FRACTOGRAPHY

Fractography is the study of the fracture surfaces of materials. At the macro (i.e., visible) scale, different materials fracture differently, depending on their atomic structure, mineral composition, grain size, and natural flaws. The difficulty for students is to understand the relationships between the visible phenomena on the surfaces and the materials’ invisible inner structures.

Immersive VR would allow students to be transported into the world of the infinitesimally small to observe the phenomena at atomic scale. However, they would lose sight of the phenomena which are observable on the surfaces, hence still experience difficulties relating the two scales [7]. Conversely, AR can make the experience tangible, allowing students to hold a physical object in their hand and to trigger a fracture by selecting a stress force and a stress point on the object’s surface. The students can then control the speed of the simulation, making visible the otherwise very fast, hence invisible fracture phenomenon. They can also “zoom in” the surface of the material to make a microscopic image appear.

The two AR applications presented in this paper have been co-created within interdisciplinary student-staff partnerships. The partnerships are made of producers (computer science students and staff) and clients (materials science students and staff) working together towards the creation of VR and AR learning resources [8]. Both applications run on Android mobile phones and are implemented using 3ds Max, Blender, Unity3D, Vuforia and C#.
III. FIRST AR APPLICATION

In this first application, the AR system recognises word cards printed with the names of three different types of material (glass, cement and ceramic), which the students hold in their hand or place on their desk. Once the type of material has been recognised, a virtual model of a sample is overlaid on top of the card, as well as simple UI components for the student to choose the magnitude of the force (strong/soft) that is applied on the material’s surface, as well as the speed (fast/slow) of the fragmentation simulation (see Fig. 1). The fragmentation itself is triggered by selecting a stress point on the virtual sample. After fragmentation, the student can observe the internal molecular composition and structure of the material using a two-finger zoom gesture on the surface of the virtual model.

We collected feedback from 17 volunteer students on a Materials Science undergraduate program. A demonstration video was shown to the students, following which they installed the application on their phone. Word cards were provided. After experimenting with the application, all students filled in an online questionnaire.

- **General knowledge of AR and attitude towards AR:**
  13 students (large majority) have used AR before, and 12 students believe that AR can be of great help when learning Materials Science.

- **Feedback about the application design and functionality:** a majority of students (n=10) thinks that the operating steps are easy to use and remember; 11 students think that the application can recognize the target images quickly enough; 12 students think that the recognition and tracking functions work well enough; 9 students think that the interaction is good; 13 students think that the application is easy to install.

- **Feedback about the usefulness of the AR application:**
  7 students only think that the application can improve their understanding of fractography; 9 students would recommend this AR application to their classmates.

Students’ suggestions mainly focused on the following aspects: the digital objects should be more realistic; the application should recognize the word cards in different fonts, including handwriting; more kinds of material should be included; more functions should be available; some guidance on how to operate the application should be provided; there should be more detailed information about the internal molecular composition and structure of the three materials.

The students’ feedback clearly indicates their readiness to use AR as a learning tool. It also shows that students find the use of the AR application easy, quick and robust enough. However, the perceived benefit in terms of learning is less clear, mainly because of the inconvenience of the word cards, a lack of realism, and the limited scope.

IV. SECOND Prototype AND MORE Reality

The main motivations for developing a second AR application are to address some of the earlier feedback and to strengthen the connection and dependency with the physical environment. This second application (still under development) is not meant to be used on its own but is embedded in the physical lab experimental process. It has four main functions.

The **preview function** (similar to the first application) provides explanations about fractography and interaction with virtual material samples and fracture simulations.

The **experiment function** requires students to have prepared a physical sample, which is used to trigger the AR recognition function and the simulations. Students are then required to break their sample: the AR application detects the pieces, explain the impact on the sample and simulate the resulting fracture on a virtual overlay.

The **virtual microscope function** provides detailed information about the molecular structure of the materials. Students need to have prepared a suitably small physical sample, which is used to trigger the display of a simple UI for controlling a virtual microscope (see Fig. 2). The microscope can also be controlled by changing the physical distance between the phone camera and the real sample.

Finally, the **review function** displays images of the real samples, which have been captured during the experiment.

The connection with reality is at three levels: via the use of real samples (link to experimental skills), via the control of the virtual microscope (link to lab equipment), and via the capture of images (link to the experimental process). Using a low-fi prototype, feedback on the system functionality has been collected from 87 students on the same Materials Science undergraduate program.

- **General knowledge of AR and attitude towards AR:**
  31% of the students have used AR before, 64% have heard about AR before, and only 5% don’t know about AR at all; 67% of the students think this AR application can help a lot, 32% think it can be helpful, but is not necessary, and 1% think it is not helpful.

- **Feedback about the preview function:** 72% of the students agree that it shows clear information about the experimental steps, 70% think it helps anticipate what is going to happen in the experiment, 45% think it can greatly complement other learning materials; 5% of the students think the preview function is not useful.

- **Feedback about the use of real samples in the experiment function:** 47% of the students think it will be easy to prepare the samples, 30% think it will help them improve their laboratory skills, but 20% think it will be difficult to make suitable samples; 91% of the students
think that interacting with the virtual samples (rotating and zooming) is helpful, while 8% think that observing the physical samples is enough.

- **Feedback about the microscope function**: 74% of the students think that the virtual microscope can help them get familiar with the real microscope; for the control of the microscope, there is a slight preference for the camera interface (30%) over the UI (24%).

- **Feedback about the review function**: 41% of the students think that capturing and later viewing images of their own samples and experimental results is good, compared to 23% of the students who think that standard images would be better, 36% have no preference.

Students’ suggestions mainly focused on the following aspects: the digital objects should be more realistic; more explanations about the materials’ micro structure; more about simple stress analysis; more material types; the application should run on any phone.

From this feedback, we notice the same students’ readiness to use AR and the belief that it can efficiently support learning. The second application has not yet successfully addressed all the limitations of the first application though, as some of the comments remain (e.g., more realistic models, more material types, and more explanations about the micro structure). Interestingly, the students mentioned the use of AR (especially the preview function) as a useful complement to other learning materials, and the idea of controlling the virtual microscope by approaching the phone to the physical samples is well received.

About the use of real material samples, the views are mixed, with only about half of the students confident that preparing good samples is doable and that the capture of images of the physical experimental environment is a good idea. A significant minority of students (20%) are concerned about the difficulty of preparing the samples (a fundamental laboratory skill) and the fact that the application requires the samples to be of a good standard (size, shape and thickness) in order to recognise them. This is both a technical constraint and a requirement from the Materials Science teacher, who expressed the requirement of using the AR application as a means to assess the quality of the students produced samples.

V. CONCLUSION

We presented two AR applications for teaching fractography. While one of them is essentially virtual, the second is strongly anchored in reality as it requires the handling of real material samples. Some students anticipate not being able to produce good enough samples, which they fear will prevent them from using the AR application. This is an interesting observation as the harsh reality of any Materials Science lab experiment is that it requires the availability of adequate samples. This raises the question of whether this requirement should be maintained or lifted when using AR. There is clearly a tension between the teacher’s view on this question and some of the students’ view. Where the teacher advocates the use of physical samples as a requirement to use the AR application and as a means to assess the students laboratory skills, many students view the AR application as a learning complement on the theoretical rather than the experimental aspects of fractography. Further evaluation will be conducted about the effectiveness of an AR system anchored in reality to support laboratory skills after the deployment of the second prototype.

REFERENCES


Work-in-progress—Visualization of Area Units with Augmented Reality

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Abstract—Area measurement has a high priority in mathematics school education. Nevertheless, many students have problems understanding the concept of area measurement. An AR tool for visualizing square units on objects in the real world is developed to enable teachers to support understanding already in primary school. This work-in-progress paper presents the initial test version and discusses the first teaching experiment results. The students’ feedback and use of the app showed possible adaptations of the AR tool, e.g., that the idea of dynamic geometry could be incorporated in the future.

Index terms—Augmented Reality, mathematics education, primary school, area measurement

I. INTRODUCTION

Most mathematics education curricula include area measurement, which is “widely viewed as fundamental” [1]. It is also needed in many professions, ranging from tailoring to occupations based on mathematics STEM subjects. Therefore, an understanding of area measurement is usually introduced in primary school, and the calculation of area takes place in secondary school at the latest. Generally, the concept of area measurement is part of the mathematical school education and is also needed, e.g., to understand integral calculation. With that in mind, it is alerting that many international studies show the poor performances of students in area measurement, especially of shapes other than squares or rectangles [e.g., [2]–[4]]. One reason for incorrect solutions is the confusion between area and perimeter. This is because many students have not understood the concept of area measurement. They often have a strong memory of formulas [5] and hope to use them for the appropriate questions. This suggests that the students can use formulas by memorization but have not internalized the concept behind the calculation. To counteract this problem, this paper presents the first version of an AR (Augmented Reality) tool for supporting the understanding of area measurement.

II. THEORETICAL BACKGROUND

A. Mathematics Education Background

It is widely accepted that there is a distinction between conceptual and procedural knowledge in the knowledge process (e.g., [6], [7]). This distinction is also shown in the field of area measurement. If students know sequences of procedures and can remember and repeat the steps, they have procedural knowledge [6]. For example, they learn the formulae to measure the surface of an area but cannot use them in different contexts, so it is visible that they only memorized the formulae. This means they can solve easy tasks by memorizing the procedure on how to solve similar tasks, such as calculating the area of rectangular shapes by measuring the length and the width of the area and then multiplying them to get a solution [8]. However, problems arise when tasks are changed or extended, e.g., transfer tasks. In this case, studies show (e.g., [4], [9]) that students have problems finding solutions of composite surfaces, e.g., the shape of the letter “L”. Herendiné-Kónya [3] discovered that, if students get a triangle on checked paper, they have problems to determine the area. Some of the students tried to multiply all three sides instead of counting the squares. Hence, the students have procedural knowledge to calculate the area by multiplying the sides but do not know what it means to calculate three sides of lengths. Wertheimer [10] described a linked problem: he reports about a child who correctly calculates the area of rectangles but still does not grasp how the area is built up from the row times its parallel repetitions, as is revealed when counting the unit squares. According to Kilpatrick and colleagues, conceptual knowledge means the “comprehension of mathematical concepts, operations, and relations” [11]. A reason for routine execution and less about the relationships could be that many mathematics books focus on procedural knowledge, especially for primary education. They include tasks on measuring a length but exclude the length principles (e.g., [12], [13]), such as using the same unit of length constantly and that the choice of units depends on the total length. These principles are also essential and necessary to understand area measurement because the determination of an area is based on the length principles. Furthermore, Breidenbach emphasizes that the formula “length times width” is wrong. The correct formula is “area of the rectangle = base strip times number of strips” [14].

The difference between length and area measurement is that lengths are one-dimensional, and areas are two-dimensional. The students must also understand this. Therefore, some studies focus on dynamical geometry (e.g., [15], [1]) and examine how the area changes by changing the length or the width. Other studies with fixed rectangles focus on covering these rectangles with square units (e.g., [5], [16]) to illustrate different ways to cover an area. Students should understand the structure of columns and rows without overlapping or gaps to achieve the number of square units. This knowledge is important to understand how to convert into smaller and larger units of measurement and how the total area determines the standardized units’ selection.

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B. Augmented Reality (AR)

AR enables the interaction of digital and analog experiences. Visualizations and animations can be integrated into the real world via digital media such as tablets or AR glasses. Various studies have shown that the direct integration of information on objects can support the learning process (e.g., [17], [18]). AR has the potential to help understand the concept of area measurement, especially the conversion of area square units. Furthermore, it can be operated with objects in the real world by estimating the area of different objects. Estimation is a necessary competence that is often neglected in studies [19] even though both children and adults show problems with it [20]. There are some shortcomings in current apps in AppStores for displaying and measuring lengths, widths, and areas of objects [21]. These apps aim to show the distance measured between two or more points. This is helpful if a user wants to find out the length or the area of an object in the real world. But for an explanation behind the given result, it is necessary to show the measurement units of the length and visualize the structure of rows and columns for the area.

This paper focuses on this research gap and aims to present a first version of the AR tool, which uses Augmented Reality to illustrate the structure of rows and columns for the representation and conversion of an area. In the future, it should also be clarified to what extent the learners will develop conceptual understanding by using the AR tool.

III. RESEARCH DESIGN

The Educational Design Research approach (e.g., [22], [23]) is used to develop and optimize a learning environment. In this way, a content-related and didactically reflected use of digital technologies (here AR) for learning is ensured [24]. The cycle of testing, evaluation, and adaptation is repeated several times. Currently, the learning environment is under development and is in the first phase of the approach. Fig. 1 shows the tasks.

![Fig. 1. Task to introduce area measurement with square units.](image)

After this task, the area of a real object (e.g., one side of a polyhedron-similar object) shall be determined. Therefore, a book was shown, and the students were asked “How could you determined the area of this book cover?”. This task was verbally described to the students. The AR tool which is implemented with Swift is offered as auxiliary means to solve the tasks. The learning environment was tested with four 4-graders. Clinical interviews were performed with only key questions defined and the requirement to follow children’s thinking [25]. A multiple case study [26] using qualitative data collection and analysis methods was conducted.

The teaching experiment took place in December 2021 in the Teach-Learn laboratory at Saarland University. By that time, the pupils had not learned how to calculate surface areas in class. The students were given tasks to determine areas with unit squares and then transferred what they had learned to determine the area of a real object and used the AR tool for subsequent visualization. Audio and visual recordings were made to track how the students reacted to the visualization of the unit squares with the help of the AR tool. The first version of the AR tool will be presented in the following, and the students’ reactions will be described.
displayed. Two of the students replied that when measuring, either centimeters or millimeters could be used, but centimeters were used for their calculation. Unfortunately, the process of converting could not be discussed. Nevertheless, the students’ approaches provided interesting results that may lead to possible improvements in the AR tool. These will be presented in the following discussion.

VI. DISCUSSION AND CONCLUSION

Interestingly, the students wanted to check the number of unit lengths by counting them. Therefore, following functions could be added: A point could be fixed at a corner of the object by clicking on it. Then the distance could be extended to the desired endpoint by dragging with a finger. Standardized units will be displayed to visualize the units. Afterward, the fixed point can be clicked again to measure the distance of the width and have the area unit squared displayed. This allows for the superimposed unit squares to be generated for the respective row, just as in dynamic geometry. This could clarify even more how the two-dimensional area is created by the distance of length and width. Additionally, with this functionality, any rectangular surface of an object could be displayed, making it possible to process transfer tasks.

The app could be extended by the idea of dynamic geometry, where the area does not remain constant but is created by varying the length and width. It is only possible to put the manipulated picture on top of the recognized object. This makes it difficult to transfer the code to other objects without creating a newly manipulated image. It would be better if the unit squares were created from determining the length and width. The principle would be similar to the AR measuring instruments for length measurement.

The next step is to consider adapting the AR tool and integrating these functions. Afterward, the tool will be tested again with students. In the further course of this research project, the plan is to adapt and enhance the AR tool to be integrated into a substantial learning environment [25] for area measurement.

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Work-in-Progress—Towards an AR Materials Library for Design and Engineering Education

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Abstract—Materials play an essential role in product design and affect many design aspects. Materials libraries are built by universities to provide resources and inspire design concept generation and decision-making. Augmented reality (AR) is a technology overlaying digital content onto the physical world and brings a new perspective on material library through increased engagement and interactivity. This work-in-progress paper aims to enhance materials education and foster disciplinary communication by establishing an AR materials library. The proposed library will contribute to design and engineering education by serving as a practical platform with material resources and a novel tool engaged in learning.

Index terms—augmented reality, materials library, design and engineering education, disciplinary communication

I. INTRODUCTION

In the twenty-first century, the facilitative role of technology in education has been acknowledged widely. This has led to a focus on the integration of education and technology. To a large extent, future-oriented education needs to leverage the use of technology and advance together [1]. In design and engineering education, learning about materials is essential as evidence of attaining knowledge that can support students to develop a comprehensive understanding of the industry and undertake design tasks [2]. Research on new materials, materials science, materials knowledge sharing, and materials banks open databases are more than ever before core aspects of sustainability, digital revolution, and transition to the circular economy nowadays. Several universities have established physical materials libraries to aid students’ learning. However, there are challenges, including space constraints and high capital investment [3]-[5]. As an enhanced version of reality achieved through digital technology, augmented reality (AR) in teaching is growing in popularity. Research reveals that teaching with AR is significantly advantageous compared with traditional teaching approaches regarding the extent of perception, engagement, and interactivity [6]. This study aims to make the case for AR in education further. It proposes an AR materials library that merges a knowledge learning framework about materials with AR technology to enhance learning and facilitate disciplinary communication in design and engineering education. This paper first presents a literature review of the role of materials knowledge and AR’s role in education, and then explains details of the AR materials library platform design from several key aspects.

II. RELATED WORKS

A. Role of Materials knowledge in Design and Engineering

Materials are considered an essential element in design and engineering education as they are critical in translating design concepts into reality and driving innovation in design practice [7]-[8]. It also fosters designers’ sensibility towards environmental protection and spreading the culture of regenerative design. People with design and engineering backgrounds are required to update their knowledge of materials to design with the available materials possibilities [2]. Materials, therefore, serve a vital role in fostering knowledge sharing between disciplinary subjects [9]. Some universities have developed materials libraries to offer students learning resources. Such libraries fall into two categories: physical and digital [3]-[4] and are pedagogically significant. However, they can be further improved. In the case of Laughlin’s material-object sets, it can be noted that, as the materials collection serves as a tool to enable designers to explore materials, they can be a bridge for exchanging and shifting concepts between material-oriented disciplines [4]-[5]. Physical materials library can provide material samples and sensory interaction with materials, but it requires a considerable demand of space and faces challenges of keeping it updated and connecting it with other materials banks. However, digitalizing materials platforms may solve these constraints and challenges, such as the Cambridge Engineering Selector, which can aid students in the identification and choice of a wide range of materials [10].

B. Augmented Reality in Education

AR is widely utilized in a range of fields of education, and can offer meaningful, accessible, and personalized content and experience to learners [1]. In real educational scenarios, AR-based technologies can provide perceptual assistance for learning activities by projecting media components onto the real world [11]. Meanwhile, the significance of AR in education has been acknowledged widely by researchers. Studies have proved the practicality of immersive interaction-based education enabled by AR, which involves students in engaging scenarios...
aligned with learning goals [12], AR can support a diverse range of learning styles, such as constructivist learning, which can inspire students to actively gather and analyze information and facilitate a deep and lasting connection to knowledge [11]. There is an app based on AR technology to support the understanding of crystal structures in the materials science domain and allows learners to better acquire materials knowledge by visualizing molecules [13]. This case offers a reference for AR-based material learning. For learners, the sensory properties of materials, including color, texture, sound, and smell, are crucial elements for interacting with the physical world, and the virtual world can complement information and enhance learning. Research has shown that students are more motivated and inspired if they learn in an AR-based and exploratory environment [6], [11].

III. PLATFORM DESIGN

Based on this preliminary literature review, it can be concluded that materials learning is important in design and engineering education and that AR, as an engaging technology, can optimize the teaching quality. Therefore, this paper proposes an AR materials library platform to combine materials education with AR technology. This platform consists of the database of materials information, immersive learning and interactive selection. It is intended to facilitate multidisciplinary collaboration and student engagement.

![4 Knows framework for materials knowledge acquisition.](image)

**Fig. 1.** 4 Knows framework for materials knowledge acquisition.

A. Materials Knowledge Acquisition Framework

The underlying mechanism of materials knowledge acquisition of the platform is based on the framework proposed by other researchers. There are four dimensions categorized in materials education: Know-What, Know-Who, Know-How, and Know-Why [2]. Fig. 1 displays the theoretical framework of this AR materials library.

This AR materials library will incorporate the 4 Knows structure, which will be utilized for both teacher-taught lessons and student-led learning. The first layer of the 4 Knows structure is Know-What, which can convey intuitive sensorial properties such as color, tactile impression, and temperature. There will be both physical and digital touchpoints for the sensory interaction. Through the AR equipment and physical samples, students will have a heightened sensory experience of the materials. The next layer is Know-Who, providing application examples to allow students to gain practical information and foster their aesthetic literacy. The demonstration of function and form based on AR technology can offer students a more immersive learning experience and inspiration for creation. The Know-How layer is primarily designed to assist students in recognizing how materials are processed. The AR world will facilitate an interactive and engaging experience of technical properties, with extensive audiovisual information that enables students to acquire a clear picture of the manufacturing processes. The ultimate goal is to develop students’ understanding of the manufacturing process and subsequently improve their capability to work with materials in practical projects. The final layer is Know-Why, which is a collection of physical parameters for students to comprehend the properties of the materials from the materials science perspective. The AR materials library will visualize the microstructure of materials, enabling the learning of relevant physical properties such as elastic modulus and shear strength.

B. Platform Function

This platform contains two main functions: Information Retrieval and Project Support. The information architecture of these functions is shown in Fig. 2.

![Platform function information architecture.](image)

**Fig. 2.** Platform function information architecture.

**Information Retrieval:** The platform will collect the necessary materials information to serve as the database of resources. According to the learning objectives, the platform will collect commonly classified materials. In addition, a range of new materials will also be introduced, though they are currently not being manufactured in volume. Overall, according to the materials knowledge acquisition framework shown in Fig. 1, this materials database will provide information include material properties, processing technologies, and application. Database sources across the materials library can be interdisciplinary and collaborative. First, suppliers can provide information on those materials that are extensively used, contributing to the students’ connection with the industry and keeping the database continuously updated. Second, materials scientists can provide information on materials at the leading edge of the discipline and thus orient students to explore the possibilities of materials in products. Third, the platform can be an open source that allows to link to other material banks and libraries, thus facilitating loops of knowledge.

**Project Support:** To ensure that students develop a comprehensive understanding and ability to adapt the knowledge, the design of Project Support is essential. The AR materials library will be available to students during the projects from three aspects, as illustrated in Fig. 2. First, students can access this platform to find and retrieve information about materials and obtain design inspirations at the research stage. Second, this platform provides students with virtual product models for material experience in daily practice. For example, students can apply different colors and materials to a virtual model and overlay the model in a real environment. Third, AR technology will also support students with real-time rendering in the prototype phase. In particular, students can utilize this platform for scanning hand-made models and then select materials in this AR materials library. In the augmented world, the rendering of the finished product can be visualized. The real-
time rendering function will benefit students by saving a significant amount of budget and time and allowing them complete their designs efficiently.

C. Supporting Software and Hardware

The core technological aspects enabling AR systems to function are interaction features, display devices, and tracking registration techniques [12]. Table I illustrates the software and hardware resources required in the platform establishment. About the software, Unity is a robust cross-platform 3D engine, which can be used to build applications deployed to the AR hardware. In the hardware aspect, mobile devices will be a good choice given their cost and accessibility. Handheld AR applications on mobile devices can minimize usage restrictions and is primarily for daily self-study. Additionally, AR glasses equipped with cameras and sensors can provide an immersive and interactive learning environment. With wearing the AR glasses, students will be able to use the digital materials library for difference operations, such as searching the material information corresponding to the physical sample and interacting with the displayed virtual product model for material experience in the design process.

<p>| TABLE I. SUPPORTING SOFTWARE AND HARDWARE |</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>Unity</td>
<td>Building high-quality 3D applications</td>
</tr>
<tr>
<td>Hardware</td>
<td>Mobile devices</td>
<td>Supporting daily learning without restrictions</td>
</tr>
<tr>
<td></td>
<td>AR glasses</td>
<td>Providing immersive and interactive learning environment</td>
</tr>
</tbody>
</table>

D. Advantages

In brief, this platform integrating the materials knowledge that students are expected to possess and the strength of AR technology is significant for both materials learning and collaborative communication. First, the multidisciplinary and collaborative materials database systematizes materials knowledge, ensuring this information is available in real time and facilitating interdisciplinary communication. Second, the immersive spatial environment and interactive visualization aid in knowledge acquisition. Combining virtual and tangible interaction enriches students’ sensory experience while enabling them to experience materials from diverse perspectives. Third, the framework for materials acquisition is designed for students to experience a journey from explicit sensory experiences to implicit specialized subject knowledge, which will motivate them to explore and apply the knowledge. Finally, digitized material database nurtures a sustainable lifecycle approach that addresses economic and resource concerns while keeping material knowledge updated.

IV. CONCLUSION

Overall, this paper summarizes the related works about materials learning and AR technology and then proposes an AR materials library platform construction. It is acknowledged that knowledge acquisition of materials is essential in design and engineering education. The physical materials library is limited by space and economic factors, while the online platform tends to be restricted within the inadequate sensorial information. Hence, on the basis of the materials learning and the attributes of AR technology, an AR materials library for enhancing learning in design and engineering education is suggested. The materials knowledge acquisition platform is structured on four levels: Know-What, Know-Who, Know-How, and Know-Why. Information Retrieval and Project Support are the core functions of this AR materials library. From a global perspective, introducing this AR materials library platform is significant and instructive for enhancing design and engineering education and fostering disciplinary dialogue. In the future, the platform will be further elaborated, with relevant functions implemented and experiments conducted. Additional stakeholders will also be considered to form an integrated materials education ecosystem.

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REFERENCES


Language, Culture, & Heritage (LCH)
Digitally Restoring Artefacts Using 3D Modelling Techniques for Immersive Learning Opportunities

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Abstract—Digital heritage projects are an important tool in safeguarding cultural heritage and making it available to future generations. The work presented here synthesises 3D modelling techniques with the process of digitising artefacts. New digital reconstructions can be created based on authentic data. These are then implemented in various immersive learning opportunities, such as interactive activities and engaging virtual worlds. This is applied to the restoration of two Pictish symbol stones used in an online colour configurator tool and a virtual environment.

Index Terms—digitisation, 3D modelling, immersive learning, virtual reality, digital heritage

I. INTRODUCTION

The digitising of historical artefacts is a crucial aspect of the conservation, preservation, and interpretation of culture. Advancements in technology have made it possible to create reconstructions of the past which go beyond a photograph or digital image. Increasingly, museums are digitising their collections, turning them into 3D models through object scanning, and using them as “digital surrogates” to make the artefact accessible in the digital world [1]. 3D scans can be used to interact with the artefact in new ways: rotating, zooming in, and digitally handling the artefact, something which is not common in traditional museum settings. This closeness to the digital model provides opportunities for people to get close to artefacts. However, it is often still presented in an environment that is not representative of its original context and use, or how that may have changed over time.

Digital modelling has been beneficial in developing replicas of the past. 3D modelling software and gaming engines can build objects and environments from the ground up. This has given new opportunities to interact with the past. Presenting artefacts as realistic 3D models can help the viewer understand their historical relevance as they can be visualised better. This could further be heightened by placing them in their historical setting. The importance of 3D models in increasing public engagement, accessibility, and experience has been observed in many settings [2].

This paper discusses how digital modelling techniques can be synthesised with 3D scanning to digitally restore artefacts and create authentic replicas in their original states. Artefacts which had already been photogrammetrically scanned were restored using digital modelling software and then used in various immersive experiences. Whilst the project focuses on Pictish sculptures, namely, the St Madoes Cross-Slab (Fig. 1) and the Inchyra Symbol Stone (Fig. 3), the techniques developed can be applied to other artefacts.

The next section will provide an analysis of digitising techniques and how restoration of digital models can take place. Section III will describe how historical research shaped the decisions taken during the restoration. Then, section IV will describe how the stones were restored. Immersive learning opportunities that arise from the use of the models are discussed in section V, followed by remarks on future work.

II. BACKGROUND

A. 3D Scanning Techniques

3D scanning can preserve a lot of information that a photograph cannot, such as size, texture, and surface shape. Interaction with the artefact is varied: from the use of the model in virtual or augmented reality to 3D printing and handling in physical interactions. 3D scanning of artefacts enables non-intrusive research, restoration, and exploration of theories about their use and appearance. Accurate data in 3D can be captured through photogrammetry, structured light scanning, or laser scanning.

a) Photogrammetry: Computer software can extract 3D coordinates of each point on the object from multiple overlapping photographs of an object from different angles. The spatial relationship between the points is calculated, creating a sparse-point model. The images are analysed again to create a dense-point cloud of the model. This point cloud is derived from the pixels of the image and since modern camera sensors have improved considerably, the large number of points on the model can show extensive detail. Since the data is taken from a photograph, the data points in a photogrammetry model can include colour information as well. This helps to create a digital model with accurate textures [3]. With the increase in computing power, it has become possible to handle hundreds of photos of one object. Digital cameras are readily available, and free and easy-to-use software make community-based projects a possibility [4]. Photogrammetry has proven useful in creating models of larger artefacts such as rock formations and forts [5], temples and archaeological sites [6], and stone crosses [4] amongst others.
b) Structured light scanning: The position of a 3D point can be calculated by measuring the deformation of a structured light pattern that is projected on the object [7]. When scanning small artefacts, structured light scanning is more favourable than photogrammetry as it can capture more details, since in photogrammetry less photos are taken to capture the surface of a small artefact, thus capturing less details [8]. This is also the case in finely detailed artefacts [9], [10]. The downside to structured light scanning is that it cannot be used on well-lit areas or in outdoor environments where ambient light overpowers the projected light.

c) Laser scanning: 3D data points for a model’s point-cloud are collected from sensors using a laser scanner and include typical XYZ coordinates as well as information about the material such as texture and colour [11]. Light Detection and Range (LiDAR) and other types of laser scanners use light in the form of pulsed laser that is emitted and received back to measure distance between the scanner and an object. Similar scanners are Time of Flight (ToF) which create a depth map based on reflections of a transmitted light that are usually captured with a camera. The popularity of laser scanning has recently surged due to LiDAR scanners in Apple’s iPad Pro and iPhone range, as well as ToF scanners in some consumer android products. This has facilitated crowd-sourced projects, such as the Earth Archive project which aims to scan and map the entire surface of the Earth to digitally preserve the Earth’s surface for future use [12]. Terrestrial laser scanning has successfully been used to preserve monuments and buildings [13]. Accurate replicas can be made which can help rebuild damaged buildings, like the Notre Dame Cathedral [14], and to analyse their conservation state [15], [16]. Spatial 3D models are increasingly used in virtual museums and many times, some form of laser scanning is used to achieve this.

Often, projects make use of a mix of scanning technologies, depending on the object being scanned, and the intended use of the digital model. Textures obtained from photogrammetry could also be laid over more detailed point clouds obtained through LiDAR scanning [17].

B. Methods of Restoring Digital Models

Theories about an artefact can be explored on a digital model. Non-invasive restoration and reconstruction show how an artefact looked through time. 3D scanning has been used to repair physical artefacts by 3D printing missing pieces [18]. Restoring an artefact could bring to light new ideas and link the artefact to its context. Working digitally facilitates an open workflow which keeps 3D visualisation projects sustainable and accessible as encouraged by the London Charter [19].

a) Repainting: Many sculptures were once painted with no physical remnants left today. Paint restoration work has previously been applied to digital models of Pictish stones [3]. This was done through a layered painting process which enables future experiments. Even if the result of the project is inaccurate, it can continue to develop as new discoveries are identified. Their work on medieval stone crosses had a focus of restoring the narrative function of the crosses. In fact, they chose colours which are familiar to their audience, even if there was no direct evidence of their use on the stonework. Virtual reality was used to test the 3D models. Audiences were shown unpainted and painted models and in fact, painted models were better understood by audiences. This work shows that 3D models can be used to enhance physical interaction and disseminate the historical narrative to a wider audience, immersing them in this narrative. A recoloured reconstruction of the St Madoes cross-slab was previously used in an exhibition, Picts and Pixels, at Perth Museum and Art Gallery in 2017 [20]. A 3D video was used to show the stone slab and it contributed to positive reactions from the audience. However, the model was painted in strong colours. Certain details were lost, and the damaged top part of the stone was not reconstructed.

b) Reconstruction: Recreating missing pieces can prove challenging depending on the affected area and the information available. Commonly, a similar item or area of the object is scanned and the resulting model is added to the missing part of the model being restored. This involves fitting the reference surface around the area of the damage by adjusting their point clouds [21]. While this method provides accurate repairs, it is difficult to achieve if the content of the missing area is uncertain. The reference material must also be very similar to the object being restored. Automated mesh editors have been developed using mathematical Poisson-based gradient field manipulation to combine meshes together [22]. However, this is limited to the framework used in the experiment. Other algorithms can enable intuitive cut-and-paste operation when editing surface meshes, where a detail from a reference mesh can be pasted onto a target surface, provided that there is a continuous one-to-one mapping [23].

This paper proposes more straightforward workflows which make editing a 3D model accessible by implementing 3D modelling techniques using computer graphical software. Digital software that allows manipulation of a mesh has been utilised before, such as in reconstructing missing bones in palaeontological scans [24]. However, our approach goes further by reconstructing missing pieces of the digital mesh and then restoring the object to its original appearance. The St Madoes stone was restored using Adobe Mudbox—a digital painting and sculpting software, while the Inchyra symbol stone, which had larger areas for restoration, was completed using Blender—an open-source 3D creation suite. The usage of these programs is discussed in IV.

C. Creating Virtual Environments

Museums are striving to incorporate virtual and augmented reality as an immersive tool for visitor learning and engagement. In the early twenty-first century, most museums dealt with audio clips and tangible activities to provide interactivity. However, the popularity of smartphones and the internet has made it possible to add an immersive layer to exhibits. People are nowadays more familiar with games and modern forms of interaction. Various projects have developed applications which are spread over the continuum between reality and
virtuality. Phygital heritage describes how integrating digital technology into physical reality can enrich communication of heritage values [25]. “Parallel reality” describes how a user can be present in the virtual and real worlds simultaneously [26]. Walking around a physical environment enables the exploration of its digitally restored reconstruction. Here, users do not need to switch between the real and virtual worlds in order to navigate them, but they do need to physically be at the location [27].

Other applications in museums and online are fully virtual and can allow users to experience heritage anywhere. The preferred style in such applications is of narrative communication, creating stories of the past in a complete realistic ecosystem [28]. Interaction in the virtual world leads to story progression with the object changing or coming alive in the virtual world. This is often representative of an emphatic storyline, where the user progresses through the experience and develops an emotional connection to it.

Virtual worlds have applications beyond museums. They are being used in education, entertainment, and by experts to navigate new theories [28], [29]. Immersive applications provide opportunities of experiential learning that is difficult to achieve through traditional artefact viewing. People engage differently when presented with a new world of information. Some will explore the extents of the world, others will stop and look at everything they see, interacting with each object. The objects and areas of a world could be simply treated as visualisations or as hot spots to more information. However, where data is uncertain, it should be communicated in a transparent manner. This can be achieved by documenting all sources and material and allowing them to be accessed from within the virtual environment [30]. Having this transparency ensures that a coherent virtual world can be creatively developed around an artefact even when there is partial contextual data available.

III. HISTORICAL RESEARCH

The approach presented in this paper was applied to reconstructions of two Pictish sculpted stones: the St Madoes cross-slab and the Inchyra symbol stone. These were chosen because of their importance in the Perthshire region. The cross-slab is a largely intact monolithic sculpture of the eighth century (Fig. 1), whilst the symbol stone is a possibly seventh century sculpture carved with Pictish symbols, to which at least three sets of ogham inscriptions have been added (Fig. 3). The sculptures are part of the collections of Perth Museum and Art Gallery. Since their re-discovery in the nineteenth and twentieth centuries respectively they have generally been treated as individual artefacts. In actuality, they come from the same temporal period and were found within the same landscape, something that is not immediately apparent due to the markedly changed landscape in which they once resided [31]. Hence, this was an opportunity to digitise and restore the collection of stones found here in order to present them to an audience who might not know of their link and the environment where they were found.

A. Recreating a Pictish Colour Palette

A Pictish colour palette was composed in order to establish cohesiveness between the restored models and to ensure future reconstructions on other Pictish stones. The objective was to create a range of colours that would have been available to the Picts. Therefore, concurrent historical sources were investigated to make decisions on the colour selection. These sources included pigment remains on stone and illuminated manuscripts contemporary with the Pictish period.

Portable x-ray fluorescence and Raman spectroscopy techniques have previously been used to detect pigment chemical residue on Roman stonework [32]. The lead and iron deposits revealed a colour palette rich in reds and yellows, with traces of white lead. These colours have also been observed on post-Roman, Insular sculptures including the Anglo-Saxon...
Lichfield Angel. Here, the core colours used were mixed to create different hues, as well as adding black and white to create different shades [33]. Red pigment was found on sculpted interlace of the Pictish Portmahomack sculptures, while white, which was possibly used as a base layer, was found on the Goodlyburn cross-shaft\(^1\) [20]. These findings reveal that reds, yellows, and white should be present in a Pictish colour palette. They also give an indication of which areas were painted and what effect could have been desired; most notably, using a white background to create contrast with the intricate designs.

More information was drawn from illuminated manuscripts, especially the Book of Kells (Fig. 5), created circa 800AD, and the Lindisfarne Gospels, created circa 715-720AD. These Insular artworks include intricate and colourful patterns in bright colours and a range which goes beyond red and yellow, to include blues and greens as well. These are the core hues that would have been available to Picts through natural minerals (red ochre or lead, yellow orpiment) and plants (woad blue). The colours could be mixed to create different hues and added to black charcoal or white lead to create different shades. A reconstruction of the Forteviot burial monument reproduced similar colours from the manuscripts (Fig. 6) [20]. From these colours, a 10-colour palette was created which is shown in Fig. 7. The 10 hues can be lightened or darkened and can capture accurate colours in any Pictish reconstructions.

B. Reconstructed Areas

With regards to the restoration of the stones, Inchyra has the most damage. The bottom wider part of the stone is broken off—destroying one of the fish symbols. This could be reconstructed by looking at the complete fish symbol incised on the other side. Most of the remaining restoration was in reconstructing pieces of the stone that had chipped off. Interestingly, two symbols on the Inchyra, on the side of the intact fish, were never finished by the creator [35]. These were only lightly incised in the final restored version and left unpainted to reflect their incompleteness. There is also some damage to the ogham inscriptions, mostly flaking. In order

\(^1\)The white pigment on the Goodlyburn cross-shaft was identified by eye only. It is currently awaiting XRF confirmation.
to not change the meaning of the inscription, no additional ogham lines were added, with the restoration only deepening their grooves.

The symbols on the St Madoes cross-slab have seen some erosion and damage and needed fine-tuning of their detail. The panels at the back of the stone are harder to make out but previous research had established what the symbols were originally [20]. The largest piece to be reconstructed was the top, where a pair of crouching lions were identified [31]. The reconstruction draws mostly from the lions carved on the Pictish sarcophagus found at St Andrews which was sculpted in the same period.

IV. DIGITALLY RESTORING HISTORICAL ARTEFACTS

A workflow for artefact restoration was developed and applied to both stones. This is detailed below:
1) Carry out historical research and form a colour palette
2) Plan a colour scheme for each artefact
3) Import digitised 3D model
4) Sculpt missing sections
5) Restore selected areas by painting and refining detail
6) Export model for use in future applications

This workflow can be applied to any artefact, irrespective of its historical period. The concepts in the workflow can be adapted according to the artefact; for instance, if an artefact does not have missing fragments, that step can be skipped. The following section will describe some techniques that can be applied. It is not a comprehensive list, but the tools can be reused on any 3D model, as deemed fit.

The choice of software is an important one and for this project Adobe Mudbox and Blender were utilised and compared. Mudbox is a software dedicated to sculpting and painting a 3D mesh. It was appropriate for St Madoes as most of the restoration involved manipulating the existing mesh. This was possible using the sculpting tools which alter the model similarly to real-life sculpting. Since Inchyra required more extensive reconstruction, it was restored using Blender, which offers a suite of features that go beyond sculpting and editing. These include Boolean operators which seamlessly add new parts of the mesh. Moreover, Blender comes with multiple modifiers such as Remesh and Decimate. These tools
help to fine-tune the final mesh, especially when new pieces have been added.

Blender was found to be the most appropriate program to synthesise 3D modelling techniques with the digitisation of an artefact to digitally restore historical artefacts. Working with a digital model which has been obtained through photogrammetry or other 3D scanning methods allows the final digital model to have realistic textures and accurate details. These would not be possible if a digital model is recreated from scratch.

A. Techniques Applied

Photogrammetrically scanned models, such as the two stones in this project create models with a high number of polygons. Moreover, the cloud points are often not uniform. This could be problematic when sculpting areas as the surfaces do not interact well with each other, creating vortex points or other errors. Therefore, some pre-processing is necessary to prepare the model for sculpting and painting. In the case of the Inchyra model, which was made up of many objects, the model was pre-processed by joining objects into one mesh and scaling to the correct real-life dimensions. This was followed by the Remesh modifier which created one mesh with orderly vertices and faces. This modifier can be controlled to reduce the number of faces without reducing the quality of the details. The mesh can also be Triangulated and Decimated to ensure smoother sculpting. The Remesh modifier can be reapplied to cohesively join additional fragments to the original mesh.

As discussed previously, there are several ways to reproduce missing areas in the 3D mesh. On St Madoes, this was the top part; on Inchyra, the biggest section was the bottom area, along with some smaller fragments that were dislodged at the time of discovery in the mid-1940s. For most of the smaller parts, using the in-built sculpting tools in Mudbox or Blender was sufficient to manipulate the vertices into shape. Bigger areas, such as the missing bottom of Inchyra, were done through copying similar areas of the stone. The new additions were scaled and shaped with the sculpting tools. Once complete, a Boolean Union operator merged the addition with the original mesh. This ensured any unused vertices were removed. The Remesh modifier could also be beneficial here to clean up the mesh before continuing to sculpt other details.

Once the structural changes have been made, the sculpting of details and painting can commence. Painting and refining should be done in a cyclical approach which ensures that areas of the model are viewed from every angle. Painting can be done on top of textures obtained through photogrammetry. Models which have been remeshed require a new UV projection to distribute the 3D vertex points onto the 2D texture.

B. Challenges

The main aim for a digitised cultural artefact is to preserve it for future generations and to catalogue it digitally. As such, a high level of detail which encompasses every aspect is required. However, for the model to be usable in other immersive applications, a balance must be reached between quality and size. This was a challenge while restoring. If the model has a small number of faces, it becomes difficult to sculpt details accurately. Higher-resolution meshes are required if the model is going to be displayed in life-size or bigger dimensions. On the other hand, subdividing the model excessively increases the number of faces and the size of the model. The final model becomes unusable in other applications due to a slow loading time. Computers or portable devices with less graphical power would struggle to smoothly interact with the model.

In Blender, file size can be reduced in multiple ways. The Decimate modifier reduces the number of faces with minimal shape changes by reducing unnecessary vertices in ‘flat’ areas where there is not much change in the topology. This is critical to ensure that detail is not lost. Blender also supports geometric mesh compression and can export the restored model in different formats to suite the intended use: FBX is a binary 3D format which can store multiple subdivision surfaces in less space and is ideal for use of the model in gaming engines; the glTF format, on the other hand, is optimised for real-time transmission, making it ideal for web-based applications. Because of its efficient size, it is widely used for VR and AR applications, as well as many digital heritage projects and public domain catalogues [36].

V. IMMERSIVE LEARNING OPPORTUNITIES

The goal of restoring 3D artefacts is to bring them closer to the community. Immersive learning opportunities can be constructed through having accurate 3D digital replicas and restoring them in an authentic manner. Immersive applications provide an opportunity to learn about artefacts and their context. The restoration of these two stones has brought them together and they can be presented in meaningful ways. The following sections will detail two applications that have been developed which make use of the authentic restored reconstructions.

A. Interactive Configurator Tool

There is always room for interpretation when repainting historical artefacts, especially when little concrete evidence is present. This is something that ought to be communicated to the audience, without detaching from the learning experience. An online interpretation tool which enables the application of different colours on the artefact is effective. This is presented as part of a web interface that introduces the stones, their history, and context. The website is not overloaded with information to keep the content direct and meaningful. Additionally, it raises interest and allows the user to start forming their own thoughts and theories about how the stones might have looked like. A 3D visualisation is embedded which lets the user configure the different colours of the stone to reflect their own perceptions.

The configurator was built using the JavaScript library Three.js, ensuring it can work on any modern browser. It accepts 3D models in the GLTF format and can decode compressed models as well. The application builds the scene including the object, lights, and camera on an HTML canvas.
Once the model is loaded, three.js extensions provide orbit controls which allow panning, rotating, and zooming via mouse or touch. The user can then recolour the stone by selecting any part of the stone and choosing from the swatches of the provided Pictish colour palette. The configurator can be accessed through the interactive web interface at https://cineg.org/painting-the-picts/imagine/.

The 3D configurator is a valuable learning tool which emphasises the fact that the colouring of the stone is an exploratory task. This is shown to the viewer in a subtle manner which does not detract from the richness of the experience. Restricting the colour palette to the colours available to the Picts establishes their historical accuracy, whilst the freedom to create their own colour scheme certifies that the colour scheme of the model is not an exact replica.

B. Virtual Environment

Building a virtual environment of St Madoes in the early medieval period was an essential next step in disseminating an interpretation of the historical environmental context in which the Pictish stones had operated. The landscape has drastically changed due to a railway and motorway that presently pass through it. Archaeological, topographic, and onomastic evidence indicates that St Madoes was a significant place and had been since the Bronze Age, perhaps with some element of curated ritual continuity. Known features and finds include Bronze Age burial mounds and standing stones and a Roman coin hoard and brooch. The Inchyra stone was found adjacent to a Bronze Age burial mound and itself capped a burial. The St Madoes stone was found in the church burial ground, which when founded in the seventh century may have encroached upon the remnants of a prehistoric cemetery. From the churchyard came a further piece of Pictish sculpture currently lost and the recent find of another fragment of symbol stone indicates a concentration of Pictish sculpture in the area. This makes St Madoes/Inchyra a prime location for recreating a historical virtual landscape.

The Unreal Gaming Engine was used to create the virtual environment. The landscape maps were obtained from Digimap and used to create the digital landscape. The restored stones were imported and placed in their appropriate location. A medieval chapel was recreated. No reference remains have been found, but other historically contemporary buildings indicate that the chapel was most likely built of wood with a thatched roof. The model is relatively simple, without the precise detail that is present in the stones. The door and windows do not open, and the textures are two-dimensional. This highlights the fact that it is a creatively drawn reproduction reflective of its time, and not an authentic reconstruction based on direct evidence. Barrows were added to indicate the burial mounds and a cemetery built near the church and the cross-slab (Fig. 8). The scene was populated with typical flora and completed with indications of settlements.

The virtual environment provides opportunities to walk around the scene with a first-person perspective. As a learning environment, users can freely explore the environment, intrinsically finding answers to their questions about the stones. As this can be applied to any artefact, users can learn about the people who built and used historical artefacts through seeing and interacting with the worlds they lived in, and not just through reading information. Parallels and contrasts between the current environment and the historical one can easily be drawn which assist in the understanding of this cultural landscape and its evolution.

VI. Analysis and Future Development

The work presented here was shared with several history and museum professionals who provided feedback. The debate of whether the Picts painted on a white base layer or directly onto the stone was prominent. The configurator tool was modified to reflect this by including a choice of both options. The consulted experts were satisfied with how the surfaces were digitally restored during the process of sculpting on the 3D model. There were positive comments on how the colour interplays with reliefs in the stones, bringing out unseen detail. Further changes to the virtual environment, such as depicting moving light, could add insight into the appearance of the stones at different times in the day.

The virtual scene can be further evolved into an educational game by providing a narrative structure and creating goals or other game mechanics. This could be extended to a multi-player platform which inspires collaboration and social interaction, providing new learning experiences. Characters can be added which add a level of personalisation to the game by exploring the world differently. Additional non-player characters can be included in the scene which help to pass on information.

The restored digital artefacts still have a place in the museum: the configurator for each stone can be used in a tangible user interface alongside the real-life stones to promote further thought and exploration of how the stones looked like; the colour scheme can be projected onto the stones to simulate how the colours were applied; augmented reality applications can be created to access and view the restored version whilst looking at the physical artefact.
VII. CONCLUSION

This paper has made several contributions which encourage the effective use of digitised historical artefacts. On a conceptual level, a workflow has been developed which synthesises 3D modelling techniques with digitised artefacts. This can be used to authentically restore artefacts in a non-invasive digital manner. This has been applied to the St Madoes and Inchrya Pictish stones. In the process, a Pictish colour palette was composed which can be applied to any future colourisation of Pictish stones. A colour configurator tool has been developed which boosts interpretation and the stones were placed in a virtual environment, representative of their context. The restored digital models have thus been utilised to create immersive and exploratory applications which aid in the understanding of the stones’ original landscape. This is crucial in educational contexts, where a holistic understanding of the contexts of artefacts can be achieved through interaction with such historically accurate reproductions.

REFERENCES


Research Based on Affective Filter Theory: Is Social VR an Effective Tool for Learning a Second Language?

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Abstract—This study examines the affective filter theory in a social virtual reality (social VR) setting. Motivation, anxiety, and self-confidence were measured and compared in social VR and video conferencing. The research was conducted using mixed methods with qualitative and quantitative data. One-hour Korean language learning workshops were held to establish a teaching environment for this research. The research results indicated no significant differences in motivation, anxiety, or self-confidence between social VR and video conferencing as a learning tool. However, the debriefing interview following the workshop enabled us to develop a deeper understanding of participants’ motives to practice second language learning by leveraging social VR. Also, the interview data explained the strengths and weaknesses of using social VR as a learning tool, making our study meaningful in alternative language learning environments. This feasibility study revealed the potential of using social VR as a learning tool.

Index Terms—virtual reality, anxiety, avatar, second language learning, affective filter theory

I. INTRODUCTION

Krashen’s [1] affective filter theory explained that negative emotions such as lack of motivation, self-confidence, and high anxiety could “filter” students’ language learning. We were motivated by this study; by asking this question to affective filter theory, “Can social virtual reality (hereafter: VR) offset the affective filters?”. Alongside the development of computers, Computer-Assisted Language Learning (hereafter: CALL) has been widely adopted [2], particularly during the COVID-19 pandemic (global pandemic). Many face-to-face classes have moved to online platforms to avoid physical contact. In the meantime, social VR platforms [3] and several popular video conferencing tools such as Google Meet and Zoom [4] have proliferated. This event has changed the way we connect and learn subjects with others.

Many researchers address the benefits of using technologies as learning and teaching tools. For instance, Huang & Hwang [5] suggested that students’ anxiety can be reduced through a multimedia learning environment. According to Revere and Kovach [6], when used correctly, technology can increase student participation in the learning process. This is reinforced by Shariff and Shah [7], who found that interactive YouTube learning helps ESL students gain self-confidence in an enjoyable learning environment.

Despite the advantages of using technology for learning, few studies have researched the use of social VR as a second language learning tool through an affective filter theory lens. Many scholars point out that social VR has the unique characteristics of avatars and can influence positive outcomes of learning [8], [9]. Zhao & Lai [10] emphasized that avatar use in the study was associated with lower anxiety, relaxation and self-confidence. This can be presented as a potential low affective barrier to learning [11]. Another study by Peterson [8] showed that social VR, in use of foreign language learning, can increase engagement and learner-centered social interaction. It seems that there are many advantages of using social VR for language learning rather than face-to-face communication. For example, it can catalyze speaking confidence from fear of incorrect grammar or communication [15].

Therefore, in this study, we investigate the learning effect on social VR platform (i.e., Mozilla Hub) and compare it with a video conferencing tool (i.e., Zoom) as a control group. To compare the effects of language learning in face-to-face video conferencing and avatar-based social VR environments, the following research questions and hypotheses are established:

RQ. How can social VR be used for language learning?
H1. Participants who are exposed to the social VR environment will have higher motivation after participating in the workshop.

H2. Participants who are exposed to the social VR environment will have lower levels of anxiety after participating in the workshop.

H3. Participants who are exposed to the social VR environment will become more self-confident after participating in the workshop.

This study aimed to investigate the effect of second language learning in a social VR environment. Comparing two widely used remote technologies (video conferencing and social VR) provides a clearer understanding of how affective filter theory can be applied to second language acquisition in these technologies. Additionally, the pandemic is making teachers and students more actively in using distance learning technologies. Therefore, this study is meaningful in examining the effectiveness of social VR at present time and suggesting a future directions based on the experimental results.

II. LITERATURE REVIEW

A. Affective Filter Theory in Second Language Acquisition

The two terms second language acquisition and second language learning are common in literature when developing skills to use a second language. According to Riksbom [12], the main distinction is based on an individual’s internal learning processes and the degree of consciousness they bring to the task. Second language acquisition refers to the unconscious process in which learners learn a second language. In contrast, second language learning refers to consciously active learning [12]. This paper focuses on the main concepts of these two terms. Second language acquisition has become increasingly reliant on technology as the concept of CALL means unconsciously absorbing and cultivating the ability to use a second language, whereas learning means knowingly acquiring the knowledge to use a second language.

Stephen Krashen, known for his research on second language acquisition, has marked affective filters that can influence the process of second language acquisition. Krashen [13] identified three main variables that impede language acquisition: motivation, anxiety, and self-confidence. Improved motivation, self-confidence, and relaxation help learners learn a second language more efficiently and effectively.

Several cases support the effect of affective filters on individuals’ second language acquisition process. Laine [14] pointed out the high impact of anxiety in Finnish learning environments. Three qualitative examples of learning English in a non-English environment [15] show how low anxiety leads to more successful second language acquisition. This hypothesis was further supported by applying it to a second foreign language education scenario [16]. Good second language acquisition is usually characterized by a strong desire to learn the target language and overcome learning anxiety.

Taking a step further, we identify cases of learning a second language in virtual space, especially social virtual reality environments. Computer-assisted language learning (CALL) has been one of the approaches to help learners acquire a second language. We notice a lack of investigation into a role of affective filter in second language acquisition in the social VR environments.

B. Social VR as a Language Learning Tool

Second language acquisition has become increasingly reliant on technology as the concept of CALL [17] became better known and embraced. More teachers are turning to computer-based interventions for teaching and learning [18]. The application of digital tools and the Internet has also reshaped the way students learn and perceive second languages. For example, case studies looked at language learning classes on social virtual platforms such as Minecraft and Second Life [8], [19]. In addition to these platforms, many language learning courses are conducted through video conferencing services.

Social virtual reality is an online space where people can meet and play using social interaction, disguising themselves as a virtual avatar [20]. The social VR platform allows users to work together from separate remote locations using virtual reality, conduct virtual meetings, and communicate via voice and text. Examples of social VR platforms include Figure 1 such as Altspace, VR Chat, and Mozilla Hub.

The benefits of using social VR are: (1) contextual environments [20], (2) avatar-based learning [8], and (3) increased motivation [9]. Circumstances are an important factor in practicing a language. Therefore, the researchers used high immersion to increase situational awareness. For example, Mondly allows users to practice their language in real and virtual environments such as hotel receptions, cafes or trains [21]. It creates a highly immersive 3D environment, and the learners feel their presence while processing VR situations. The second aspect is the avatar. Users do not need to show their identity and can remain anonymous in VR. According to Koulouris et al. [9], avatars can influence behavior. The ideal avatar has improved performance to complete tasks. Finally, social VR can increase motivation. According to Limniou, Roberts, & Papadopoulos [22], the 3D environment maintained motivation and interest in the learning process. Social VR has been rapidly penetrating the educational environment by taking advantage of avatars.

Fig. 1. Example of social VR (top-left: Altspace, top-middle: VR Chat, top-right: Rec Room, bottom-left: PokerVR, bottom-middle: Bigscreen, bottom-right: Mozilla Hubs).
III. Method

A. Participants

Recruitment flyers have been distributed to online communities, including University of Washington language learners, Facebook K-pop communities, Reddit, Twitter, etc. The data collection process was completely virtual due to COVID-19. A total of 31 participants from diverse populations and backgrounds were recruited. Participants in each condition group were randomly assigned to a social VR or video conferencing workshop. 16 people attended the social VR workshop and 15 people attended the video conferencing. Data on gender, age, and ethnicity were challenging to balance in spontaneous response sampling. The total sample consisted of 9 males and 21 females between the ages of 18 and 44, most of them between the ages of 25 and 34 (68%). Ethnicity is 75% Asians, 16% White, and 9% Hispanic.

<table>
<thead>
<tr>
<th>TABLE I. PARTICIPANT DEMOGRAPHICS</th>
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<tbody>
<tr>
<td>Video conferencing (n=15)</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
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<tr>
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<tr>
<td>Hispanic</td>
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</table>

B. Procedure

The research was largely composed of pre-session, workshop, and post-session. All sessions were conducted online using Zoom video conferencing software or Mozilla Hub’s social VR application. In addition, the research was a between-subject design and the process was pre-survey, workshop, post-survey and debriefing interview. As this study aimed to measure motivation, anxiety, and self-confidence within groups, each workshop consisted of at least two people. Participants were given 5 minutes to reduce the novelty effects, the participants explore the system before the workshops began. The goal of the workshop was to learn a set of basic Korean in 30 minutes. After the workshop, participants were asked to fill out a post-survey and participate in a debriefing interview session.

Workshop

Participants met the instructor via video conferencing or social VR. We chose Zoom as a representative tool for video conferencing that is widely used in schools or educational settings. Mozilla Hubs was chosen to represent the social VR platform in this study. It provides a web-based private space and ensures anonymity by eliminating the need for guest login. Therefore, from the user experience perspective, Mozilla Hubs was an effective option for use in this study.

This study aimed to compare the differences in the learning experience in social VR and video conferencing. We thus selected a language that participants knew very little but were interested enough to participate in the workshop. The reasons for choosing Korean as a second language to study are (1) that the demand for learning Korean has been increasing after the rise of K-pop, and (2) that Korean is still a minor language that many people cannot speak.

The teaching material consisted of two parts: (1) 5 common Korean conversations in a café and (2) the Korean numbering. The same teaching material was used for video conferencing and social VR. To reduce the influence of bias and human factors, only one Korean teacher consistently taught. Below was the class material to teach Korean conversation for this experiment.
The pre-survey assessed the participants’ initial status, including familiarity with the technology platforms, Korean proficiency, and interest in Korean cultures such as K-Pop and K-Drama. The questionnaires also included reasons why participants had previously used video conferencing and social VR platforms in terms of experience and motivation. After that, the level of motivation, anxiety, and self-confidence in each participant's Korean language learning ability was measured on a Likert 5-point scale. After the workshop, the participants were asked to complete a post-survey on the same Likert 5-point scale so that the team can evaluate the changes before and after the workshop.

**Debriefing Interview**

After the participants completed the post-survey, the briefing interview was conducted to understand more about the participants’ experiences. We explained the purpose of the study and began a semi-structured 15-minute group interview with other participants. Most of the interview questions were similar to the questionnaires, but with an additional “why do you think so?” question.

**C. Measurements of Questionnaire**

**Motivation**

Motivation for language learning was measured by five questions. Each question targets a different aspect of the experimental setup. For example, “I want to learn Korean,” “I want to use technology to learn Korean,” “I want to take another foreign language class in a similar format/setting,” “I prefer to learn Korean in technology (online learning) than attending school.” These may affect the participants’ motivation differently. A comprehensive measure of intrinsic motivation was acquired by the question, “To what extent do you currently want to learn Korean?” Krashen [13] identified that motivation as a major affective factor in second language acquisition. The first four response types were assigned on a 5-point Likert scale (1=Strongly disagree, 5=Strongly agree).

**Anxiety**

Regarding the measurement of anxiety levels, we adopted seven questions. The questions are “I get nervous when I speak in the class language,” “I get nervous when the teacher asks questions which I have not prepared in advance,” “I feel nervous when I knew I was going to be called in class,” “It frightens me when I do not understand what the teacher is saying,” “I feel stressed when the teacher corrects the mistakes I have made in conversation.” We also measured the overall anxiety under the question “To what extent best describes your current anxiety level of speaking Korean?” The choice of anxiety measures was also adopted by Krashen [13] as a principal affective factor in the process of second language acquisition. Additionally, Horwitz [23] has identified the effect of anxiety, which is imperative for language learning. Responses to the six questions were assigned on a 5-point Likert scale (1=Strongly disagree, 5=Strongly agree).

**Self-Confidence**

According to Krashen [13], self-confidence was measured by six questions about subjects’ self-description of their self-confidence in various situations, and higher self-images tended to perform better in second language acquisition. Examples include “I feel confident when I speak out in class,” “I feel prepared to speak during class,” and “I am an active learner.” These responses were scored on a 5-point Likert scale (1=Strongly disagree, 5=Strongly agree).

**IV. Result**

A. Baseline

To reduce bias, the baseline regarding technology use and the Korean language were measured. The survey was conducted before the workshop, and the results showed no significant differences between the two groups: social VR and video conferencing. Therefore, both groups of participants started the workshop under the same condition.

**Technology use**

Prior to the workshop, a survey asked, “How comfortable do you feel about video conferencing (Ex. Zoom, Skype, Google Meet, MS Teams, etc.) or Social VR (Ex. Mozilla Hub, Altspace, Minecraft, Animal Crossing, etc.)?” distributed to all participants. As a result of the response, there was no significant difference between the social VR group (M=2.25, SD=1.81) and the video conferencing group (M=3.58, SD=1.62) at t (26)= -2.01, p=0.54. Additionally, participants in both groups spent similar time using technology. The video conferencing group had an average of 13.5 months of usage experience and the social VR group was 11 months. As a result, there was no difference in use of technology between the two groups.

**Korean interest**

We wanted to eliminate biases about Korean language proficiency and cultural interests as they can affect participants' motivation and aspiration to speak. For social VR, 13 participants had no prior Korean experience and 3 had minimal exposure. Similarly, in the case of the participants assigned to the video conference, 8 people with no experience and 4 people with basic Korean skills. Also, there was no difference between the two groups regarding cultural interest in Korea. “How much do you prefer Korean culture (e.g., K-pop and k-drama)?” The response to this question was t(26)= -0.356, p=0.72 between video conferencing and social VR.

B. Why Did They Play Video Conferencing or Social VR?

Prior to the workshop, the question was asked, “Why do you use video conferencing and social VR in the pre-survey?” The following word cloud shows the most frequent words in video conferencing and social VR. The most frequently used words in video conferencing were meet, class, online, school, whereas the reasons why people play social VR are friends, games, experiences. The purpose of using the two platforms is explicitly different.
C. Comparison of Pre and Post in Two Conditions

For this section, we examined two (video conferencing vs. social virtual reality) by two (pre-test vs. post-test) conditions. Quantitative data were analyzed using Mixed ANOVA, and the qualitative data were analyzed by thematic coding in video transcription. In response to the hypothesis, the video conferencing participants had a higher (a)motivation, (b)anxiety, (c)self-confidence after the workshop than social VR participants. Also, there was no significant differences and interaction effect in times x group interaction.

<table>
<thead>
<tr>
<th>Interaction effect</th>
<th>Measure</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p-value</th>
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<td>.116</td>
<td>.736</td>
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<tr>
<td></td>
<td>Anxiety</td>
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<td>.088</td>
<td>.272</td>
<td>.606</td>
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<tr>
<td></td>
<td>Self-Confidence</td>
<td>1</td>
<td>.220</td>
<td>.724</td>
<td>.402</td>
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</tbody>
</table>

*note. df = degree of freedom, SD=standard deviation

Motivation

For the motivation factor, scores of workshop participants were measured from the pre-test to the post-test. The mean value of video conferencing was 3.73 (SD=0.61) in the pre-test and 3.96 (SD=0.65) in the post-test, whereas the mean value of social VR was 3.54 (SD=.54) in the pre-test and 3.88 (SD=1.02) in the post-test. Comparing the mean difference between the pre-test and post-test of the two conditions, video conferencing increased by 0.23, and social VR increased by 0.34. It implies that social VR increases more motivation to learn a language than video conferencing. However, there was no interaction effect for Time x Group, F(1,29)=0.116, MSE=0.413, p=0.736. As a result, H1 was not supported in that participants exposed to social VR had a lower motivation after the workshop.

Anxiety

For the anxiety factor, scores of workshop participants were measured from the pre-test to the post-test. The mean value of video conferencing was 3.27(SD=0.86) in pretest and 2.19(SD = .88) in the post-test whereas the mean value of social VR was 3.28(SD=0.95) in the pretest and 2.35(SD=0.66) in the post-test. The anxiety measures are opposite of the scale of motivation and self-confidence. Likert scale 5 means high anxiety. In other words, the higher the score, the more anxious feelings participants have. With these interpretations, post-test anxiety levels were more anxious in social VR. The difference between the pre-test and post-test was also found to be similar. Video conferencing and social VR decreased by 1.08 and 0.93, respectively, indicating that social VR became more anxious in learning language than video conferencing. In addition, no interaction effect was found in Time x Group, F(1,29)= 0.272, MSE=0.323, p=0.606. As a result, H2 was not supported as participants exposed to social VR will have higher anxiety than participants who are exposed to video conferencing after the workshop.

Self-Confidence

For the self-confidence factor, scores of workshop participants were measured from the pre-test to the post-test. The mean value of video conferencing was 3.30(SD=0.77) in the pretest and 3.86(SD=0.75) in the post-test, whereas the mean value of social VR was 3.45(SD=0.67) in the pretest and 3.78(SD=0.49) in the post-test. Comparing the mean difference between the pre-test and post-test of the two conditions, video conferencing increased by 0.56 and social VR increased by 0.33. It
implies that self-confidence in speaking the language increases faster using video conferencing than social VR. In addition, there was no interaction effect for Time x Group, F(1,29)=0.724, MSE=0.304, p=0.402. As a result, H3 was not supported in that participants exposed to social VR had less self-confidence than participants exposed to video conferencing after the workshop.

Fig. 8. Comparison of self-confidence (mean values) of video conferencing and social VR.

Summary of quantitative data in pre and post-test
1) Video conferencing indicates better post-workshop estimated marginal means than social VR in all features (motivation, anxiety, self-confidence).
2) Social VR groups motivated language learning faster than video conferencing groups.
3) Anxiety about language use decreased faster in video conferencing than in social VR.
4) Video conferencing increased self-confidence in language learning faster than social VR.
5) The interaction effect of Time x Group yielded statistically insignificant results for all features (motivation, anxiety, self-confidence).

D. INTERVIEW QUOTES
Language course on social VR platform could help reduce learning anxiety in some cases:
"I think it really helped me reduce my anxiety because we didn't have to have face to face interaction."
"I did feel, like, that my anxiety definitely went down."

Anonymity (not showing faces) could help decrease learning anxiety:
"I felt like I was not like not having to show my actual face. kind of helps."
"I felt less anxious than if you know, like, a video chat course."

Social VR platform was fun and comfortable learning environment:
"I think this environment made me very comfortable and felt more motivated to learn new things or to speak out loud."
"It was fun experience"

"I would like to participate in this more if it is a future language (learning) style."

Participants enjoyed using social VR, although there was a learning curve for this tool:
"Even though I had a little bit of tech problem, it was a really cool platform to learn"
"...to be able to experiment or even just to have a few minutes set aside at the start of the session that you could kind of play around with."

V. DISCUSSION
This study was a feasibility experiment to determine whether social VR could be a reliable language learning tool. Although there were no significant differences between video conferencing and social VR, the results showed that, over time, the learning environment in social VR was more motivating than video conferencing. Many participants mentioned positive feedback in terms of motivation in the debriefing interview. For example, participants said that it was a fun experience using social VR for language learning. It was unclear whether this nuance included the novelty of using new technologies such as social VR for language learning. However, it was clear that many people were highly motivated by social VR and would be willing to play it for language learning in the future.

Moreover, the results showed that social VR had higher levels of anxiety than video conferencing. This was the exact opposite of the hypothesis. In the debriefing interview, we were able to find the reason why social VR causes more anxiety. (1) Participants have used Zoom several times, whereas Mozilla Hubs was new to them. It is inevitable that they will be more comfortable controlling the technology they are more familiar with. (2) The purpose of many participants in the workshop was to learn a language that they would like to see more human interaction with; such as lip-sync or body language. In this case, social VR did not provide enough human interaction components for the participants. However, some interview data showed positive feedback that social VR is preferred because they do not need to see a real face. Therefore, personality may also be one of the factors that influence anxiety.

We recognize three limitations of this study. Recruitment of participants was difficult due to COVID-19. First, the experiment had a small sample size, and the statistical precision and power of our study could be different if there were more participants in each condition. Therefore, we believe that future studies with larger sample sizes over long periods of time are necessary to reinforce our findings. Second, most of the participants were college students and had a lot of experience using Zoom in their classes, but most of them were new to Mozilla Hubs. Ease of use and familiarity with the technology can affect the results in pre and post-sessions. Lastly, participants did not use a VR headset when learning a language on the Mozilla Hub. This can affect the results as computer monitors are less immersive than using of VR headsets. It is necessary to supplement these limitations in the future.

Overall, social VR has not successfully elucidated the affective filter hypothesis compared to video conferencing technology, except for increased motivation of social VR.
However, numerous qualitative studies have suggested promising uses of social VR for second language learning, along with high satisfaction, low anxiety, and willingness to use. It is believed that further experiments with the described methods are worthwhile in the future. It is hoped that the feasible results of this study can contribute to the development of a more productive social VR version as a language learning tool in the CALL field.

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Game-Based Virtual Reality for Languaculture Learning: An Example of the Forbidden City

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Abstract—In the digital era, learners are closely engaged with various kinds of technologies. Particularly, virtual reality (VR) has revolutionized our conventional ways of teaching and learning. Despite the wide adoptions of VR in education, our knowledge of how VR can facilitate EFL learners’ L2 linguistic and L1 native culture learning is fairly limited. The present work-in-progress paper reports on an on-going study that explores a self-developed VR system, which aims to support Chinese learners in improving their English language knowledge and Chinese culture knowledge via a simulated world. Research design and methods will also be discussed in this short paper.

Index Terms—language learning, culture learning, VR

I. INTRODUCTION

Virtual reality (VR), according to Wang, Callaghan, Bernhardt, White, and Peña-Rios [1], refers to the simulations and 360° videos that place users in an immersive, virtual, and 3D environment. Different from the technology of augmented reality that superimposes virtual elements onto the physical world, VR has the salient feature of engaging users within a synthetic world.

The Immersive Learning Research Network (iLRN) [2] suggests that VR, along with other emerging technologies, enable educators and learners to re-image teaching and learning; VR has showcased the potential to reshape the traditional teacher-led lessons and to create authentic and experiential learning environments, which are conducive to student learning. In addition, researchers remark that social interactivity is an outstanding feature of VR learning [3], which tends to bring about the natural acquisition of language skills.

Particularly, iLRN points out the indispensable role that VR plays in improving the efficiency of science, technology, engineering, and mathematics (STEM) education as it well aligns with the hands-on and problem-solving features of these hard disciplines. Based on the latest review [4], current research is to a large extent limited within the STEM subjects whereas the use of VR in language learning is an area that remains less explored. Though language educators have started to realize the various benefits VR may bring, an in-depth understanding of the usefulness and challenges of VR in facilitating student language and cultural learning is of prime importance before fully and successfully integrating this emerging technology into the second language (L2) education field.

When talking about second language education, applied linguists have increasingly suggested that an integration of linguistic and cultural competences should be well developed. This is partly thanks to Agar’s [5] proposal of “languaculture,” meaning that linguistic and culture learning is inseparable and should be learnt in a joint fashion. It is quite common to observe that language teachers in China involve Chinese learners in some L2 English language activities that are embedded in L2 cultural learning settings (e.g., Make up dialogues to order food in an English restaurant).

Yet, with the development of English as a lingua franca and translanguaging, language teachers have acknowledged that to better prepare students to become global citizens, native cultural awareness (NCA) is a key construct for every individual but often overlooked in today’s language education [6]. Knowing how to communicate one’s own culture through the medium of English is a question for language teachers to ponder. However, most of the English classrooms in China have not yet paid attention to the training of local Chinese culture through the medium of English, which is key to the development of students’ national identity in a globalized world.

Against this backdrop, this short work-in-progress paper reports on a novel, ongoing, and empirical study conducted in a Chinese university with the application of a non-commercial, game-based, and immersive VR learning system in teaching and learning the L2 English language within the L1 Chinese cultural environments.

II. GAME-BASED Languaculture Learning

Games almost accompany everyone throughout their whole life, digital or non-digital, real-time or turn-based, educational or recreational. Although games are quite often viewed by
parents and teachers as distractions to learning, more educators and researchers have realized the unique opportunities from games that may contribute to deep learning. The rationale for successful learning in games tends to rely on the interplay of different features of games, including competitions, interactions, rewards, challenges, and control [7]. These factors jointly play a central role in creating a space for autonomous learning.

To better capture the idea of games in education, we draw upon Reinhardt and Sykes’ [8] taxonomy of game-enhanced and game-based L2 learning and pedagogy. Game-enhanced language learning (GELL) focuses on the learning opportunities afforded in digital games that are not designed primarily for learning, such as adventure, e-sports, and shooters games. In contrast, game-based language learning (GBLL) refers to teachers and students engage in digital games specifically developed for language learning purposes. One major feature of GBLL is that teachers’ and students’ user experiences matter significantly to the developers. It is vital for designers to receive feedback from these two groups of users and careful considerations of language learning and teaching philosophies are valuable in improving the game designs, especially for self-developed games.

In language learning, educators and researchers have been researching the effectiveness of GELL. It has been discovered that learners engage in GELL generally report positive results, including the facilitation of learner autonomy [9], creativity [10], and vocabulary acquisition [11]. Yet, a number of key factors mediate students’ game-based learning experiences (see an overview in [12]), such as gender, the target language skill (e.g., vocabulary vs. pragmatics), and the existence of teacher intervention.

Compared with GELL studies, little has been known about the use of GBLL so far, partly due to the reasons such as the negative attitudes from parents and teachers and the lack of financial support to develop specific language games [8]. To better understand the use of games that are specifically designed for language learning, this study reports on the adoption of a self-developed VR system, focusing on the development of language and culture knowledge.

III. VR-ENHANCED LANGUACULTURE LEARNING

To understand the existing VR-enhanced languaculture learning (VELL), this section begins with a general distinction among non-immersive, semi-immersive, and immersive VR [2]. When using non-immersive VR in language education, learners resort to desktop computers, exploring the virtual world through a keyboard, a mouth, and a computer screen. A semi-immersive VR system allows users to experience the synthetic world but remains strong connections with their physical surroundings. In contrast, fully immersive VR provides a user with an opportunity to view the virtual world through a Head-Mounted Display (HMD). According to Li and Lan [3], despite the differences, the three types of VR aim at providing constructive learning environments through autonomous, self-discovery learning.

Over the past decade, VR studies in the context of languaculture learning are sparse. Based on Parmaxi [4], only a small number of VELL studies were reported from 17 international journals from 2015 to 2018, most of which relied on non-immersive VR technology. Though previous research has made attempts to develop a great many skills (e.g., 21st century skills), traditional language skills were mostly investigated among the reviewed studies. In particular, English speaking skills had been looked into partly due to the interactive feature of VR.

Parmaxi’s review was conducted a few years ago. However, thanks to the ubiquity, affordability, and accessibility of VR, VELL research is growing rapidly in the past five years. First, language educators have begun to pay closer attention to the use of fully immersive VR. Alfadil [11] investigated Saudi Arabian learners’ use of the English vocabulary in a VR gaming setting. Learners in this study felt more motivated, attracted, and confident in learning compared to the students who received the traditional classroom teaching. Second, VELL is no longer limited to developed countries or regions. For example, Shadijev, Wang, and Huang [13] involved students from China and Uzbekistan. By using 360° video-based VR technology, their students were able to further their intercultural learning through four dimensions including knowledge, attitude, skills, and awareness. Third, research has reported the dual development of linguistic and non-linguistic skills. In a recent study by Wu, Miller, Huang, and Wang [14], a group of nursing students were afforded unique opportunities to apply their nursing subject knowledge into practice. More specifically, embedded in a fully immersive VR operating room, students were requested to assist a non-player doctor to finish a surgery. Through this learning process, learners were able to make use of the English language to achieve real-life tasks and apply, consolidate, and advance their nursing knowledge learned in their previous content courses. Results suggested an intertwined play of authenticity, interactivity, multimodality, and reduced anxiety for learners, which created a productive learning environment. Fourth, other less commonly taught languages such as Chinese [15], Spanish [16], and Japanese [17], were researched with the aid of VR, though they were still underexplored.

Without a doubt, recent studies have moved our limited understanding, but we still lack in-depth knowledge of the effective incorporation of VR in languaculture learning, especially the joint development of L2 linguistic and L1 cultural knowledge [3]. Faced with this challenge, the present paper reports on an exploratory, game-based VR study in the Chinese context with a focus on the development of English linguistic skills (L2) and Chinese cultural awareness (L1).

More specifically, we attempt to answer the following research questions:

1) What are EFL learners’ perceptions and experience of VELL in relation to L2 language learning?
2) What are EFL learners’ perceptions and experience of VELL in relation to native culture learning?

IV. THE FORBIDDEN CITY – AN ONGOING PROJECT

Due to the ongoing nature of the project, the remaining section briefly introduces the VR system and outlines the research design. No data will be reported in this work-in-progress paper.
The VR system

The Forbidden City is a game-based VR learning system developed by the School of Foreign Languages, Shenzhen University in collaboration with a commercial company in 2020.

The VR project features interactive and exploratory learning through virtual simulation technology, enabling students to complete a variety of immersive English language learning and interactive Chinese culture tasks. This project is unique in that it brings together the learning of students’ native Chinese culture (L1) and the English language (L2) so as to improve students’ cross-cultural communication skills. That is, in the simulated, ancient royal palace, learners are able to improve their knowledge about various traditional Chinese cultural elements, including Chinese architecture, history, customs, poetry, and festivals, but through the medium of English as most of the interface, dialogues, and instructions are all delivered in English.

In this system, there are seven palaces or scenes (Fig. 1), including two types of learning tasks. Firstly, learners can practice their English speaking through AI-empowered speaking exercises. Fig. 2 is an example of the Hall of Supreme Harmony. Learners are first introduced to the palace and then required to read out the English introductions through their microphones. The system automatically evaluates the speaking based on content and accuracy of pronunciation. Similar speaking activities are available in the other six palaces. This type of exercise primarily focuses on the training of English speaking and the improvement of Chinese cultural knowledge.

Secondly, in the three VR scenes of the Hall of Supreme Harmony, the Palace of Earthly Tranquility, and the Imperial Garden, Chinese cultural and English linguistic knowledge is delivered via dialogues between non-player characters (e.g., Fig. 3) and applied, constructed, and internalized via different kinds of activities.

In each scene, the relevant historical and architectural information is firstly summarized before some key knowledge points are explained in detail. Interactive games are interspersed in each scene to examine learners’ understanding of L1 cultural and L2 linguistic knowledge. For example, in the Hall of Supreme Harmony, students need to finish a sundial timing game and a game to return the mythical creatures (Fig. 4). Another example in the Imperial Garden is that students are invited to finish a fun picture game and a game about an ancient poetry festival. After accomplishing all learning steps in the garden, students can enter the Hall of Preserving Harmony to attend the final imperial examination.

Together with the speaking and pronunciation tasks throughout the project, an examination (containing single-choice questions, multiple-choice questions, translation questions, and fill-in-the-blank questions) is assigned to evaluate students’ vocabulary knowledge and translation skills, as well as their acquisition of cultural knowledge about the Forbidden City. In addition to that, Wenyuan Chamber is a place
that offers students high-quality reading materials for further understanding Chinese culture.

Fig. 4. A matching exercise.

The project is now presented in different types of languages: English, Spanish, and Portuguese. Adopting the modular teaching mode, teachers can flexibly apply and combine the modules to meet their different language teaching needs.

B. Research Methods

The study was conducted in a public Chinese university. To explore students’ perceptions and experiences with The Forbidden City, 91 year-1 Business English major undergraduate students were invited to participate in the present study. None of the students had learning experience with immersive VR that specially designed for language learning. They were instructed to explore the VR system under the guidance of their language teacher. After receiving some technical guidance, students self-explored the synthetic world in their free time. They were required to finish the learning tasks in the VR system. Based on their experience, they filled out a questionnaire survey and composed a reflective journal.

Since this was an exploratory study and none of our students had been engaged in such a novel learning experience, we aim to understand how they would react and accept this new learning approach. A questionnaire was thus designed based on Tsai [18]. In total, the questionnaire contained 18 question items, covering aspects of the perceived usefulness and the ease of use, technical support, attitudes towards learning a language and culture, and learning activities in the system. The questions were piloted with an expert in technology-enhanced language learning and further revised based on the third author’s suggestions. The questionnaire was then distributed among the students via the website: https://www.wjx.cn/. 83 valid questionnaires were collected and SPSS was used to interpret their answers.

In addition to the student questionnaire, the student participants reflected on their learning experience by compiling a reflective journal. They noted down their thoughts and feelings when they used the VR system, from the ease-of-use, language learning, to culture learning and technical challenges. Thematic analysis was applied to this data set and the analysis was carefully guided by Braun and Clarke [19].

V. Conclusion

This paper reports a work-in-progress immersive learning study that makes use of a self-developed VR system in a Chinese university. We first review some literature on game-based language learning and VR-enhanced language learning, followed by a detailed introduction to the VR world in this study. The VR system recreates the ancient Forbidden City and provides a variety of language and culture learning activities for learners. Then, the paper discusses an ongoing empirical study based on this system. As the study is being carried out, this short paper limits itself from including concrete data or preliminary findings. The findings will be reported at the official conference later in 2022.

References


Work-in-Progress—Preliminary Analysis of Spatial Perception in AR application with Eye-Tracking Data

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Abstract—This preliminary paper aimed to explore spatial perception in AR application with eye-tracking analysis. We used historical events and building to provide a spatial AR experience. Three persons participated in the study, but one failed to collect the eye information properly. They experienced four tasks to explore the space in historical building AR application while eye-tracking information was gathered with Tobii pro glasses. We examined the participants’ eye movement with the scan paths. According to the findings, they tend to move their gaze according to the line of buildings when they scan the entire spatial structure. But when they were asked specific building explanations, they focused on the specific spot like roof or crevice areas of a building window, or other avatars.

Index terms—spatial perception, AR, eye-tracking

I. INTRODUCTION

Augmented reality (AR) has been evaluated as an efficient learning tool in the cognitive perspective and cognitive theory of multimedia learning achievement [1]. The AR-based learning material could promote generative processing and facilitate better learning [2]. In particular, AR learning material is capable of providing spatial information by augmenting 3D learning material objects on the desk. This spatial graphic can enhance learners’ immersive experience and understanding of learning materials.

More than 80% of human information is provided by vision [3], whereas spatial information is also acquired through visual information [4]. Eye-tracking for collecting visual information has emerged as a key tool to provide real-time and natural examination of thinking and cognitive processes [5]. Therefore eye-tracking has been used in spatial cognition relation research. The eye information could explain how learners interact with spatial information and how spatial information is perceived in decision-making [4]. The eye-tracking data is interpreted as recording the gaze coordinates in the visual stimulus space, and the collection of eye-tracking data is the stream of gaze samples of the user in the space [6]. Eye-tracking data is analyzed in the space where gaze coordinates are recorded [6]. Scanpaths refer to the spatial distribution of gaze points [7], which explain the process of gaze movement for spatial perception visually [4].

Eye-tracking has been used in AR learning material research because eye information is known to have the ability to explain the relationship between visual materials and learners’ attention [8]. Wang et al. [1] conducted a study to check the degree of cognitive load between text data, AR data, and actual physical data through gaze tracking, and as a result, AR-based apps could provide learners with similar experiences without significant differences from actual physical materials. There is a paucity of research on how to percept virtual space provided by AR learning materials. Therefore, a basic study is necessary to understand how spatial perception appears in the learner's cognitive processing.

II. METHOD

A. Participants

In this study, two graduated students in South Korea participated. Participant A was a 33-year-old male master's graduate of Chinese Language & Literature, whereas participant C was a 25-year-old female master's student of Educational Psychology.

B. Application

This study uses the app '5·18', This App handles the historical events ‘5·18’ on Gwang-ju area in South Korea which is Democratic protests against dictatorship. This is an Android application developed in Unity, using AR Core. This application uses image-tracking technology to build a virtual space based on the logo of Korea's 5·18 foundation. This app includes mainly four scenarios (Table I). Participants can understand the background of the 5·18 incidents in the virtual space, watch, participate in the main activities of the 5·18 incidents, and interact using virtual avatars.

TABLE I. AR APPLICATION SCENARIO

<table>
<thead>
<tr>
<th>Task</th>
<th>Scene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>There is a water fountain in the center; one person is giving a speech on the water fountain, four people are holding Tai Chi flags, and there is a large audience surrounding them.</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>There are very long buildings in front and on the right, and 5 people are distributed in the scene.</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Inside the building, there are many coffins on the ground, and many people are sitting in the opposite direction</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Similar to Scenario 2, but only with buildings in front, with shadows of five figures attached to the buildings, and many people in front of the buildings</td>
</tr>
</tbody>
</table>

C. Experiment Procedure

The experiment proceeded with the following steps:
1) describing the experiment purpose and AR application
2) calibration (Fig.1 (left))
3) observing the entire scene from a distance (Fig. 1 (right))

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4) moving around the scene to observe the scene in all directions (Fig. 2)

5) eye-tracking data collection while doing tasks on AR application.

Fig. 1. Left: calibration, right: observe from a distance.

Fig. 2. Move around and observe from different directions.

Table II shows the four tasks.

<table>
<thead>
<tr>
<th>Task</th>
<th>Scene</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td><img src="image1.png" alt="Image" /></td>
<td>in scenario 1, explore the construction and space and explain it.</td>
</tr>
<tr>
<td>Task 2</td>
<td><img src="image2.png" alt="Image" /></td>
<td>in scenario 2, explores the construction and space and then, explains the features of buildings. You will then compare the structure of the building in scenario 2 and those in scenario 4.</td>
</tr>
<tr>
<td>Task 3</td>
<td><img src="image3.png" alt="Image" /></td>
<td>in scenario 3, explore the construction and space and then explain the internal and external features of the building.</td>
</tr>
<tr>
<td>Task 4</td>
<td><img src="image4.png" alt="Image" /></td>
<td>in scenario 4, explores the construction and space and then, explains the features of buildings. Now, compare the differences of structure between buildings in scenario 2 and those in scenario 4.</td>
</tr>
</tbody>
</table>

III. RESULTS

A. Case A

- Scenario 1: Participant A started observing from the center, and then his eyes spread outward. This description is congruent with the direction of the line of sight, and the description is from the center to the outside.

- Scenario 2: There are two buildings in the front and the right, and the building in front is very long. For this more three-dimensional scene, participant A looked forward from the center of the screen, then to the left, and then to the right. After roughly confirming which buildings there were, the screen moved left and right to confirm in detail. After checking all the information from the right to the left, Participant A started explaining and then talking while watching. There was an interruption, and participant A came back to the front; he also roughly confirmed the whole and then started to continue the expression.

- Scenario 3: Inside the building, participant A was still observing from the middle, then looked ahead. The participant looked to the right, then to the left. The expression started with the whole feeling of the scene, followed by the front, then the ground, then the things in the room, and finally, it was noticed where he was. When asked about the audience on the opposite side, participant A also described from the whole to the part. After returning from the back of the building to the front, he also confirmed the whole and then starts to continue the expression.

- Scenario 4: Participant A looked forward, left, and then right. The screen moved slower this time because it was said before scenario 2 and scenario 4 were compared. But even if there was nothing in that place at that time, the line of sight still went to that place to confirm because there was a hospital in scenario 2. Then the participant went back to the right and pulled the distance away, and directly started talking about the difference, stating that the hospital was gone. Then continued to confirm, confirmed the back of the building, went back to the front, and confirmed that there was a photo attached at that time.

B. Case B

- Scenario 1: Participant C confirmed the center first, then confirmed the surrounding, and began elucidating when confirming the surrounding. Then the participant explained that there was a Tai Chi flag in the middle, and four people were carrying the flag.

- Scenario 2: Participant C confirmed the middle first, then from the left to confirm, before confirming the building in front as a whole, and went on to confirm the details of the building in front and began the description. Finally, the participant confirmed the building on the right, comparing the two buildings for evaluation. As a case in point, the building in front was four stories, while the building on the right was five stories. Both buildings were white and the windows were black. Nothing was written except the hospital, it was impossible to know what building it actually was.

- Scenario 3: Participant C looked forward first and observed carefully, started the description, and then described the differences between the coffins and the kind of feeling they gave. Then, the participant started describing the color of the floor, the color of the building, and the shape and height of the building. The participant felt that people’s expressions were sad and tired through background music and colors.

- Scenario 4: First, participant C observed the building in front, and then observed from the left, making an overall
observation than a detailed observation. According to the pictures posted on the outside of the building, it was speculated that people were present inside the building. When explaining the difference, participant C said in scenario 4, people can be seen through the windows. In addition, she thought the building was shorter than the buildings in scenario 2, but the color of the buildings was similar. The buildings in scenario 4 were more like one, while the buildings in scenario 2 appeared to be separate.

In this experiment, in comparison to other scenes, the composition of scene 1 is more similar to a plane rather than a three-dimensional complex structure. Both participants first focused on the central part of the scene and observed the speeches on the water fountain and the people holding Tai Chi flags. This is consistent with what people do when they look at pictures or look at the screen. When observing scenes 2 and scene 4, buildings appeared in the scenes. Both participants observed from the left side. Both participants were right-handed, which is consistent with the findings of Kinsbourne [8], who observed that right-handed people tended to assume they were on the right and looked left first when people were solving space-related problems [9]. Fig. 3 shows that when the participant observed the person holding the Tai Chi flag, their attention was focused on the head of the avatar. Kiefer et al. [4] indicate that people deploy their attention to a new location by saccades after repositioning. There is a redistribution of attention, and the effect is staring. The head and face are the most representative features of a person, and the participants gazed at the head of the avatar when redistributing their attention. As illustrated in Fig. 4, when the participants observed the building, they focused their attention on the exterior lines of the building, which is also similar to the picture provided by Kiefer et al. [4] where people's eye paths for shadow relief focused on the exterior lines of the shadowed relief, because goal-driven intent controls visual attention, and the exterior lines of a building are its most recognizable features.

Fig. 3. Participants gaze at the head of the avatar

Fig. 4. Both participants look from the left and focus on the building lines

IV. DISCUSSION

To begin with, when people explore the plane, their attention will first focus on the center of the plane, and then expand their observations from the center to the edge. Next, when a person observes a three-dimensional environment, such as a building, a right-handed person will start from the left side of the building. Third, when people observe other things, at the end of the saccade and select the observation object, the attention will first be focused on the representative features of the thing. When observing a character, the attention will first be placed on the character's head or face. Fourth, when observing the shape of a building, people will first focus on the exterior lines of the building and observe along the lines to form a three-dimensional look and feel.

We suggest future studies based on some limitations of this studies. First, the data was small, with only two participants. Thus, more experiments will be needed in the future. Second, the experiments should include left-handed participants for comparative experiments. Both participants were right-handed in this study. Commonalities between the participants were found and consistent with the results of previous researchers, because no left-handed participants and the results were not convincing.

V. CONCLUSION

This study used eye-tracking to explore the way and characteristics of people's spatial cognition in an AR environment. The AR environment used is an augmented reality educational software that introduces historical events, which, in turn, includes multiple avatars and different buildings. When recognizing people, buildings, and spaces, we analyzed the characteristics of their sight through the process of experiment participants using this software, also learning more about the process of people's spatial perception. This provides a direction for the development of augmented reality software in the future. Future studies are required to increase the number of participants and conduct more systematic analyses.

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Medical & Healthcare Education (MHE)
Immersive Haptic Interface Simulating Skin Biopsy for Dermatological Skill Training

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Abstract— Dermatological skill training is essential for medical students to perform successful skin tumor surgery. However, there is no existing system that can provide high-quality tactile simulation and training as the substitute of clinical training with patients. In this study, we developed immersive haptic simulation combined with virtual reality for simulating two important dermatological skills, outlining and incision, and investigated the effectiveness of the developed system to be used as a training tool at clinic or school. In the evaluation study, professional (dermatologists, residents, medical students) and non-professional (students in computer science) groups of people were invited to test the developed system in terms of usability and efficacy of multimodal feedback (virtual graphic and haptic feedback). The evaluation results suggest that the training system has potential for high adoption, especially with haptic feedback in a virtual reality environment. The quantitative results based on a proposed metrics prove the ability of the training that discriminate experts from non-experts as well as objectively measure the dermatological skills.

Index Terms—haptics, VR simulation, image-based rendering, skin cancer, surgical skills training, objective assessment

I. INTRODUCTION

One of the core goals in medical education is competence in planning and performing procedures (e.g., surgeries). At a minimum, these require separate educational components for the training and assessment of these skills. Traditionally, education for procedural skills was characterized by the Halstedian “see one, do one, teach one” paradigm. However, safety concerns have limited trainee access to patients [1]. We are now entering into a “learn, see, practice, prove, do, maintain” paradigm, where “practice” and “prove” occur in simulations [2]. Thus, medical trainees develop and demonstrate competency before interacting with patients. Therefore, high-quality simulation is crucial for improved medical education and patient care.

In the United States, medical training programs teach procedural skills through a combination of didactics, observation, workshops, and assessments. In an attempt to standardize surgical training in 1997, the landmark Objective Structured Assessment of Technical Skill (OSATS) was introduced for surgical residents as demonstrated in [3]. However, recent studies have suggested that OSATS and other observation-based assessments are unreliable due to the subjectivity of raters, limited data capture, and limited preceptor time leading to insufficient trainee guidance [4]. Some have argued that objective metrics may improve training by providing real-time guidance to accelerate learning and better gauge competency via more accurate assessment [5], [6].

Since Seymour et al. [7] demonstrated that surgical skills learned in a lab directly translate to improved skills in the operating room, simulations on virtual reality and physical models have been developed widely. In particular, trainees could sense and control objects in realistic environments. Haptic virtual reality simulation for procedures has been successfully used, validated, and commercialized in non-dermatologic specialties.

Within the domain of haptic virtual reality simulation for dermatologic surgical skills training, we have made the following technical contributions. (1) We developed an immersive haptic interface simulation that takes clinical skin tumor images as the input and instantly creates an immersive surgery environment using VR glasses integrated with a stylus haptic device. (2) We proposed and implemented an efficient image-based haptic rendering algorithm that provides realistic tactile feeling synchronized with a virtual blade. (3) We systematically evaluated the VRHSP in terms of usability and efficacy with human participants (medical participants and non-medical participants) from two sites (University Hospitals Cleveland (UHC) and Kent State University (KSU), respectively). (4) We designed metrics for objective measurement on the accuracy and efficiency of dermatological skills for outlining and incision. The rest of this paper is organized as follows. In Section 2, existing approaches of surgical VR simulation with haptics and haptic rendering are introduced. In Section 3, the development and implementation of the VRHSP, including the virtual reality surgical environment and a realistic tactile haptic rendering algorithm are described. In section 4, the protocol and metrics used for testing usability and efficacy among human
participants are explained. In section 5, qualitative and quantitative results are reported. In sections 6 and 7, we discuss and conclude our system in terms of usability, limitation, and future direction.

II. RELATED WORK

NeuroTouch, a bimodal virtual reality haptic neurosurgery simulator, was developed by Sebastien et al. for brain tumor surgeries [8]. Azarnoush et al. proposed and validated metrics that are reasonable for measuring psychomotor skills to show the efficacy of the system [9], [10]. Tavakoli et al. designed a haptic user interface for endoscopic surgery and training [11]. Similarly, Baumann developed a haptics and VR simulator for laparoscopic surgery training [12].

The haptic rendering methods are implemented in these surgical simulations. Well-known haptic rendering methods used in polygonal methods are the virtual finger-proxy algorithm by Ruspini et al. [13] and the god-object algorithm by Zilles [14]. Furthermore, the haptic rendering algorithms are created for surgical purpose [15], [16]. Salisbury et al. [17] designed haptic rendering algorithm of cutting. There are also several studies that focused on force rendering feedback from in-vivo skin images in terms of tactile roughness estimation with 3D surface reconstruction [18]-[20], tactile surface restoration using deep learning [21], [22], and 3D tactile surface reconstruction using a light field camera [23], [24]. In addition, many virtual simulations have been proposed extensively for non-skin surgical specialties. However, none of these systems aim to develop hand-motor skills for skin tumor surgeries.

Dermatology has received less attention than other specialties for virtual reality aided surgical training [25] and haptic rendering. This is despite extensive work in both virtual reality and haptic feedback for virtual skin exams and for diagnosis of skin carcinomas [26]. Thus, the goal of our study is to develop VR simulation for incisions with haptic feedback and to verify the effectiveness of the haptics. The Virtual Reality Haptic Surgery Platform (VRHSP) that we propose will offer a novel dermatologic training solution and expand opportunities to do creative research in dermatologic surgery training.

III. METHOD

A. Development of a haptic-VR framework simulating skin tumor surgery

We are developing a virtual reality haptic surgery platform, the VRHSP, for medical trainees to interact with dermatology images in an immersive surgery environment with VR glasses and a haptic device. As shown in Fig. 1, the VRHSP consists of several components.

The VRHSP is a multimodal platform that consists of a head-mounted display (HMD), 3 degree of freedom (3DOF) haptic interface, and a PC workstation. The two simulated surgical environments for outlining and incision steps are based on the Unity game engine with faux skin tumor images as inputs. Visualization and haptic rendering are generated for each specific skin image. The user manipulates virtual tools to proceed a surgery to the virtual skin through a 3DOF haptic device while viewing them through an HMD. User inputs are transmitted to the PC workstation, which controls visual and haptic feedback during the procedure.

The OpenHaptics [27] plugin is used to develop haptic rendering in the Unity game engine with haptic parameters which are stiffness, damping, dynamic friction, static friction, and pop through. As seen in Fig. 2, the original Geomagic Touch stylus handle is replaced with a number 3 scalpel handle. The scalpel handle is made of stainless steel and is 12.5cm long. Thus, the user interacts with the haptic device in a way similar to interacting with a scalpel.

Fig. 2 shows an armrest designed to support the user's wrist (width: 32cm, length: 28cm, height: 13cm), much like a dermatologist rests their wrist during a procedure. The armrest structure is made of wood with a sponge attached where the wrist makes contact to relieve the strain. The center of the armrest is positioned 13 cm high, serving as a reference point 4cm above the height of the skin in the simulated environment.

The VRHSP has four main stages with the following sequence: outlining practice, incision practice, an outlining test, and an incision test. Fig. 3 shows the simulated environments for outlining and incision task simulations. The simulated surgical environment consists of a virtual surgical suite with a table in the center that supports a faux skin sample surrounded by a surgical drape. There is a “submit” button to move to the next trial.

In the outlining simulation, the user can outline by using a virtual pencil that is connected to the stylus of the haptic device. Once a collision is detected between a ray enclosed by the pencil and a skin mesh mapped with a skin image, the VRHSP...
outlines on the mesh on the collision position. Two red arrows guide the user to be aware of the start and end vertices of the ellipse until the user starts to outline.

Fig. 2. The modified interface of the Geomagic Touch to have a number 3 scalpel handle (left) and the armrest (right).

In the incision simulation, the user uses a virtual scalpel connected to the stylus of the haptic device to cut the skin surface mesh and two layers of multi-plane meshes under the surface mesh. Once the user cuts more than one layer behind the skin surface, it draws a faux incision using sequential blood textured pixel interpolated between collision points as the user cuts. If the user only touches the surface mesh with insufficient force to cut the surface, it draws a white line to simulate a scratch. Similar to the outlining simulation, a red arrow guides users to the start incision.

There are three different spaces in this system, represented by Unity coordinates, haptic coordinates and real-world coordinates. Without synchronization, an unwanted gap occurs between the spaces. Therefore, calibration between the three coordinates is necessary. The skin image is used for haptic calibration. The diameter of the margin around one of our faux skin tumor images is 1 cm (i.e., length of ellipse minor axis). We draw the diameter of the margin in the outlining practice stage and compare it with the real-world length as measured by a ruler. We synchronize 1 cm in unity coordinate and 1 cm in reality using the formula, 0.133 unity coordinate = 1 real-world cm. For the VR calibration, we position the skin image in the middle of the haptic device at the height of 9 cm above the table which synchronizes the height of the armrest 4 cm above the skin.

Fig. 3. Outlining and Incision task in the VRHSP. (Left: Outlining test stage, Right: Incision test stage).

B. Image-based Haptic Rendering for a Skin Tumor Surgery Procedure

We have implemented an efficient image-based haptic rendering algorithm that makes the surgery simulation more realistic. The input skin image is attached as a texture on a plane mesh. To create a more realistic visual, the physically-based rendering [28] approach is applied to the skin image. For the physically based rendering, the normal map is implemented to false height and depth information. Also, the haptic rendering includes the inner layers of the skin which gives feedback in 1 dimension, namely height.

In both the outlining and incision tasks, surface haptic rendering is used to simulate tactile feedback from the skin. There are haptic coefficient parameters provided by the OpenHaptics library: stiffness, damping, dynamic friction, static friction, and pop. These parameters can be adjusted for each skin image to generate a contextualized haptic rendered surface.

Fig. 4. Proposed multi-layered force rendering model for plane meshes with the skin layer. Pi represents the i-th plane mesh in a layer. F is the force of cutting. Pt is pop through parameter. Right: A sketch of skin layers.

As the first step, the VRHSP generates multiple plane meshes within the skin and the underlying muscle layers (see Fig. 4). For each layer, all of the generated plane meshes are positioned in the layer at equal intervals. All of the planes have the same scale and the same x, z values as the surface. After generating all of the plane meshes within a single layer, each plane’s y value in the unity space is changed per Equation 1. PrePi denotes the y value of the i-th plane of the layer. PrePy denotes y value of the last plane in the previous layer. In the case of the first layer (i.e., skin), PrePy denotes the y value of the surface. d is the depth of the layer and n is the total number of the plane meshes in the layer. A pilot study suggested that 50 planes within a layer provide the best force rendering without discontinuity.

\[ Py_i = \text{PrePy} - \frac{i \ast d}{n} \] (1)

Then, the haptic rendering algorithm for determining pop through parameter is applied to each plane mesh as the second step. The pop through parameter in the OpenHaptics library defines how hard a user must push against the surface of an object before it “pops through” to the other side. Within a layer, the coefficient parameters for the haptic rendering on planes are constant (stiffness, damping, dynamic friction, and static friction). However, the pop through parameter for each plane is changed because it influences friction. The lower or same pop through value on the lower plane mesh of the layer will ignore
the friction forces generated from the pop through parameter. Equation 2 computes the force feedback \( F_i(x, y, z) \) where \( k_i \) denotes a material stiffness coefficient of the \( i \)-th surface layer, \( d_i \) denotes the penetration depth between haptic probe and the virtual proxy on the \( i \)-th plane surface and \( f_r \) denotes residue forces. Fig. 4 shows the force feedback model of each plane mesh until pop through occurs, which is described in Equation 2.

\[
F_i(x, y, z) = k_i \cdot d_i + \sum f_r(i) \tag{2}
\]

The pop through value of plane meshes in each layer, \( Pt_i \) is computed using Equation 3. The start pop through value of the first mesh of the layer, \( sPt \), and the end pop through value of the last mesh of the layer, \( ePt \), are predefined. \( n \) is the number of the plane meshes in a layer, and \( i \) is the iterator of the plane mesh. It generates the sensation of two layers (i.e., skin and underlying muscle).

\[
Pt_i = sPt + \frac{i \cdot (ePt - sPt)}{n} \tag{3}
\]

IV. EXPERIMENT

We systematically evaluate VRHSP in terms of usability and efficacy with non-medical and medical human participants from two sites Kent State University and University Hospitals Cleveland, respectively. This section describes the experiment to evaluate the VRHSP.

A. Participants

We conducted the experiment with six non-medical participants from Kent State University and six medical participants from University Hospitals Cleveland. To verify the ability of VRHSP to discriminate non-medical from medical participants, participants from these two different groups were recruited. Medical participants were selected at random by recruiting all medical students, residents, and attendings working in clinic on the day of the experiment. Bias was addressed by making participation voluntary, blinding faculty to participant results, and deidentifying participants. Non-medical participants were randomly selected by recruiting all non-medical students. The experiment was approved by the Institutional Review Boards. Two of the non-medical participants have previous experience with VR and haptic, but none of the medical participants have previous experience with VR and haptic. One non-medical participant and one medical participant had excluded post factum because their data is not meant as recorded, likely because they did not pop through the skin. None of them had visual or haptic impairments. Participation was voluntary, and informed consent forms describing the study objectives were signed by all participants.

B. Apparatus

In order to provide realism for the proposed approach, we use a PC equipped with an Intel® i7-6700K CPU, 16G RAM and a NVIDIA GTX 1060 6GB with a standard monitor, Geomagic Touch haptic device, and a HTC Vive Pro Eye HMD containing two active-matrix organic light-emitting diode (AMOLED) screens, with a resolution of 2,880 X 1,600 pixels, a refresh rate of 90 Hz and a 110° field of view. A keyboard and mouse are only used to fill in participant IDs at the start of the study. An armrest is placed to support participants’ wrists.

C. Procedure

Participants are asked to adjust the height of the chair and wear the HMD while the position of the haptic device is fixed. Then, a research coordinator gives a verbal tutorial of the system. In order to prevent any bias from noise, earplugs are provided to participants. After fitting the equipment, a research coordinator starts the simulation. Participants perform two simulations, outlining and incision, under two conditions, with haptic feedback, and without haptic feedback. The experimental setup is illustrated in Fig. 5.

Fig. 5. Left: A non-medical participant proceeding the experiment, Right: A medical participant proceeding with the experiment.

The study follows a sequence of four parts: outlining practice, incision practice, outlining test, and incision test. A simple practice session is given before the participant starts testing. In the outlining practice stage, participants are able to compare their outline result with an ideal answer. Participants are allowed to practice repeatedly outlining until starting the test.

In the incision practice session, visual feedback guides the user towards the ideal result. Horizontal and vertical angle errors greater than 30° are corrected with a red arrow radiating from the scalpel handle within the virtual reality simulation. A graph of actual versus ideal depth is provided for participants to compare to. Participants are given unlimited practice time.

After the practice stages, participants complete the outline test stage and then complete the incision test stage. In each test stage, 5 faux skin images are displayed under two conditions (with haptic feedback and without haptic feedback) in random order without replacement (10 trials total). The faux skin images in Fig. 6 are captured with a Nikon DSLR camera by photographing faux skin tumors (5-12 mm diameter rubber circles approximately 2mm thick and inked with a black and red pen). Images are taken both before and after outlining the incision with a blue surgical marker (5mm margins surrounded by a 3:1 fusiform ellipse).
The sequence of the trials is randomized so that participants do not know which condition (with haptic or without haptic) or which image comes next. We conduct each trial of the outlining and incision stages using the following procedures: Participants start outlining or making an incision from an arrow with the text “Start here” that points at the ellipse vertex. After completing a trial, participants click the submit button using the virtual pen or virtual scalpel to move to the next trial.

The ideal depth for the incision stage is set at 1 cm for all trials (approximate depth of a skin layer). Participants can move their body position and adjust the height of their chair freely.

At the end of the experiment, participants are asked to fill in a questionnaire and complete the NASA Task Load Index (TLX) [29] instrument. The NASA TLX instrument consists of six rating categories (scale: 0 to 20) regarding participants’ estimation of the VRHSP’s mental demand, physical demand, temporal demand, self-performance, effort and frustration. Additional survey questions include: (1) Which condition did you feel better between haptic and no haptic in drawing? (2) Which condition did you feel better between haptic and no haptic in cutting? (3) Do you think this platform would be helpful for learning about skin biopsy? (4) Were you able to perform the tasks intuitively? (5) What were the most challenging things while performing a drawing or cutting task? Please explain.

D. Data Analysis

Based on the landmark 1997 OSATS study, trainees’ surgical skills are typically assessed by experts using procedure-specific checklists and global rating scales. [3,30] VR has allowed for the collection of both standardized checklist-based metrics as well as novel procedure-specific metrics formerly unmeasurable without technology. VRHSP builds on this convention by incorporating standardized metrics that is summarized in Table I from a published elliptical excision checklist (EEC) [31]-[33] as well as novel procedure-specific metrics validated by an expert (Dr. Bryan T. Carroll, University Hospitals Cleveland Medical Center).

Two metrics of the outlining task: time spent outlining, and the mean of Euclidean distance errors. Time spent outlining demonstrates proficiency and is measured for each outlining trial. The mean of Euclidean errors shows the accuracy of a participant’s outline compared to the ideal answer. Individual distance errors are taken as the distance between points along the participant’s path and the closest point along the ideal answer.

Six metrics of the incision stage: time spent making an incision, mean of depth errors, mean of x angle errors, mean of z angle errors, area accuracy, and area efficiency. Time spent is as described for outlining. The mean of depth errors demonstrates the accuracy of the average depth of an incision compared to the ideal depth of 1cm. The next two metrics, x (vertical) and z (horizontal) angle errors, compare the participants angle at each point along the incision path to an ideal angle of 45° and 90°, respectively. Accuracy is the percentage of the participant’s incision area involved in the ideal incision area which shows the amount of undercut. Efficiency is the percentage of the ideal incision area involved in the participant’s incision area which shows the amount of overcut area. In this experiment, the metrics were used as dependent variables and non-medical participants with haptic, non-medical participants without haptic, medical participants with haptic and medical participants without haptic are the independent variables.

TABLE I. METRICS OF TWO SURGICAL TASKS (OUTLINING AND INCISION TASK)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outlining</strong></td>
<td></td>
</tr>
<tr>
<td>Time spent</td>
<td>(O_t = O_{t\text{end}} - O_{t\text{start}}) The time stamp taken when the participant submits. (O_{t\text{start}}) The time taken when the participant starts outlining.</td>
</tr>
<tr>
<td>Mean of Euclidean distance errors</td>
<td>(\overline{O_{err}} = \frac{\sum_{i=1}^{n} \sqrt{(x_i - x_{i-1})^2 + (z_i - z_{i-1})^2}}{n}) x and z coordinate of each answer point. (x_i, z_i) Total number of the participant’s points.</td>
</tr>
<tr>
<td><strong>Incision</strong></td>
<td></td>
</tr>
<tr>
<td>Time spent</td>
<td>(I_t = I_{t\text{end}} - I_{t\text{start}}) The time stamp taken when the participant submits. (I_{t\text{start}}) The time taken when the participant starts outlining.</td>
</tr>
<tr>
<td>Mean of depth errors</td>
<td>(\overline{D_{error}} = \frac{\sum_{i=1}^{n} (y_i - \frac{\sum_{j=1}^{n} y_j}{n})}{n}) The ideal depth. (y_i) y coordinate of the participant’s each point. (n) Total number of the participant’s points.</td>
</tr>
<tr>
<td>Mean of x angle errors</td>
<td>(\overline{X_{error}} = \frac{\sum_{i=1}^{n}</td>
</tr>
<tr>
<td>Mean of z angle errors</td>
<td>(\overline{Z_{error}} = \frac{\sum_{i=1}^{n}</td>
</tr>
<tr>
<td>Area Accuracy</td>
<td>(\text{Accuracy} = \frac{\text{Area}}{\text{Area}}) (\text{Area}) Cut surface area in the ideal answer. (\text{Area}) Cut surface area of the participant.</td>
</tr>
<tr>
<td>Area Efficiency</td>
<td>(\text{Efficiency} = \frac{\text{Area}}{\text{Area}}) (\text{Area}) Cut surface area in the ideal answer. (\text{Area}) Cut surface area of the participant.</td>
</tr>
</tbody>
</table>
V. RESULT

In this section, we report results from the evaluation of the VRHSP usability study. Quantitative results are based on metrics in Table 1. Qualitative results include free response questionnaire data and analysis of the NASA TLX instrument.

A. Quantitative Result

We calculate and share results based on metrics defined in Table 1. Note that NMP means non-medical participants, MP means medical participants, H means with haptic, and NH means without haptic. For statistical analysis, the paired t-test is used to test the mean difference between pairs (NMP-H VS NMP-NH, MP-H VS MP-NH, NMP-H VS MP-H) of measurement. Square grey brackets indicate statistically significant differences (* p<0.05, ** p<0.01, *** p<0.001) between a pair.

Fig. 7 shows the quantitative results based on outlining metrics. The results of time spent on outlining step did not show many differences (NMP-H:21.68, NMP-NH:24.77, MP-H:22.01, MP-NH:24.5) except for the non-medical participant with haptic and without haptic (t-statistics = -3.04, p = 0.006 ).

The non-medical participants showed less Euclidian error than the medical participants (NMP-H: 0.183, NMP-NH: 0.173, MP-H: 0.2, MP-NH: 0.198) where no significant difference was found in all pairs by t-test (NMP-H VS NMP-NH: t-statistics = 1.95, p = 0.63, MP-H VS MP-NH: t-statistics = 0.29, p=0.78, NMP-H VS MP-H: t-statistics = -1.96, p=0.06).

Regarding the results from the incision (fig. 8), both groups took more time with haptic than without haptic (NMP-H: 39.09, NMP-NH: 31.23, MP-H: 30.03, MP-NH: 23.59) in the incision step. The t-test on the time spent for incision in both non-medical participants and medical participants found significant differences between conditions (NMP: t-statistics = 4.82, p < 0.001, MP: F = 4.05, p < 0.001). This result also shows that medical participants took less time than non-medical participants with haptic. The result from the t-test showed a significant difference between incision time in NMP-H and MP-H (t-statistics = 3.72, p = 0.01). Both groups made more than double depth errors in no haptic condition (NMP-H: 0.44, NMP-NH: 1.08, MP-H: 0.40, MP-NH: 1.19). The t-test showed the significant difference of depth error in conditions from both non-medical participants (t-statistics = -5.78, p < 0.001) and medical participants (t-statistics = -7.16, p < 0.001).

Both groups showed similar X angle error in each condition, while non-medical participants made more errors than medical participants (NMP-H: 10.83, NMP-NH: 10.59, MP-H: 6.23, MP-NH:7.71). The t-test found that the angle errors between two groups with the haptic condition are significantly different (t-statistics = -3.41 p = 0.002). The same results were found in Z angle error with more gap between groups (NMP-H: 20.34, NMP-NH: 20.64, MP-H: 9.56, MP-NH:10.09). The t-test showed a significant difference of Z angle error between the two groups (t-statistics = 3.56, p = 0.001).

The accuracy of both groups was higher with haptic. Especially the medical participants had a huge gap between conditions (NMP-H: 87.84, NMP-NH: 78.59, MP-H: 87.31, MP-NH:10.09). The t-test showed that the accuracy between conditions in both non-medical participants (t-statistics = 4.53, p < 0.001) and medical participants (t-statistics = 12.37, p < 0.001) are significantly different. The efficiency of both groups showed the same pattern of accuracy (NMP-H: 90.18, NMP-NH: 86.45, MP-H: 92.27, MP-NH:73.07). The t-test showed a significant difference between conditions for non-medical participants (t-statistics = 2.56, p = 0.017) and for medical participants (t-statistics = 7.2, p < 0.001).
B. Qualitative Results

Fig. 9 shows the participants’ responses to the NASA TLX instrument. All participants from both participant groups selected “haptic” as the preference for questions 1 (Which condition did you feel better between haptic and no haptic in drawing?) and 2 (Which condition did you feel better between haptic and no haptic in cutting?). Also, all participants chose “yes” in question 3 (Do you think this platform would be helpful for learning about skin biopsy?). Only one participant chose “no” (10%) in question 4 (Were you able to perform the tasks intuitively?). Non-medical participants answered question 5 (What were the most challenging things while performing a drawing or cutting task?) that it is hard to rotate the scalpel the correct way and find the proper depth of the incision. Medical participants answered that the feedback is too sensitive, “pop through” pressure is a challenge to master, the weight of the scalpel is too heavy, the HMD touches the actual physical table in the room, and it is hard to reposition when the start and stop points are off-angle.

![Fig. 9. The results of NASA TLX from non-medical participants (top), and medical participants (bottom).](image)

VI. DISCUSSION

In terms of usability evaluation, we valued three things which are performance, preference, and ability of discriminating trainee levels. In terms of performance evaluation on the VRHSP, the depth error, accuracy, and efficiency in incision directly relate to haptic feedback. These metrics in haptic condition were significantly higher than no haptic condition in both non-medical participants except for the efficiency in non-medical participants. Especially, there was a considerable gap of depth error between the two conditions where the error in the haptic condition was significantly lower than no haptic condition in both participant groups. These results demonstrate that the performance with haptic feedback is better than without haptic feedback. Furthermore, the new algorithm of haptic rendering for incision enhanced the platform's performance.

In terms of preference on haptic feedback, positive indicators from NASA TLX are pointing to the haptic feedback. The high performance and low negative indicators overwhelmingly support the preference for haptics. The results from question 3 (“Do you think this platform would be helpful for learning about skin biopsy?”) from medical participants are especially meaningful because medical participants compare their experiences on VRHSP with other familiar alternative simulation methods (e.g., porcine or silicon skin). All the participants in both groups answered, “This platform would be helpful for learning the skin biopsy procedure,” which emphasizes the value of the platform.

In terms of the ability to discriminate non-medical from medical participants, most of the results show no significant difference between the participant groups. However, the time spent in outlining task, x angle error, and z angle error are significantly lower in medical participants than non-medical participants. We speculate that the difficulty of reducing angle errors in incision tasks caused the non-medical group to take more time. Also, the comments of question 5 on the difficulty in rotating the scalpel by non-medical participants support this opinion. One interesting feature observed during the experiment is that while non-medical participants rarely move their bodies to adjust the angle of the scalpel, most of the medical participants moved the whole body to get the correct angle. This feature is reflected in both quantitative and qualitative results. Therefore, it seems that the platform equips the ability to discriminate the level of the trainees with metrics.

In this study on the usability of the multimodal platform, the VRHSP, we focused on the comparison between haptic feedback conditions, but we have a lack of comparison between other visual environments such as PC and mixed reality. Mixed reality is also widely used in the medical field recently [34], [35]. Expanding the VRHSP to a bimodal platform would be meaningful to optimize usability.

The VRHSP only covered two tasks in elliptical skin excision, which has nine steps. (identify, outline, anesthetize, incise/cut, undermine, remove, caudate, suture, bandage). We are aiming to expand the steps of the skin tumor surgery task in the VRHSP with a bimodal environment to become the ultimate training platform in the dermatology field.

A small number of participants and skin images of the initial study was a limitation in this study. Bias from individual features or habits cannot be reduced with a small number of participants or images. Thus, in the future study, this limitation will be improved by sampling a larger number of participants and analyzing the data.

Another limitation of the VRHSP is the rigid body skin model. Differ to the real skin, the skin mesh in our platform is a rigid body which cannot be deformed in real-time. A deformable skin model and haptic rendering method has potential to provide more realistic haptic feedback.
VII. CONCLUSION

In this paper, we presented the multimodal virtual training platform, the VRHSP, that integrates VR glasses and a haptic device for dermatological surgery training. The VRHSP has been implemented with a new image-based multi-layer surface haptic rendering algorithm that emulates realistic tactile feeling during surgical simulation. We verified that the haptic feedback increases the performance and usability of the VRHSP using both quantitative and qualitative results. Also, we designed new metrics for objective measurements on accuracy and efficiency of surgical skills. In the future, we plan to extend the VRHSP to use other viewing technologies such as Oculus and Microsoft MR glasses and different types of haptic devices to enforce the system.

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Undergraduate Nursing Students’ Experiences and Perceptions of Self-Efficacy in Virtual Reality Simulations

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Abstract— Immersive virtual reality (VR) simulations are gaining prominence in undergraduate nursing education because they (a) can mimic the dynamism of clinical settings for students, (b) enable educators to scaffold theory-practice integration and multiple skill development, and (c) provide programs with a cost-effective curricular solution for supporting clinical practice-readiness. In this paper, we investigate first- and second-year nursing students’ experiences with Simulation Learning System with Virtual Reality (SLS with VR) during a 7-week study in Fall 2020 and assess change in their self-efficacy from pre-post. An inductive thematic analysis of students’ responses revealed that they experienced a heightened sense of engagement in VR, and SLS with VR afforded roleplaying in authentic clinical situations. A statistically significant improvement was found in students’ ratings of self-efficacy variables such as their understanding of content, ability to make clinical judgments, caring for patients, working in teams, and ensuring safety and quality in clinical situations. These findings contribute to a growing body of literature that is focused on supporting nursing education stakeholders to understand and embrace the effectiveness of VR in preparing future nurses for patient well-being and the complexities of health care settings.

Index Terms— virtual reality, undergraduate nursing education, self-efficacy, student perceptions, randomization testing approach, thematic analysis

I. INTRODUCTION

According to the U.S. Bureau of Labor Statistics [1], employment of registered nurses is projected to grow seven percent over the next decade. This growth is faster than the average for all occupations in the U.S. Meanwhile, the nursing profession continues to face a gap in the supply and demand of nurses due to factors such as nurse burnout and an aging workforce [2]. Additionally, many entry-level nurses are unprepared to practice in rapidly changing and increasingly complex health care environments [3]. In view of these trends and challenges, leaders in nursing education have urged the field to continue their commitment to quality research and education. This appeal is relevant and timely as the demand for well-trained nurses has grown globally during the COVID-19 pandemic [4].

Nursing programs are striving to enhance the quality and quantity of nursing students’ experiences within clinical simulation laboratories to help prepare them for the complexities of the nursing profession. This goal is juxtaposed with ongoing challenges in providing students with relevant and realistic clinical experiences, catalyzing an increased use of immersive technologies such as virtual reality (VR) simulations in nursing education programs [5]. VR simulations can be defined as “a variety of immersive, highly visual, 3D characteristics to replicate real-life situations and/or health care procedures (p.56)” [6]. VR simulations can be further characterized by core characteristics of immersion, interactivity, and presence that support students’ meaningful application and synthesis of knowledge [7].

A surge of recent papers has demonstrated that the use of VR simulations in nursing education positively impacts learning outcomes (e.g., knowledge) [8]-[10]. Empirical evidence is also growing regarding the effectiveness of VR simulations for nursing students’ preparation for clinical practice (e.g., practicing safety). However, little is known regarding students’ learning experiences in VR and the effectiveness of these high-fidelity simulations for improving students’ self-efficacy. We argue that understanding students’ perceptions and the impact of non-academic factors, such as self-efficacy, are important when developing curricula and instructional strategies using VR to support students’ clinical readiness in a holistic manner.

This paper, therefore, investigates nursing students’ responses on a pre-post survey to understand their perceptions of self-efficacy and learning experiences in VR simulations. The following research questions are examined, “How do undergraduate nursing students describe their learning experience in VR simulations?” and “How does participation in VR simulations affect undergraduate nursing students’ beliefs about their clinical competencies?”

The paper is organized in the following manner: First, we review research on self-efficacy and establish its significance in supporting students’ academic success. We also examine burgeoning research on understanding students’ experiences and outcomes mediated through VR simulations and underscore the need for nuanced investigations. Second, we
describe the research methods, including the context for the larger study this paper is situated in. We introduce Simulation Learning System with Virtual Reality (SLS with VR) for undergraduate nursing education and describe the participants who used SLS with VR for seven weeks in 2020. In this section, we also describe the survey items and the analytical procedures applied to answer the research questions. Third, we report findings for each research question followed by a discussion. Fourth, we conclude our paper with implications for educators and researchers interested in advancing nursing education research and practice through immersive learning environments such as VR simulations.

II. LITERATURE REVIEW

Self-efficacy, a core aspect of social cognitive theory, refers to judgments that people make about their capabilities to perform actions necessary to achieve designated outcomes [11]. These beliefs are important as they can function as powerful predictors of motivation, cognition, affect, and behavior [12]. Students with high self-efficacy are more willing to undertake challenging tasks, persist longer when they encounter difficulties, and achieve at higher levels [12, 13].

A strong sense of self-efficacy could be particularly important for nursing students who often experience high levels of stress as they progress through undergraduate coursework and prepare to take the National Council Licensure Examination for Registered Nurses (NCLEX-RN) [14]. An extensive body of research has demonstrated that self-efficacy is positively associated with college students’ success across a variety of academic environments and student populations [15; 16]. Research has shown that self-efficacy beliefs are often better predictors of success than prior knowledge, accomplishments, or skills [11]. Self-efficacy has also been recognized as a predictor of academic success in nursing education, indicating that students’ self-efficacy expectations had a strong effect on NCLEX-RN outcomes [17].

Self-efficacy of nursing students has been studied mostly within digital simulation environments for clinical experiences with researchers reporting increased self-confidence [18]-[20]. In a meta-analysis assessing the effectiveness of VR within nursing education, Chen and colleagues [21] identified four studies that examined confidence, but no statistically significant differences were found between VR and other education methods. They also reviewed four articles that reported participants’ satisfaction scores with only one VR group showing greater satisfaction when compared to control groups. Cant and Cooper [19] noted that literature reviews have commonly reported improved confidence and strong student satisfaction with simulations in nursing education.

More recent studies also suggested that nursing students reported high levels of satisfaction and positive learning experiences with the use of VR [19]-[23]. For example, Saab and colleagues [23] examined undergraduate nursing students’ perspectives after incorporating the Enhance Men’s Awareness of Testicular Diseases (E-MAT) VR intervention. The “captivating, innovative, and empowering nature of VR” emerged as a key theme in which participants reported increased confidence and described VR as novel, engaging, and memorable. In another study, Chang and Lai [24] facilitated a focused group interview to understand nursing students’ experiences of participating in a VR simulation of the nasogastric tube care skill training process. Researchers [24] employed a thematic analysis on students’ responses and illustrated the following themes “convenient to practice, but requires adaptation,” “fast skill learning process,” “stress-free learning environment,” “environmentally friendly,” and “lacks a sense of reality” (p.4).

Despite the prevalence of this research, there is a dearth of studies on the effectiveness of immersive VR simulations from the perspective of nursing students. While there are emerging studies that support the use of virtual simulations in nursing education, the evidence for self-efficacy is mixed, indicating the need for further research. Lastly, most investigations on students’ experiences with VR simulations (a) have been restricted to short-term encounters that are anchored in single scenarios or training processes, and (b) have not included best practices in simulation education during their intervention (e.g., prebriefing, simulation and debriefing).

To address these gaps, we examined the effectiveness of SLS with VR for improving nursing students’ clinical readiness.

III. METHODS

This examination is situated in a larger 7-week quasi-experimental study (October to December 2020). The goals of this study were to test the effectiveness of SLS with VR with faculty and students in undergraduate nursing programs. Specifically, for both sets of participants, we were interested in establishing a baseline (e.g., understand current practices with simulations, experience with VR, hopes and concerns for learning with VR simulations), documenting experiences with SLS with VR (e.g., understand ease of set up and usefulness of onboarding resources, discover what students enjoyed and struggled with while learning with SLS with VR), assessing effectiveness of SLS with VR (e.g., model classroom discourse for enactment of clinical judgment (CJM) and quality and safety education for nurses (QSEN) competencies, assess change in students’ self-efficacy for learning with SLS with VR), and obtaining feedback for improving SLS with VR.

In this paper, the first research question aligns with the goal of establishing a baseline. We attempt to understand students’ experiences of learning in VR simulations by examining their self-reported responses about what they enjoyed while participating in SLS with VR simulation scenarios. The second research question aligns with the goals of assessing the effectiveness of SLS with VR. We examine changes in students’ ratings on pre and post study surveys to assess whether participating in SLS with VR simulations impacted their perceptions about becoming competent to participate in clinical situations.

A. Participants

Convenience sampling was employed to seek participation from undergraduate nursing programs in the United States that were interested and available to participate in the study. A total of 223 first- and second-year students and 13 faculty participated in the study from six nursing institutions. Of the 207 students who indicated their program affiliation, 118 were
enrolled in a Bachelor of Science in Nursing (BSN) program, and 89 were enrolled in an Associate Degree in Nursing (ADN) program. Of the 223 students, 32% (N=71) had some experience with video games. Of these 71 students, only 37% (N=26) students played games often or very often. Of the 223 students, 60% (N=127) had no experience with VR. However, 30% (N=64) had beginner-level experience with VR, followed by 8% with competent-level experience (N=18). Their experience with VR was derived from a console owned at home, tours and exhibits, tourist attractions, or resources at college libraries and the workplace.

B. Simulation Learning System with Virtual Reality

SLS with VR enables nursing schools to provide undergraduate students with immersive clinical experiences, alongside traditional simulation experiences. The following physical and technical set up is required: a minimum of 10’ x 10’ space with up to 25’ by 25’ maximum space, minimum of two compatible VR headsets, a laptop computer with Windows operating system for faculty facilitation. A second laptop and monitor for student observation is optional but recommended. When facilitating simulations, the following roles are recommended for a successful experience: two student nurses that can work as a team in the scenario, a facilitator who can moderate the scenario (typically an instructor or lab coordinator), and student observers.

Typically, each SLS with VR session, whether facilitated in person or remotely, involves some asynchronous activities (before and after a session) and synchronous activities (pre-briefing, simulation experience, and debriefing phases). For instance, simulation exercises and quizzes, reading assignments and skills labs that are specific to a simulation scenario may be assigned for preparation and practice, before and after a session. Pre-briefing and debriefing are best practices in simulation education that are used to understand scenario objectives, discuss role assignments, set performance expectations, acclimate to the VR environment space, review learners’ experiences, and reflect on their actions in the simulated clinical situations.

During the simulation, faculty select, view, and moderate scenarios from an interactive interface (i.e., moderator tool). Faculty have a choice of 100 scenarios across multiple content areas in nursing including Health Assessment, Fundamentals, Medical-Surgical, Maternity, Pediatric, Psychiatric, Community and Leadership. Example scenarios include Postoperative Respiratory Distress, Fall and Pressure Ulcer Risk Assessment, Colostomy and Hyperkalemia Secondary to Medication Error, Scheduled Cesarean Delivery, Post-traumatic Stress Disorder, and Home Health. The scenario objectives are translated to expected clinical actions and mapped to knowledge, skills, and attitudes essential for practice readiness (e.g., QSEN competencies). Students participate in the VR scenarios using supported VR hardware (e.g., Oculus Quest 2 headset equipment and hand controllers). Faculty have a full view of what students are experiencing in the VR space through the moderator tool. Faculty also have access to orders and actions that help them facilitate a scenario, including opportunities to introduce multiple virtual characters (e.g., patient, nurse, doctor, dietitian, employer, and distractions (e.g., phone calls) that students must interact with and address respectively (Fig. 1.). Students are required to make decisions in real time that have direct patient implications in realistic clinical scenarios. Direct patient interactions and responses, as well as communication with family members, makes developing communication skills easier for students (Fig. 2). This video provides a brief walkthrough of the set-up, design, and experience.

C. Procedures

For this study, faculty could choose the scenarios they wanted to facilitate, the students they wanted to include in each session and their role assignments. As such, student participants were not randomly assigned. Of the 44 SLS with VR scenarios that were available across multiple content areas during the study, 18 scenarios from Community, Fundamentals, Maternity, Medical-Surgical, and Pediatric disciplines were used across the six institutions. Data collection procedures were designed to accommodate the uncertainty of college openings during the peak of the COVID-19 pandemic. That is, researchers were prepared to support participants and collect data synchronously and asynchronously in an online-only, hybrid, or in person formats. This was possible because SLS with VR is designed for participants to collaborate in a virtual space while being present in physically remote locations. Please
refer to Shah and colleagues [25] for a detailed explanation of the study procedures.

D. Data Sources and Analysis

To answer the research questions addressed in this paper, we used students’ responses on pre-post surveys. For each participating institution, responses on the pre-survey were obtained before students experienced their first scenario in SLS with VR and the post-survey was administered after students completed participating in a scenario (as direct participants) assigned to them by their instructor.

To examine students’ experiences (research question 1), we applied thematic analysis to the following question on students’ post survey, “What did you enjoy while participating in SLS with VR?” The technique affords an exploratory orientation this is relevant to our work since evidence about the impact of immersive VR on nursing students’ experiences and clinical readiness is still emerging. We adopted an inductive approach to identify, analyze, and report patterns (themes) embedded throughout the data obtained from students’ responses [26].

Self-efficacy (research question 2) was measured through variables such as understanding of content, making clinical judgments, providing individual patient care, functioning as a member of the healthcare team, promoting safety for patient, self and others, and identifying factors that influence quality of care. An example of item from the post-survey is as follows, “My understanding of content deepened as a result of participating in the assigned VR simulation scenario.” Students rated each self-efficacy item on the pre and post survey on a five-point Likert scale, where 1 = Strongly Disagree and 5 = Strongly Agree.

We looked to see whether participating in SLS with VR increased participant ratings, kept ratings unchanged, or decreased ratings. In other words, we were not looking at the size of the mean difference but were instead looking at change as a categorical variable. To see if the ratings increased at a level significantly greater than chance, we took a randomization testing approach. For a paired sample situation, one randomly draws within a person which rating is first versus which rating is second for every person within a given sample. One then records whether the randomly assigned ratings decreased or increased (those staying the same will be constant, as it does not matter which of those ratings is first). One replicates this a large number of times in order to create a null sampling distribution. We took this approach because the shape of the distribution of changes violated the normality of differences assumption of the standard paired-samples t-test.

In Table I, we demonstrate some example draws of the randomization sampling technique. Each draw takes the original data for each person and randomizes which rating was first versus which rating was second. The gray shading in the table indicates a case where the draw has rearranged the data from the original data’s order. We conducted 20,000 sets of these random draws, which randomly rearranged the data within person for each draw.

We were testing the null hypothesis that there was no significant increase in the ratings for each question. Randomizing the data within participants will, on average, create approximately the same number of changes that are increases and decreases. By rejecting the null hypothesis, we could demonstrate that the proportion of increased ratings was greater than statistical chance.

For this paper and to answer research question 2, we used data only from those students who completed a portion of both the pre and post survey. For people that took more than one post survey, we only used the person’s first post survey response. This yielded a sample of 140 students. Of these 140 students, we only chose responses from those students who rated any of the self-efficacy variables as 2 (disagree), 3 (neutral) or 4 (agree) on a five-point Likert scale (1=strongly disagree, 5=strongly agree) in the pre survey. This decision was made to control for ceiling and floor effects in rating change. We only considered responses from students whose responses had the freedom to move in the positive or negative direction from pre-post. For this approach, the null hypothesis was that participating in SLS would have no effect on ratings. The alternative hypothesis was that participating in SLS would increase participant ratings. This resulted in a final sample size between 95 and 101, depending on the variable involved.

IV. Results

A. Nursing Students’ Learning Experiences in VR

Two themes emerged from students’ responses on what they enjoyed while participating in SLS with VR. First, students reported that they experienced a heightened sense of engagement in SLS with VR simulations. They described scenarios as immersive and interactive, evoking a strong sense of presence and realism, and offering multimodal stimuli and immediate feedback to learners. For instance, a student said, “I enjoyed that the patient and wife were interactive, as well as being able to actually draw up insulin, check blood sugar and actually feel pulses. I loved that I was able to hear heart and lung sounds as well.” Another explained, “I enjoyed that I felt like I was in the patient’s room and got to perform what felt like real patient care; this gave me more experience with patient care and working on my own.”

We only considered responses from students whose responses had the freedom to move in the positive or negative direction from pre-post. For this approach, the null hypothesis was that participating in SLS would have no effect on ratings. The alternative hypothesis was that participating in SLS would increase participant ratings. This resulted in a final sample size between 95 and 101, depending on the variable involved.
Second, students reported that SLS with VR afforded them with opportunities to role play as nurses in authentic scenarios and practice social, cognitive, and psychomotor skills. Students described several encounters like patient and family interactions, working with an interprofessional team of peers and virtual characters, and performing nursing actions in a safe environment. Two illustrative quotes are provided below:

“I enjoyed the experience of working with a patient (and family member) while working as a team with my partner. It helped us work as a team while caring for a patient and interacting with family as well, which I feel is a huge aspect in patient care.”

“I really enjoyed the communication aspect of participating in SLS with VR simulations. I feel like it gave me a better understanding of common questions patients and their loved ones might have. I also enjoyed that it was very realistic in terms of the type of equipment and materials that we would use in real life to assess the patient. I think my favorite part, however, was that I was allowed to make mistakes and ask questions if I needed further assistance in caring for my patient. As a result, I feel better prepared to care for patients in real life that may present with similar conditions because it gave me entail on how to potentially organize and choose my assessments in the future for patients.” Table 2 provides an illustrative quote for each code under the two themes to further represent students’ learning experiences in VR through SLS with VR.

**TABLE II. EXAMPLE OF STUDENTS’ RESPONSES FOR EACH CODE UNDER THE TWO THEMES**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Code</th>
<th>Students’ Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heightened Sense of Engagement</td>
<td>Immersive</td>
<td>I enjoyed the experience. I loved how the virtual reality was set up, and how it made you feel like you were really in the patient room.</td>
</tr>
<tr>
<td></td>
<td>Interactive</td>
<td>I really enjoyed being able to take care of this care and being able to get situations to answer the phone as well as answer questions to the wife in a real life scenario. I think that this was a great experience.</td>
</tr>
<tr>
<td></td>
<td>Presence</td>
<td>The environment was very surreal. I felt the patient's true existence and to care for her.</td>
</tr>
<tr>
<td></td>
<td>Realism</td>
<td>I enjoyed that it was real life-like. During other simulations in person it was hard to envision real life as not everything was there whereas this VR was an actual hospital room. I was very impressed with this.</td>
</tr>
<tr>
<td></td>
<td>Multimodal stimuli</td>
<td>Sound effects and visuals</td>
</tr>
<tr>
<td></td>
<td>Immediate feedback</td>
<td>It was really nice to be able to have such a realistic environment that reacted back to your choices and movements. Being able to feel pulses and hear lung sounds and have the patient respond to your actions was really nice.</td>
</tr>
<tr>
<td>Role Playing in Authentic Situations</td>
<td>Interacting with patients and family</td>
<td>Continuously interacting with the patient and family was helpful to gain a realistic expectation of how patient encounters work.</td>
</tr>
<tr>
<td></td>
<td>Working with peers and virtual characters</td>
<td>I enjoyed the process of problem-solving with the patient with my peer. We took all the information and tried to make sense of what was going on in the scenario.</td>
</tr>
<tr>
<td></td>
<td>Performing actions in a safe environment</td>
<td>Practicing communication skills with the patient and family, and practicing noticing a medication error</td>
</tr>
</tbody>
</table>

**B. Change in Nursing Students’ Self-Efficacy**

Figure 3 provides a visualization of the ratings that increased, stayed the same, and decreased in the original data. Given the size of the “Rating Increased” portions of this plot compared to “Ratings Decreased”, it is not surprising to find that all six variables had a proportion increase that was statistically greater than chance.

Table 3 outlines the proportion of improved ratings from the null distribution as well as from the data. As is evident, students’ ratings on all self-efficacy variables had a proportion of improvement that was higher than the 97.5th percentile of the null distribution (corresponds to the upper end of a two-tailed test with a nominal alpha of .05). We rejected our null hypothesis that participating in the SLS with VR had no effect on participant affect. This confirms a statistically significant improvement in ratings after participating in the SLS for all six variables among students that gave ratings of 2, 3, or 4 on the pre survey.

**TABLE III. PROPORTION OF IMPROVED RATINGS FOR STUDENTS’ SELF-EFFICACY**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Content</th>
<th>CJM</th>
<th>Patient</th>
<th>Teamwork</th>
<th>Safety</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null 2.5%</td>
<td>0.19</td>
<td>0.16</td>
<td>0.18</td>
<td>0.21</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>Null 50%</td>
<td>0.26</td>
<td>0.22</td>
<td>0.25</td>
<td>0.28</td>
<td>0.25</td>
<td>0.23</td>
</tr>
<tr>
<td>Null 97.5%</td>
<td>0.32</td>
<td>0.29</td>
<td>0.31</td>
<td>0.35</td>
<td>0.32</td>
<td>0.29</td>
</tr>
<tr>
<td>Proportion from Data</td>
<td>0.33</td>
<td>0.33</td>
<td>0.40</td>
<td>0.40</td>
<td>0.33</td>
<td>0.31</td>
</tr>
</tbody>
</table>

**Result** Sig improvement, $p < .05$

**V. DISCUSSION**

The purpose of this investigation was to examine undergraduate nursing students’ experiences with VR simulations and assess the change in their self-efficacy for clinical competencies.
Thematic analysis of students’ responses indicated that participation in Simulation Learning System with Virtual Reality (SLS with VR) enriched students’ clinical simulation experiences in at least two ways. First, the technological affordances of VR scenarios enabled a heightened sense of engagement (see Table 2). Second, the pedagogical affordances of VR scenarios facilitated role playing in authentic situations (see Table 2). These findings corroborate with extant reports of students’ experiences of VR simulations [23], [24]. They are also expansive because students’ experiences in this paper were anchored in eighteen SLS with VR scenarios from multiple content areas and facilitated over 7 weeks.

Students reported a statistically significant improvement in their self-efficacy for variables such as understanding of content, ability to make clinical judgments, caring for patients, working in teams, and ensuring safety and quality in clinical situations because of participating in SLS with VR scenarios (see Table 3 and Fig. 3). This kind of operationalization of self-efficacy in the context to clinical competencies is a novel contribution to literature on VR simulations in nursing education[10, 17, 20]. They are also relevant for demonstrating the benefit of SLS with VR for promoting success in nursing programs [14, 18] and the acceptance of VR simulations in general for supporting clinical readiness.

This paper is situated in the context of a larger and on-going program of research for SLS with VR involving academic-industry collaborations between nursing educators, learning scientists, learning analysts, and psychometricians. Since 2020, we have strived to acclimate nursing programs with VR and its potential in nursing by translating existing research [27, 28]. We have also supported nursing educators in implementing VR [29]. Finally, we have conducted quantitative ethnographic examinations to investigate faculty practices while implementing SLS with VR. This has involved modeling classroom during pre-briefing, simulation, and debriefing phases [25]. We have also demonstrated the effectiveness of SLS with VR for facilitating practice of clinical judgement measurement model tasks and quality and safety education for nurses’ knowledge, skills, and attitudes [30], [31]. An empirical and practical approach may facilitate a comprehensive understanding and systematic adoption of VR simulations in nursing education.

VI. IMPLICATIONS AND FUTURE DIRECTIONS

This examination provides evidence that VR simulations can positively impact nursing students’ self-efficacy, engage them in authentic experiences, and promote a heightened sense of engagement. These findings present some important implications for practice. First, nursing educators may recognize opportunities for facilitating VR simulations throughout students’ programmatic journey while introducing them as early as the freshman year. Second, VR simulations can be applied across multiple content areas for facilitating exposure to unique clinical situations, and practice with an array of cognitive-social-psychomotor skills. Third, VR simulations can enable programs to continue training their students to be practice ready and adopt this curricular innovation at scale to address the changing landscape of the nursing profession [1]-[5]. SLS with VR provides an ecosystem of tools, scenarios, and guidance for nursing education programs to facilitate students’ practice readiness and align with best practices in simulation education.

As scholarship in this area grows, these findings also establish implications for researchers. Broadly, there is a need to continue examining students’ engagement in VR simulations using multiple data sources and analytical approaches (e.g., randomization sampling and related techniques [32]). Specific implications are as follows: First, the extent to which students are supported to identify with professional nursing roles that reach far beyond tasks, skills, and procedures can provide insight into the design of VR simulations (SLS with VR in this paper). Second, the extent to which clinical simulation experiences can (a) scaffold nursing students’ practice of cognitive-psycho-motor-social skills by situating their practice within specific content areas (e.g., fundamentals, medical-surgical, pediatrics), and (b) provide feedback on their decisions; thus, mimicking what learners will encounter in the real workplace can provide insight into how well the VR simulations can integrate with curricular goals (clinical nursing competencies as variables of self-efficacy in this paper).

VR simulation use in nursing education can be effective in supporting clinical readiness for the next generation of nurses and contributing toward improvements in the safety and quality of health care. Future research should continue to contribute to this burgeoning area and examine additional factors of incorporating VR simulations (e.g., the difficulties students experience, faculty motivations and apprehensions).

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Evaluating Co-Creative XR Resource Design and Development; Observations From the Field.

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Abstract—There has been an increased interest in medical education and, specifically, in identifying appropriate methods to ensure efficiency in medical students’ learning process. The design and development of Immersive experiential technologies, including Virtual patients, chatbots, and Virtual, Augmented, or Mixed Reality (VR/AR/MR), through co-creative methods, find fertile ground to support medical educational material. The aim of the current paper was to evaluate the perceptions and gain insights on healthcare technologists’ and educators’ experience regarding a series of co-creation sessions conducted during the design and development of XR educational resources. Results of the qualitative research showed that co-creation can be an interactive and engaging method that involves individuals from multidisciplinary backgrounds for effectively designing XR educational resources. However, strict adherence to best practices, as described in this work, is required to avoid hindering the effectiveness of the process and the quality of the final resources.

Index terms—XR educational resources, virtual reality, augmented reality, co-creation, agile methodology

I. INTRODUCTION

A. Virtual Reality (VR) Application in Healthcare Education

In the past century, there has been an increased concern about the amount of educational content that healthcare professionals need to acquire before being able to proceed with their practice in real-life situations. Medical knowledge is critical and requires an adequate theoretical background along with implicit knowledge and experience [1]. The challenge for necessary educational methods and practices is constantly highlighted. In this context, immersive experiential technologies find fertile grounds to grow and support medical education. Specifically, virtual patients, chatbots as well as Virtual, Augmented, or Mixed Reality (VR/AR/MR) have a great impact on both the affective and educational state of healthcare students through their increased engagement [1][3]. In addition, it has been argued that acquiring cues from multidisciplinary educational content can effectively allow students to visualize abstract laws in tangible methods [4]. These technologies’ sensory immediacy results in an intuitive anchoring of the essential information to the learner and facilitates paradigm building that, in turn, enables learners’ acquisition of robust and deep knowledge while minimizing the possibility of establishing, or maintaining conceptual errors [5].

B. Refocusing Co-Creative Approaches in Immersive Content Creation for Healthcare Education

Participatory Design (PD) approaches are considered essential for an adequate and effective design and development process of educational resources as they rely on the active engagement of all relevant stakeholders from the early stages of the process through co-creation workshops [6] Specifically, co-creators are able to provide necessary tools for expression and ideation of their needs and requirements as well as proceed to key decisions throughout the whole design and development process [7]. Following this perspective, the adaptation of co-creative approaches in immersive content creation has been highly proposed [8]. The main idea of this methodology lies in the flexible scheduling of collaborative educator and technologist joint work. This process can be achieved through Scrum pushes that are promoted by the Agile development framework [9], exploiting semantic back-ends within ubiquitous game development platforms. However, there is a need to refocus specific details for the co-creation and co-design workshops for XR healthcare educational resources. In that context, this work aims to outline lessons learnt, in the context of the ENTICE project (https://entice.eu/), about acceptance and suitability of co-creation methods in immersive educational resource design and implementation.
II. METHODOLOGY

A. Participants

Four members and active contributors of the ENTICE resource co-design team participated in this study. The academic and technical backgrounds as well as the levels of experience in co-creation were diverse. The backgrounds of participants reflect their interdisciplinary character, specifically, interview participants included two (2) learning technologists (software developers) and two (2) healthcare educators. All participants were core members of the XR team from the early stages of the project up until the final developments and were actively participating in the co-creation sessions.

B. Design and Procedure; Problem-Centered Interviews with Developers and Educators

In order to collect necessary data, problem-centered interviews were conducted. The main characteristics of the interviews were particularly useful to bring to light the subjective experiences, viewpoints, and perceptions of participants in relation to the design and development co-creation process of the educational resources. Following the principles of qualitative research such as openness, flexibility and orientation, the interview guide was not formulated as a rigid questionnaire, but rather as a structured conversation aiming to elicit spontaneous feedback on all significant viewpoints of the co-creation process. The interview guide (Table 1) was based on the following five broad thematic areas [25] that ensured the comparability and comprehensiveness of the experiences’ collected by participants: 1) Adequate entry points and continuity of co-creation, 2) Competencies, skills and training, 3) Mutual understanding, 4) Integration of end-users’ realities and 5) Balancing influence.

The interviews lasted approximately 20-30 minutes and were recorded. The first cut through the material will allow for identifying and grouping the significant quotes in relation to the most prominent challenges of the co-creation process. However, it is important to continuously reflect and critically compare interview statements, in order to collect and define actionable conclusions from the interview material. This critical reflection and conclusion extractions are presented in the first part of the discussion of this work.

### TABLE I. MAIN INTERVIEW THEMATICS AND KEY QUESTIONS TO STAKEHOLDERS

<table>
<thead>
<tr>
<th>Main interview themes</th>
<th>Key questions to stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate entry points and continuity of co-creation</td>
<td>- In which stages of a research project does the involvement of stakeholders make sense?</td>
</tr>
<tr>
<td></td>
<td>- Did your involvement in the practice seem appropriate at the stage that it was included?</td>
</tr>
<tr>
<td></td>
<td>- Would you consider another point of entry?</td>
</tr>
<tr>
<td>Competencies, skills and training</td>
<td>- Do researchers feel well prepared and where can they acquire the expertise, skills, and experiences to conduct co-creative research?</td>
</tr>
<tr>
<td></td>
<td>- Do you feel well prepared to participate in the co-creation process?</td>
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<tr>
<td></td>
<td>- Do you consider your contribution productive?</td>
</tr>
<tr>
<td></td>
<td>- How would you prepare or be facilitated better to participate in co-creation sessions?</td>
</tr>
<tr>
<td>Mutual understanding</td>
<td>- What are appropriate formats, methods, and tools to develop a shared language?</td>
</tr>
</tbody>
</table>

III. RESULTS

A. Thematic 1: Adequate Entry Points and Continuity of Co-Creation

In co-creation approaches, it is important to choose adequate points of entry for the effective engagement of educators and developers. This can be a significant challenge, as it seems that early engagements on the design and development process of XR educational resources is essential according to interviewees’ experience and viewpoints. This statement is supported by two of the interviewees:

‘‘I think that it is important to have guidance from the educators from the early stages of the design and development of the resources. When you try to develop resources with content that you are not familiar with, it is really important to involve the educators that are specialists, so that they can envision and help the developers on the design of the resources. Without the educators’ guidance, we could have designed resources that do not reflect their real practical needs.’’

‘‘It was important to interact with each other from the early stages of the design process. In this way, we could share what and how we envision the resources from different viewpoints. We were able to understand what each other wanted and that allowed for the development of the scenarios we aimed for. Through this process, we did not waste any time.’’

On the other side of the spectrum, it was argued that perhaps the involvement of the educators in the early stages of the design and development process can results in delays:

‘‘I believe that the educators should have been involved in the first couple of co-creation sessions, as we did, and have discussions on the material and the content that could be visualized through XR resources. Afterwards, the developed resources could be presented to educators, in order to gain feedback.’’
B. Thematic 2: Competencies, Skills and Training

In addition, the next thematic focused on the skills and competencies that are needed to conduct co-creation activities in meaningful ways. The outcomes indicate that within a multidisciplinary team, it is important that the coordination and moderation of the co-creation sessions are well prepared. However, it was mentioned by one interviewee that it would be more beneficial to have a well-organized organizational chart, in order to allow for better task allocation within a specific timeframe.

‘‘In the beginning of the project, I was concerned about how we would develop the resources, however after discussions with the developers, who could deploy the visualization of the resources, it ended up to be an impressive procedure. The interaction among us allowed for the creation of wonderful things. I think the final resources will be much more of what we envisioned we would develop. ’’

‘‘Overall there was good coordination of the project, however I would say that as a developer I faced a couple of delays due to the delay of the iterations cycle. Perhaps a better organizational chart for better task allocation in a specific timeframe would help to be more productive. ’’

In addition, there were a couple points raised regarding interviewees’ productivity of their participation. Two respondents mentioned that their productivity was not as satisfactory as they wanted it to be, as interviewees did not feel they had adequate time to get well prepared for the sessions. Additionally, due to Covid-19 restrictions, online meetings were organized instead of face to face sessions, which had an impact on stakeholders’ efficiency and productivity throughout the project. To this end, it was proposed that the efficiency of the sessions would have been achieved even more in the case of face to face meetings.

‘‘I genuinely think that I wasn’t as productive as I wanted to be throughout the project, due to lack of time and heavy workload. I think for face to face meetings would have helped. ’’

‘‘People didn’t have the necessary time to prepare for the detailed conversations we needed to do during the co-creation sessions, because time has been a luxury we haven’t had. It’s been a perfect storm, a lot of people have struggled to maintain projects during the last two years. ’’

C. Thematic 3: Mutual Understanding

During the co-creation process within a project, heterogeneous actor groups are involved. Specifically, in the ENTICE project core members of the team were from different multidisciplinary backgrounds from different countries, resulting in a language barrier. An additional barrier to the understanding of stakeholders between each other is that Covid-19 did not allow for face to face meetings, minimizing in this way the interaction and strong engagement. However, considering all these barriers, the communication was achieved at a great level through the roles of the coordinators and moderators, as roles and task allocations were clear for everyone. This is supported by the quotes below:

‘‘I think the communication among the team members was successful. The people who were working as moderators of the co-creation sessions were helpful, because the essential feedback and input was collected. All members knew exactly where to refer to in any case. The roles and task allocation were clear. ’’

‘‘I think for a project like ours, a big project, with lots of different technical and academic specialist skills, the challenge of co-creation, is that you need to keep everyone engaged so everyone is on the same page, everyone is clear of what they are trying to achieve especially when having a diverse group of colleagues. There is also a difference in language and culture, which I think adds to the difficulty, especially having done the meetings online, due to Covid-19 restrictions. I think it’s really difficult to keep everyone on the same page. Stakeholder engagement is really critical’’.

In addition, the online interactive tools that were used during the co-creation sessions were considered highly useful and helpful. This is in accordance with the statement below:

‘‘The Miro board that we used for the co-creation sessions was very convenient and useful, as we could write down all the input educators were providing us with. I had a more clear view of what the next tasks will be.’’

D. Thematic 4: Integration of End-Users’ Realities

Stakeholders from different backgrounds and perspectives usually have their own priorities regarding the design and development of the XR resources that should be taken into account during the co-creation process. Interviewees mentioned that they believe their practical needs will be reflected through the resources and that they will genuinely assist medical students to gain a greater understanding of their curricula, aiming to motivate them as well. In the following quote, one interviewee points to this issue:

‘‘I believe that XR resources will help them gain greater understanding of the different structures in specific positions of the human body. It is really important for them to see what we are able to see in surgery. Future doctors will be more motivated and will understand much easier the context.’’

However, one interviewee expressed the view that due to lack of face to face meetings, they were not able to observe this incremental change and, therefore, there is a risk for not meeting end-users’ needs.

‘‘I think my practical needs will be reflected through the resources, again though I suppose without the face to face meetings we haven’t been able to see that clearly. The incremental change, so the risk is that when we finally do see the end resource it might not match to what my expectations were.’’

The Agile methodology has been adapted in this project, with co-creation sessions and weekly sprints being successful, aiming to strengthen the team and allow for the exchange of knowledge among experts. This is argued in the quote below:

‘‘The weekly Sprints were really helpful and strengthened the team. We could see our progress and exchange knowledge among us in case an issue appeared during the development process. ’’
E. Thematic 5: Balancing Influence

In large projects, it is important to distribute fairly, equitably and transparently the influence of each member of the team. The challenge is that it is necessary to take into account all different interests and provide the opportunity to balance between the decisions of stakeholders. To this end, it is essential to create a friendly, open-minded environment, where everyone can share their ideas and thoughts. This viewpoint was supported by three interviewees:

‘‘There was plenty of opportunity to have discussions and be part of the decision making process.’’

‘‘Personally speaking, I could express my thoughts and concerns and other team members would help me and vice versa. I truly believe the co-creation sessions allowed for open discussions.’’

‘‘I felt I had an engaging role during the decision making process. I could always express my ideas and they would be appreciated.’’

IV. DISCUSSION

This qualitative work tapped on a small sample size, albeit one that had immediate and large-scale involvement in an extensive co-creative process for the design and development of immersive educational healthcare resources. This process, spanning almost half a year and involving almost biweekly meetings for co-creating resources provided healthcare technologists and educators with an “360o” almost tacit understanding of the co-creative process, its advantages, its shortcomings and the necessary conditions for it to be a successful way to design and iterate on XR resource development. Using a thematically structured interview format on these subjects we gathered concise qualitative feedback which, unsurprisingly, coalesced to overarching themes regarding the interplay of participatory methods with the specific needs of XR resource development. In the following paragraphs, we outline these themes and the points emerged.

Regarding the usefulness of the co-creative approach the consensus for its maximization can be summarized in the following points marked by educators:

- Participatory design provides outcomes that are larger than the sum of its parts
- XR resources in healthcare education facilitate the creation of mental models beyond just the recitation of knowledge.

Developers stated that participatory design process should emphasize content and not technical, implementation details. Regarding the people and organization of the process the consensus reached by developers was that:

- Clarity of distinct and specific roles and good organizational skills are essential
- Timely and full engagement is required by all members of the team to achieve integration of feedback to resources and subsequent quick turnaround times on them to achieve tangible progress in each session.

Educators mentioned that personal communication is paramount especially in projects which involve multilingual multinational teams that need to collaborate on rapid iterations of XR resources.

- Regarding technical facilitation and coding practices the consensus reached by educators was that:
- Facilitation and collaboration tools are essential.
- There is need for training of the participants to the point of blind familiarization.
- Quick turn-around of resources are essential for the success of co-creation sessions since each subsequent session needs a tangibly advanced iteration of the resource to be able to capitalize on it and provide meaningful feedback.

Developers stated that Agile methodologies or other similar approaches are essential for quick turn-around towards co-creation sessions.

The current study constitutes a small-scale qualitative research with a relatively small sample size. However it provides a good initial insight on the perceptions and acceptance of co-creation approaches for immersive resource design and development given the breadth of the semi-structured interviews’ topics. While this is a good starting point, in the future we aim to extend the participant base, as well as the thematic content of this work in order to provide a more generally applicable view of participatory methods in immersive resource development.

These principal results tie in well with our previous work [8] that identified four essential steps to the co-creative process in XR resources. A) Preparation and planning, B) actual co-creation, C) technical facilitation and training leading to D) rapid prototyping provides an ever progressive new jumping point of feedback in the “virtuous cycle” that facilitates rapid deployment of XR resources and promotes ease of design and development across topics or even educational institutions. Participatory design methods slowly emerge as a way to democratize digital citizenship. This trend emerged even more vividly during the COVID-19 pandemic [10]. In that context combining these practices with Agile methodologies can be an avenue for XR content development democratization in healthcare education. In that context an increasing proliferation of these formats requires rather strict adherence to good practices in the implementation of these methodologies, so that co-creative sessions do not become hindrances in the development process, but instead are impact multipliers for collaboration and rapid XR resource development.

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Work-in-Progress—eXtended Reality Training for Safety and Medical Procedures: Experiences From a User-Centered-Design Approach to Implementation

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Abstract—eXtended Reality (XR) environments appear to be a promising approach to training in various contexts; however, their potential for safety and medical procedures is still not fully understood. The aim of the presented research project is the user-centered implementation of an XR training for various occupational groups and volunteers of first responder organizations (e.g., physicians, paramedics, health care workers, police officers, firefighters). To achieve this aim, the project has followed three implementation steps: First, multi-stakeholder workshops were conducted to define two use cases for the most promising application areas. Second, based on the previous step, identified use cases were implemented as XR training scenarios. Third, scientific evaluations of the training applications are conducted focusing on subjective and objective performance indicators, learning success, training experience, acceptance, and potential barriers from an end-user perspective. As the last step is still ongoing, this paper puts emphasis on the outcomes of the stakeholder workshops, the respective decisions taken towards selecting two use cases, and the design of the evaluation study.

Index Terms—extended reality, training, learning, immersive learning, procedural training, user-centered-design, psychology, pedagogies

I. INTRODUCTION

Future training scenarios for first responders (e.g., tunnel accidents, disaster control and potential terrorist threat scenarios) are characterized by the cooperation of a wide variety of emergency response organizations. To be able to appropriately educate and train such operations or the groups of first responders affected by them, a particularly large amount of time and organizational effort is required today. To counteract this increase in effort, simulation has proven to be an effective and efficient method in training and further education. In recent years, beyond physical simulation, training in so-called eXtended Reality (XR) environments has proven to be promising. In this respect XR related training offers the ability to implement learning theory from experiential [1], [2], [3] and phenomenological learning [4], [5] in a comprehensive fashion. According to current scientific evidence from the areas of stress resilience training for athletes and police officers (cf. [6]), the improvement of the action competence of the trainees by means of XR has been sufficiently proven.

It can be assumed that this improved learning performance through XR simulation can also be transferred to other employment groups in safety and medical contexts since these contexts also include stressful, high-pressure situations and require a high level of action competence. However, the potential of XR-based trainings for safety and medical procedures is still not fully understood. In this paper, we present findings from the XRTrain project that focused on the user-centered implementation of an XR training for various occupational groups in safety and medical contexts.

The remainder of the paper is structured as follows: In section II we report on the different stakeholder groups identified in the initial phase of the stakeholder involvement and describe the setting and results of the stakeholder workshop conducted. Section III presents the two use cases selected for implementation and explains the reasoning behind the use case selection. Section IV describes the planned evaluation study and finally section V draws conclusions and gives an outlook on future project steps and results to come up.

II. STAKEHOLDER INVOLVEMENT

To understand the needs of the future trainees regarding virtual learning environments in safety and medical contexts, a thorough requirement analysis adhering to principles of user-centered design has been an inherent part of the research project.
**Workshop Design:** Regarding user involvement we aimed to address a broad range of educational stakeholders in the fields of health and safety. Care was taken to ensure the greatest possible mix from various disciplines, therefore we invited lecturers, teachers, human resource and teaching strategists, and practitioners from companies and first responder organizations to a one-day stakeholder workshop. The aim of the workshop was to identify training and application areas where existing state-of-the-art XR technologies can be used efficiently as well as requirements for XR training from the perspective of the different stakeholder groups. The workshop was structured as follows: To acquaint the participants with the possibilities of XR technologies in the context of training and learning they were introduced to existing XR training approaches. In this hands-on session, participants were given the opportunity to try out the different applications. Subsequently, within *session 1* the potential XR technologies bear as an educative tool was discussed. *Session 2* was oriented towards identification of learning objectives and target groups for XR training in the health and safety sector and *session 3* discussed opportunities and challenges for XR training on an organizational level. After these sessions a joint wrap-up and selection of promising use cases concluded the workshop. Whiteboards and additional transcripts were used to document the workshop. For analysis, based on Mayring’s approach [7], statements from the workshop were grouped inductively into different categories.

**Workshop Results:** Due to the limited space of this work-in-progress-paper, we only report the results from the workshop in a heavily condensed fashion concentrating on findings necessary for the use case selection. The discussions in *session 1* revealed that the participants deemed XR technologies as welcome addition to blended learning concepts in a way that it enables repetitive training of procedures for indispensable hardware and environments as well as for riskful procedures that can barely trained in real world settings. Social settings with verbal and nonverbal communication were deemed as less suitable for training via existing XR solutions. *Session 2* came to the conclusion that the primary target group for XR training includes practically all practitioners in the medical field whereas for the safety field rather technical personnel (e.g., those engaged with maintenance or repair) would profit from XR-based learning. Regarding learning objectives the comprehension and resilience of procedures within administration of medication, anamnesis, diagnosis of certain diseases, resuscitation, hygiene routines, reactions in a recurring emergency situation (e.g., in the event of an epileptic seizure), correct behavior in the event of a fire, escape or the inspection of technical equipment and machines have been identified as utmost promising. The reasoning frequently appearing in the workshop was that all these tasks typically follow “decision trees” or “step-by-step procedures”. These are activities that are structured in a more or less standardized sequence of steps, hence repetitive training in different manifestations, with distractions or with missing or incomplete information sets is urgently needed here and would improve compliance and resilience. Also, the opportunity to realize such XR-based procedural training - as a low-threshold learning activity that is available on short call without the need of extensive preparation, travelling, specialized environments or machines - would allow for more frequent learning sessions over time.

Out of the discussions within *session 3* the training of sensory-motor skills was identified as a learning objective that is not well trainable with existing XR technologies. The same holds true for teaching the identification of certain scents and their meaning in critical situations with existing low-cost XR headsets. Also communication skills as learning objective were seen rather critical as natural human-to-human interaction can not be achieved with current systems, hence managing conflicts, leadership in a team as well as teamwork is not well trainable. In terms of opportunities an assumed widespread availability of XR training could critically minimize the time and cost of travel to trainings, thus reducing a bottleneck in terms of regular staff training. Furthermore, it can complement existing trainings as preparatory or supplementary XR training would shorten training times in real-world environments. From a quality management perspective, there are advantages in the easy standardization of training through XR and the measurability and good traceability of performance during training. Similarly to session 2 the training of procedural skills was seen as very promising as the ability to actively perform actions and decisions throughout a procedure would definitely improve compliance. With respect to sensory feedback and scent creation in XR environments current technological developments are ongoing in order to be able to tackle such learning objectives in the near future.

**III. USE CASE SELECTION**

Based workshop results, two use cases were selected that address participants’ needs in terms of training and can effectively exploit the possibilities and advantages of XR training. Over the course of the project, the two use case were implemented as headset-based XR training on the Oculus Quest 2 with interaction via standard controllers.

The first use case relates to working in a shock room with an emergency trolley. The reasons for choosing this environment are as follows: 1) shock room layouts as well as the equipping of emergency trolleys are not identical in different hospitals, 2) shock rooms and emergency trolleys are usually not available for training due to permanent operational readiness and 3) there are a number of different procedures associated with this environment that need to be trained. Therefore, the digital twin based on XR is flexible way to realize the training despite the scarce availability of relevant equipment and environments in the real world. From a target group perspective, training within such a context would be highly important for new personnel and in preparation for real world training at training facilities such as the SIM Campus facilities. Meaningful performance metrics for this use case would include preparation time and errors, for example. Figure 1 depicts a screenshot of the implementation of this use case. It shows an emergency cart featuring an overlay of the
necessary equipment as assistance on top of the cart and some equipment already placed. The trainee is asked to prepare an endotracheal intubation procedure. The trainee can switch the overlay on and off to identify if she is already able to prepare the intubation equipment without this assistance. Also, interruptions of the procedure can be realized (e.g., virtual colleagues stepping into the room and asking something).

The second use case concerns the training of a building evacuation procedure (XR-based implementation shown in figure 2). This scenario is relevant for a broader target group compared to the first scenario and covers a variety of possible personnel groups. In addition to standard escape routes, alternative situations could also be trained within XR, for example a situation in which standard escape routes are blocked by obstacles. This makes it easy to transfer this scenario to other work environments with similar, safety-relevant exercise scenarios (e.g., specific safety measures in the event of a fire in a tunnel). The assessment of performance in this use case is also straightforward in XR (e.g., by measuring the time from alarm to reaching the rally point, way length etc.), making feedback and effects of the training more comprehensible.

![Fig. 1. Screenshot of the implementation of the first use case in XR showing the preparation of equipment for a medical emergency procedure.](image1)

The second use case concerns the training of a building evacuation procedure (XR-based implementation shown in figure 2). This scenario is relevant for a broader target group compared to the first scenario and covers a variety of possible personnel groups. In addition to standard escape routes, alternative situations could also be trained within XR, for example a situation in which standard escape routes are blocked by obstacles. This makes it easy to transfer this scenario to other work environments with similar, safety-relevant exercise scenarios (e.g., specific safety measures in the event of a fire in a tunnel). The assessment of performance in this use case is also straightforward in XR (e.g., by measuring the time from alarm to reaching the rally point, way length etc.), making feedback and effects of the training more comprehensible.

![Fig. 2. Screenshot of the implementation of the second use case in XR showing a hallway of the SIM Campus simulation hospital.](image2)

IV. Evaluation Study

To empirically investigate the training effectiveness as well as potentials and limitations, the implemented virtual training scenarios based on the two use cases were evaluated in two mixed-methods studies (one per scenario). Studies were conducted in January 2022 at the SIM CAMPUS simulation hospital facilities. For both studies, 40 subjects from the field of health care and nursing were randomly assigned to an intervention group (n = 20) and a control group (n = 20). Both studies started with a practice phase in which the material preparation of an endotracheal intubation (intubation scenario) or the evacuation of a building (evacuation scenario) were trained. Experimental groups completed the training either in the XR environment (intervention group) or with printed instructional material (control group). Subsequently, both groups were asked to apply what they had learned in a real-life practice environment. By collecting demographic data sets, objective performance indicators, and quantitative self-reports, as well as conducting qualitative interviews with the participants, the evaluation sheds light the potential of XR-based trainings from a variety of perspectives.

For both scenarios, the participants rated the XR environment as easily accessible and reported high satisfaction with the application. In addition, for intubation scenario, initial trends indicate added value of XR training in terms of shorter times to solve the task and lower error rates for the XR training group.

V. Conclusion and Outlook

In this paper we have reported on our user-centered-design related findings from the XRTrain project. We presented results from the stakeholder workshop aimed at identifying requirements for XR training in medical and security related work contexts. Based on these results, we identified two use cases that would then be implemented throughout the project as research prototypes. These prototypes are in turn scientifically evaluated using a mixed-methods approach. We have outlined the study design and shared first impressions from this scientific evaluation. A detailed analysis of results from the evaluation is still on-going and will shed light on the added value of XR-based training for safety and medical procedures in terms of learning success, and provide further insights into training experience, acceptance, and potential barriers from an end-user perspective.

References


Abstract—Colonoscopy, or lower gastrointestinal endoscopy, is a medical procedure whereby displacing a flexible endoscope along the large intestine, a healthcare professional can perform examinations and even perform some interventions. This paper presents a Work-in-Progress towards a virtual training environment for colonoscopy, LoGIViT, based on the use of immersive technologies. Employing Unity engine and virtual reality headsets, LoGIViT aims to provide an affordable simulator reproducing the physics involved in the procedures. LoGIViT is prepared to enable the programmatic generation of large intestine scenarios with various features and conditions dynamically generated that can be configured by the user and generated dynamically.

Index terms—lower gastrointestinal endoscopy, virtual training environment, Unity

I. INTRODUCTION

Colonoscopy, or lower gastrointestinal endoscopy (LGIE), is a medical procedure involving the exploration of the large intestine using a flexible endoscope. Since its apparition in 1969, this procedure has become very demanded as a screening procedure to detect malignancy or pre-malignancy adenomatous polyps, which can develop into colorectal cancer. Currently, colonoscopy remains the prime means for colorectal cancer and is the gold standard of screening programs [1]. Similarly, this procedure is also used to better diagnose and treat other large intestine conditions.

The colonoscopy procedures require a particular device known as a flexible endoscope [1]. This device has evolved from early designs with limited capabilities to more sophisticated flexible instruments with advanced imaging capabilities, specialized features for advanced therapeutic interventions, and different designs to enable examination of specific areas of the lower gastrointestinal tract, such as the large intestine in the colonoscopy case.

The performance of colonoscopy procedures also requires specific manual motor skills and good hand-eye coordination from the endoscopist. One of the biggest challenges for the training of new endoscopists is explaining the elaborate choreography of motor movements to introduce the endoscope through the large intestine reaching the cecum.

Some information can be obtained from the screen’s image, but the more important information source is the haptic feedback provided by the endoscope itself. A novice is thus confronted with a broad range of manual skills, which should be trained sufficiently before participating in the clinical setting with real patients. Like in other surgical specialties, the skills required for colonoscopy have been taught and learned by practicing on real patients under the tutelage of more experienced surgeons. This “see one, do one, teach one” model is expensive for hospitals as qualified endoscopists could perform colonoscopic procedures faster and safer working independently. In addition, other issues such as ethical concerns are also considered because the use of real patients.

As a response to the learning needs, new colonoscopy educational and training solutions have been developed, such as video-based education, computer-based apps, and simulators, both mechanical and computerized. Indeed, medical literature has already recognized the benefits of existing simulators [2], concluding that simulation technology can be a valuable form of education for endoscopy novices if properly supervised during training and if there is also an integration of clinical training.

In the market there exist several LGIE trainers [3]: EMS Trainer, EndoVision, Colon Endoscopy Trainer, etc. They enable the practice of colonoscopy procedures, but also have some main problems. Firstly, they include a limited number of training scenarios or guided training where many interactions are built in animations. Secondly, more advanced virtual training environments (VTEs) seek training reliability increase by using specialized hardware that often results in space limitations and high costs, only available in sparse medical institutions. Through LoGIViT (Lower Gastrointestinal Virtual Trainer), we want to solve these problems allowing to 1) create highly configurable training colonoscopy scenarios including the variety of large intestine diseases; and 2) facilitate their broad availability through the use of generally available and affordable VR devices based on the Unity engine.

II. RELATED WORK

A colonoscopy simulator is an educational tool to train surgeons on the performance of colonoscopies acquiring a good competency in diagnostic-therapeutic skills necessary, without any risks to the patient. Despite there is currently no
standardized simulator for colonoscopy, numerous upper and lower gastrointestinal endoscopy simulation models and platforms can be prepared or purchased [4]. Four broad categories of endoscopy simulators are distinguished:

- **In-vivo models.** Using mainly live swine. The main issues are the difference between animal and human anatomy and the requirement of an appropriate lab to manage the live animal.
- **Ex-vivo models.** Using animal organs mounted in physical frames adapted to mimic the desired anatomy. More realistic tissue feeling is provided, but they are considered the most difficult to incorporate into training.
- **Mechanical simulators** ($2000-$15000). Inanimate plastic or rubber models with various degrees of realism. Relative low price and easy setup, but they provide little realism and only enable a reduced set of possible configurations.
- **Computerized simulators** ($50000-$140000). Physical devices with embedded sensors to reproduce the endoscope movements in a virtual scene displayed on the attacked screens. Cost, limited portability, and lack of realistic haptic feedback are the major drawbacks of these simulators [4],[5] (e.g., GI Mentor, CAE Endo VR, Endosim).

The benefits of using endoscopy simulators have become more apparent over the last few decades as the overall use of these products has become more widespread. However, the main problems such as high cost, limited training scenarios and the need for expert guidance and supervision are still present.

**III. DESCRIPTION OF THE SIMULATOR**

**A. Training configuration management**

LogiViT allows generating and saving different highly parametrized large intestine configurations, providing high training adaptability. When the VTE is started, the user is presented with a menu scene with its own GUI. In this menu, the user can create and parametrize training configurations, saving them for future usage, modify existing configurations, or even share with other users. A training configuration with default values is also allowed if the user wants a quick basic training. The creation of a training configuration allows defining which diseases to reproduce in the lower gastrointestinal (LGI) system, severity or stages for these diseases, affected LGI segments, propagation degree and LGI system parameters related to variations by genre. Common intestinal diseases such as polyps or diverticula will be implemented with their respective textures, models, and different stages. Difficulty management can be achieved by enabling or disabling additional functionalities. Using a guided camera in the LGIE procedures to inspect the intestine independently of the endoscope position or the generation of radiographs (limited in quantity or not) are some examples that aid to achieve difficulty management.

**B. LGI system procedural generation**

Most current LGIE trainers use a repository with patient cases simulating different bowel tracts and pathologies, models generated from synthetic data such as computed tomographies (CTs), or models that reproduce real-time interactions on physical dummies with embedded sensors [5]. Such approaches limit the training's adaptability to predefined, limited and repetitive bowel tracts, where variations arise from the diseases' changes in stages and placement.

LogiViT's innovative approach provides variable bowel tracts employing procedural generation from an intestinal segment template and Bézier curves. The generation of the LGI system model is completed by applying the parameters of the loaded training configuration, presenting the final model in a new scene. With large intestine in its canonical form and employing one Bézier curve for each segment, we modeled a canonical bowel tract which will be used as a template for generating all the future bowel tract variations (Fig. 1). Finally, we obtain the procedurally generated large intestine by duplicating, bending, and contorting the segment model between the position points of each Bézier curve of this tract (Fig. 2). The segment template includes a collection of shape interpolations whose values modification allows obtaining segment versions with the corresponding taeniae and segmentation for each LGI system section and even imitating peristaltic motion in run-time. The training configuration data is applied to the generated model during this procedural generation, resulting in the final LGI system presented in the scene. Future updates will include several mechanisms to fix clipping issues between segments and a run-time editor to modify the canonical tract to create and link new bowel tracts to the training configurations.
symptoms employing a camera with predefined displacement and unlimited rotation. Supposing this mode was not selected in the training configuration, our generated LGI system model is accompanied by the instantiation of an endoscope model, which reproduces the characteristics and limitations of a standard Olympus CF-Q145L endoscope. The physical model was discretized in a finite number of capsules chained by configurable joints, which establish flexion and rotation constraints to simulate the flexible endoscope (Fig. 3). An initial dynamic model has been developed based on the built-in Unity physics. However, position-based [6], force-based (Newton 2nd law), and beam-based finite element method (FEM) [7] approaches are currently in development to compare and obtain the best performance/cost ratio solution. Other endoscope functionalities such as air suction or insufflation were also developed.

Fig. 3. On the left, the continuous flexible endoscope model; on the right, its discretization.

D. User interaction

Completing the procedural generation and instantiation processes allows the training to start and grant the user control over the scene elements. In disease recognition training with a guided camera, the users can use mouse + keyboard or gamepad for motion management, providing an experience physically similar to a desktop simulation. However, these input methods provide a desktop experience with limited (haptic) feeling and feedback that hinder our objective of a realistic and immersive experience for the LGIE procedures training. The most straightforward way to reach higher degrees of immersion [8] is to achieve higher degrees of visual fidelity (e.g., by using VR headsets and virtual models with high resolution) and manipulating real objects (e.g., sensorized objects) for the haptic feedback. The creation of a virtual environment which supports usage of VR headsets and a physical 3D printed endoscope model with embedded sensors for motion management will be assessed in future developments.

E. Collision detection and deformation management

The other key aspect in reaching a high degree of fidelity and effectiveness of the LGIE training is solving deformations on endoscope and LGI system contact. As the LGI system model generated is treated as a unique element with a high vertex count, the calculations made by the Unity engine to update the model collider after a collision are too expensive and reduce the global performance. A custom algorithm was developed to manage this problem. Instead of a unique collider, the model is divided into a collection of smaller ones, created during the LGI system generation based on the model vertex adjacency and stored for fast access and update. Collider minimum size is fixed but can be increased to adjust to each user device's availability of computational resources, increasing collision detection precision in exchange for extended calculations in the procedural generation process and increased heap memory usage. Despite using smaller colliders, the deformations from contacts are propagated through the whole model using joints between vertex as a mass spring-based approach, the simplest approximation of elasticity theory. As this results in relatively reduced precision, a FEM approach is under development to obtain more accurate collision solving [9].

IV. CONCLUSION

This paper presented an alternative solution for learning, assessment, and training needs related to the colonoscopy practice. Viability, cost/performance ratio, visual fidelity, and haptic feedback are key features that will be evaluated to obtain a valid VTE. Future work will assess the previously mentioned future developments and the release of a first version to get preliminary results. Controlled test groups will be established with experts and students in colonoscopy to obtain feedback for improving the dynamic model solutions for future versions.

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Abstract—We present our work in progress, a real-time mixed reality communication system for remote assistance in medical emergency situations. 3D cameras capture the emergency situation and send volumetric data to a remote expert. The remote expert sees the volumetric scene through mixed reality glasses and guides an operator at the patient. The local operator receives audio and visual guidance augmented onto the mixed reality headset. We compare the mixed reality system against traditional video communication in a user study on a CPR emergency simulation. We evaluate task performance, cognitive load, and user interaction. The results will help to better understand the benefits of using augmented and volumetric information in medical emergency procedures.

Index Terms—volumetric communication, mixed reality, emergency assistance

I. INTRODUCTION

Video communication has become increasingly important over the past years. Online meetings became part of our everyday lives. The Covid-19 pandemic forced students to learn remotely and many professionals to join business meetings from home.

Similar to video, volumetric communication is becoming more important in many industries such as medicine, education, and logistics. Compared to video, volumetric communication contains spatial information and allows for more natural and intuitive communication. Combined with mixed reality glasses, volumetric communication aims to make the parties feel as they are co-located. In this paper, we examine the benefits of volumetric communication in combination with mixed reality glasses for remote assistance in emergency situations. We propose a mixed reality system that captures a person giving CPR to a patient and sends it over to a remote expert that guides the local person through the steps. The local scene is shown in fig. 1. In many countries, cardiopulmonary heart diseases are the main cause of death. According to the WHO [1] about 17.9 million people (around 32% of all deaths worldwide) die of such diseases every year. Therefore, an early performed CPR can increase the chances of surviving a cardiac arrest.

We compare how the mixed reality performs in remote emergency procedure assistance compared to video commu-
necation. We are particularly interested in measuring cognitive load and overall task performance.

The main contribution of this paper is the proposal of a volumetric communication system for remote assistance in a medical CPR emergency situation. Moreover, we contribute a study design for comparing volumetric against traditional video communication for emergency assistance.

II. RELATED WORK

Volumetric communication contains spatial information compared to video communication. The spatial view can be used to augment objects in 3D. Thus, the communication parties can interact with virtual objects. A remote operator is able to point at different locations. This technique is used in the medical field [2], [3] as well as for technical procedural tasks [4].

In the past researchers focused on Cardiopulmonary resuscitation (CPR) training [5]-[7] in virtual reality. We present the first system to support real-time assistance for emergency CPR in mixed reality. In contrast to current mixed-reality approaches [8], [9], a remote expert can give individual guidance to a local operator throughout the CPR procedure.

III. METHOD

We develop a mixed reality system to allow for real-time communication between a local learner and a remote instructor. The learner is located where the procedural task takes place. Only the learner can physically work on the task. The learner and the instructor communicate using mixed reality glasses. The communication takes place using visuals and audio.

The objective of this method is to make the communication feel as seamless as if the instructor and learner collaborate in person. The instructor should be able to teach the learner without any limitations related to the fact of not being co-located. Similarly, the student should not feel the need for the instructor to help through parts of the tasks in person.

A. Instructor’s View

The instructor’s virtual view consists of a volumetric representation and video screens of the local scene. The volumetric view is provided by two cameras capturing the learner working on the procedural task from different angles. The instructor can switch between the cameras depending on which camera provides a better view of the scene during a given operation. The volumetric view allows the instructor to get a 3D view of the scene by looking through mixed reality glasses. The spatial information allows the instructor to get a better understanding compared to traditional video.

B. Learner’s View

For the learner, the physical, real-world view is more important than the virtual view. The learner sees the object that is manipulated through the mixed reality headset. In addition to the physical view, the learner gets virtual information from the instructor. The learner sees the virtual hands of the instructor to get the information about where the instructor is positioned spatially relative to the procedure. Moreover, the virtual hands provide the learner with directions from the instructors. Besides the hands, the learner’s virtual view contains procedure-specific virtual objects that are used by the instructor to guide the learner. The objects are used, for example, to show which tool to use, to show how to use a tool, to abstractly illustrate concepts of the procedure, and to give directional guidance.

C. Interaction

The interaction between instructor and learner is verbal and visual. The verbal interaction is the same as in video communication. The visual communication happens through gestures, object manipulation, and the actual observation of the procedure by the instructor. The gestural communication is bi-directional. The instructor observes the learner’s gestures through the 3D camera view. The learner sees the virtual hands of the instructor. The gestures include beat gestures that support speech as well as deictic, iconic, and metaphoric gestures. The virtual hands encourage the interaction with deictic, iconic, and metaphorical gestures when providing procedural guidance to a learner. Besides the hands, the instructor interacts with the student using virtual objects. The objects consist of tools and annotations. The instructor uses the tools to explain how the tool is used.

D. Hardware and Technology

The instructor and the learner use the Microsoft Hololens 2 mixed reality headset to communicate. The Hololens 2 provides a 2048 x 1080 pixel resolution per eye and 52 degrees field of view (FoV). Two Microsoft Azure Kinect cameras are placed at the local site to record a 3D view of the learner and the procedure. The 3D view contains 1920 x 1080 pixel color information and 320 x 288 pixel depth resolution. The limitations of the current camera setup are the resolution and the quality of the time-of-flight depth sensor. Small details on the volumetric view are lost and distorted because of the low depth resolution. Another limitation of the time-of-flight technology is the difficulty of capturing reflective and transparent surfaces.

IV. EXPERIMENT

We conduct a user study in which we compare mixed reality against video communication in an emergency situation. The emergency situation the student is facing is Cardiopulmonary resuscitation (CPR). Through mixed reality, CPR assistance becomes intuitive because the remote expert can guide the local operator by giving directions in their field of view. Hence, the local operator can keep his focus on the patient and the task. Compared to in-person assistance, virtual assistance has the advantage of less space taken away and less distraction.

A. Setup

We prepare an emergency situation, the local operator has to face without prior notice. The situation consists of a mannequin on which the CPR has to be given and an automated
We measure procedure performance, system interaction, and compare mixed reality with traditional video communication. In our study, we operator. The communication is based on audio and mixed reality that is sent over to a remote expert who assists the local operator. The communication is utilized throughout the different parts of the procedure. 

We recruit CPR students who are mainly in the age group between 18 and 25 years. The CPR students in this age group are required to learn about the procedure as part of their driver’s license or medical school education. The students are not required to have any prior knowledge about CPR. However, the students are asked if they have had any prior CPR training in post-procedure questionnaires. The students are divided into two random groups, that will perform mixed reality and video training separately. We use experienced CPR experts to assist the students through the emergency situation. The experts will lead both the mixed reality and the video procedure.

We evaluate the performance of the procedure, the cognitive load, and the mixed reality interaction. The performance of the student on the procedure itself is measured objectively and used to compare video and mixed reality for this specific task. The quality of the CPR is determined using a Laerdal Little Anne QCPR [10] mannequin. The sensors in the mannequin give instructors detailed feedback measuring pressure, rate, and ventilation. In addition to the objective measure, we evaluate the cognitive load of the learner and the instructor. The cognitive load is measured with the NASA TLX [11] and the SIM TLX [12] questionnaires. The cognitive load evaluations measures how much additional stress is added when using digital communication during a CPR emergency. In addition, we also develop a task-specific rating questionnaire that allows us to gather quantitative results on how the mixed reality communication is utilized throughout the different parts of the procedure.

V. Conclusion

We presented a mixed reality real-time communications system for medical emergency procedures. The system consists of 3D cameras that record a volumetric view of the procedure that is sent over to a remote expert who assists the local operator. The communication is based on audio and mixed reality using the Microsoft Hololens 2 headset. We evaluate our system on a CPR emergency simulation. In our study, we compare mixed reality with traditional video communication. We measure procedure performance, system interaction, and cognitive load. The results will show us what benefits mixed reality can offer compared to video communication in a CPR emergency situation. In future work, we plan on integrating an avatar representation of the remote expert, animated from speech [13], [14].

ACKNOWLEDGMENT

We would like to thank Scott Schechtman, and Rahil Ashraf for explaining and showcasing the state-of-the-art in CPR simulation with mannequins. We would also like to thank Erin Horan, Safinaz M Alshiakh, and Yasser Ajabnoor for their help. This material is based upon work supported by the National Science Foundation under Grant No. (2026505 and 2026568).

REFERENCES

Abstract—There are several non-pharmaceutical treatment approaches, from simple to more complex, for the care of dementia patients, such as the use of immersive technology with virtual reality (VR). However, there are some difficulties in using wired and controller-based VR devices for dementia patients. This work-in-progress paper describes our steps to implement a wireless VR experience with a hand-tracking interaction system. Before testing the environment with patients, we first evaluate the usability of the VR experience by conducting a user study with ten participants. The results indicate above-average usability and low task load. Future developments in this area may improve the application of VR in memory training.

Index Terms—virtual reality, dementia, alzheimer, hand tracking

I. INTRODUCTION

Although dementia is well studied in the literature, there is very little treatment that can be offered to patients. The most common treatments are Non-Pharmaceutical Treatments (NPT) which optimize physical health, cognition, activity, and well-being. NPT can improve cognitive functions in patients with dementia. It consists of the regular activities, physical exercise (e.g. regular daily activity training or ergometer cycling), therapeutic role-playing (e.g. reminiscence therapy), nursing care (e.g. proper eating, drinking and keeping a sanitary environment), horticultural therapy and self-cognitive training (e.g. coloring books or crossword puzzles) [1].

Thanks to consumer VR devices, VR is much more accessible and has improved immensely in recent years. It also opened up the opportunity for new treatment and exercise applications in the medical field. Recent advances in technology have expanded NPT from simpler approaches such as environmental interventions to more advanced methods such as virtual reality (VR) [2]. There is quite a bit of research on VR and dementia. For example, [3] investigated the impact of VR therapy and simulation of activities of daily living in dementia patients. Their results showed a positive potential for VR intervention. However, our approach using hand tracking and the Oculus Quest 2 is quite new. As we found in the literature, one of the main difficulties for patients when performing VR exercises is the interaction system with the controller. In addition, the cable connection may restrict their movement and make it difficult to perform the experience. This study is the first step in our development process to present a more intuitive user experience during memory training. We implemented an interaction system that uses only hand tracking and gesture recognition to provide a more natural way to interact with the virtual environment. In this study, we developed a simulation of a shopping experience to create a daily-life scenario for memory training. Users were asked to go through a shopping list and pick up all the required items at the checkout. At the end, we can observe the number of items collected, the items missing, the time needed, and the number of times users checked the shopping list. During the study, we used standard and custom questionnaires to evaluate the usability of the system. We conducted this study to investigate whether the use of hand gestures and the standalone wireless VR experience has positive effects on the user experience compared to traditional wired HMDs with controller input. This work is part of ongoing work to develop a VR mental exercise application for dementia patients to determine if VR exercises can be a useful tool for NPT as self-cognitive training. We will extend the study by conducting it with a larger participant group of the elderly to observe their propensity to do so and the feasibility of this approach for them.

II. METHODOLOGY

This section covers the structure and procedure of the study. It also describes the details of the design and implementation of the VR experience.

Setup: The target platform for our study was Oculus Quest 2. The Oculus Quest 2, as a standalone HMD, offers several advantageous aspects that make it attractive for memory training studies. Standalone HMDs can facilitate user movement during the virtual experience by reducing the constraints of wired VR devices. The high mobility and more affordable price of the Oculus Quest 2 compared to other VR headsets make it a good candidate for use in treatment and caretaking facilities. Moreover, the user can even conduct the therapy session remotely and in a personal space. It is also possible
to use the device while seated to ensure patient safety while using a headset.

The Oculus Quest 2 has two controllers for VR interaction, but it also supports hand tracking. Hand tracking has several advantages over traditional controller input. Foremost, the user does not need to learn the controller’s button layout to use the application, and this can add more intuitive control to the virtual experience. On the other hand, experience with elderly and disabled people shows that they often struggle when interacting with the controller as an input device, which may make them less willing to continue therapy sessions. Accordingly, we used the hand tracking approach in this study to investigate the possibility of improving the user experience with this input method. **Virtual Reality Application:** In this study, we developed a VR experience with hand-tracking interaction using the Unity game engine. Unity provides an easy-to-implement environment for various applications with several advanced features for VR implementation. We used XR and Oculus integration plugins for VR integration with the Unity game engine. We developed the gesture detection script with a modified version of the Oculus 2 integration package. With the help of the package, one gets access to the individual bones of the virtual hand, which roughly represent the bones of the real hand. Based on these bones and their position, one can recognize predefined gestures by calculating the distance/deviation of the bones of the predefined gesture from the position of the hand bones. If the sum of the distances is within a certain threshold, the gesture is registered. The gestures registered are used to enable interaction in the virtual environment. To avoid motion sickness, we implemented a custom teleportation system using hand gestures, which function by pointing with the index finger on platforms on the floor and then teleporting the player to that position. The main story of our VR application is a shopping experience where the user is asked to gather a list of items. The graphical representation of the environment is almost realistic with daily-life supermarket items such as milk, salt, coke, etc. based on the brands available in local supermarkets to give the user a familiar feeling.

**Participants:** The study was carried out during the COVID-19 pandemic and lockdown limitations. In addition, most dementia patients can be counted as a high-risk group at this time. Accordingly, we decided to do the preliminary evaluation with participants without dementia disease to evaluate the usability of the application. Nevertheless, the findings of this study still may give an overview of the general usability of the application. A group of participants consisting of 10 people (six female and four male) attended this study. All the participants were between 23 and 34 years old. Two have never tried virtual reality, five had little experience with virtual reality, two used it about every six months and only one person uses it every month. Given the COVID-19 pandemic guidelines, we used a particular protocol to reduce the probability of infecting participants. In the evaluation area, both participant and instructor wore masks. In addition, the VR device was disinfected before and after each test run.

**Procedure:** At the beginning of the evaluation, participants filled out a short demographic survey. The survey contained the name, age, the highest level of education, occupation, and gender.

The experience begins for the user at the entrance of the store. On the user’s left hand is a description that indicates how much time they have to memorize the items displayed on the list, and the instruction that the game will begin as soon as they press the start button on the description (Fig. 1a). After pressing the start button, the list of collectable items is displayed for 10 seconds, and the user can try to remember the list as well as possible. It is also possible to check the list later by looking at their left hand. The user can navigate by pointing to the platforms in front of the shelf with the index finger for two seconds. To increase precision when pointing, a laser beam visualizes pointing the direction at the tip of the index finger (Fig. 1b). After teleportation, the user is in front of one of the shelves. After finding the items on the list, they can perform the grab interaction (make a fist) to pick up the item. By using the grabbing interaction, the VR application can recognize the predefined position of the bones for that particular object and arrange the bones of the virtual hand to hold the object in a natural way (Fig. 1c). The user can collect the grabbed object by placing it in the shopping cart. To allow the user to focus on the task and not struggle with moving the shopping cart, the cart follows the user after teleportation (the shopping cart teleports near the user). The shopping cart is always placed in a predefined position on the opposite side of the shelf. Users can recheck the list by looking at the palm of their left hand for 2 seconds. A loading animation of the list growing in their hand indicates that it is about to appear. The amount and the time of looks are tracked and displayed at the end of the experience on the scoreboard. To finish the game, users teleport in front of the cashier and press the button on the desk. After pressing the button, the user’s score will appear on the scoreboard. The correctly collected items and the forgotten items are displayed there. It also shows how much time the player took to collect the items and how often and how long they looked at the list (Fig. 1d).

**Questionnaires:** To assess the usability of the experience, we used the System Usability Scale (SUS) questionnaire as shown in [5], which contains 10 items on a 5-point Likert scale. We considered NASA TLX (6 items) as shown in [6] to assess if the task load could be low enough to conduct this training with the elderly. SUS is used in this paper to assess the usability of the system in general and it is common for other VR studies such as; [7]. We also used a custom questionnaire to find room for improvements in the application.

Immediately after the experience, participants filled out the SUS questionnaire, the NASA TLX, and the custom questionnaire.

**III. RESULT AND DISCUSSION**

The results of our initial study show the average normalized SUS score is 76.25. According to R. Lewis and J. Sauro [8] a score of 76.25 is considered a B on the system usability
scale and can be interoperated as an above-average score. We used NASA-TLX to evaluate task load during the virtual experience. The results of this evaluation show low values for demand and frustration items of NASA TLX as follows: Mental Demand(mean 4.5, standard deviation 3.6), Physical Demand (mean 3.9, standard deviation 4.93), Temporal Demand (mean 5.3, standard deviation 4.9), Performance (mean 14.9, standard deviation 5.45), Effort (mean 3.5, standard deviation 3.44). This may be related to the point that the task was not very demanding mentally or physically or in terms of time. Based on our qualitative questions, none of the participants claimed to have nausea, dizziness or any other discomfort. One participant of the participants has claimed the image of the VR Headset to be slightly blurred. None of the participants claimed to have felt stress, anxiety or any other negative emotion during the exercise. Eight out of the ten users claimed they had a fun experience upon the question “What was your overall experience with the game?” Four of the ten people asked what they at least liked answered the navigation in the VR experience. (Fig. 1b).

The custom questionnaire consisted of 5 questions with answers ranging from (1 do not agree) to (5 do agree) with the following results: “Did you find it easy to navigate and move in the simulation?” (mean 2.8, standard deviation 1.4), “Did you find it easy to grab and drop items?” (mean 4, standard deviation 0.94), ”Did you find the instructions in the game clear and comprehensible?” (mean 3.9, standard deviation 1.29), “Did you find it easy to look at the shopping list?” (mean 4.4, standard deviation 0.97), “Did you find the scoreboard at the end of the game clear and comprehensible?”(mean 3.89, standard deviation 1.45).

The decent SUS scores suggest that it is possible to create an application using gesture detection. It’s very likely that tutorials included in the application and further improvement in the movement system, would further increase the SUS score.

From the custom questionnaire and observation, it appears that the main problems of users had been with the movement in the application. Due to the constraints of not using a controller, movement is handled by gesture detection by pointing at teleportation platforms. Overall the gesture detection for the movement did work correctly, the main problem according to the users was the lack of visual feedback when they pointed at the teleportation platform. The rather low score for the question could indicate that more gamification of the application is needed and that the score at the end of the level is not enough to keep participants motivated to further train in the application.

IV. CONCLUSION

Cognitive training can reduce the severity of cognitive function loss in dementia patients. In addition, the immersive nature of VR compared to other memory exercises allows for a better assessment of how patients would perform in a real-world scenario. It is expected that the simplification of exercises in the form of virtual reality training could lower the barrier to entry for cognitive training and lead to higher persistence in training intervals. In this study, we investigate the feasibility of using hand recognition as an interaction method for memory training exercises. Based on the overall favourable perception of the application by the participants, we expect a lot of potential for the use of this interaction system for memory training. Further studies with dementia patients may improve our understanding of the usability, advantages, and limitations of this method.

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Nature & Environmental Sciences (NES)
Supporting Watershed Literacy with a Desktop Virtual Reality Exploration Game

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Abstract—A prototype desktop Virtual Reality (dVR) exploration game was developed as a curriculum enhancement activity for promoting watershed literacy with middle school students. It focuses on the spatial components, geography, and history of their local watershed. The dVR exploration game was implemented in the summer of 2021 in eastern USA during the COVID-19 pandemic with 35 learners aged 10–14 during summer school. Immediately before and after gameplay completion, the participants answered a 9-item watershed literacy measure assessing essential elements of watershed understandings. The preliminary findings revealed players’ improved ability to identify their own local watershed and how it connected to the ocean by rivers, creeks, and human-made structures. The watershed literacy measure was found to be a valid and reliable instrument.

Index terms—desktop virtual reality, exploration game, watershed literacy, middle school

I. INTRODUCTION

Water is a paramount element to provide sustainable resources for humanity, industries, and the environment [1]. Nevertheless, studies have demonstrated that both children and adults have a poor understanding of water resources and systems that are mostly responsible for unsustainable water usage worldwide [1], [2]. The watershed concept is also misunderstood by people of all ages [3]–[5] and this is especially the case with middle school learners [6]–[10]. The Environmental Protection Agency (EPA) explains that “a watershed — the land area that drains to one stream, lake or river — affects the water quality in the water body that it surrounds. (...) Because we all live on the land, we all live in a watershed — thus watershed condition is important to everyone” [11]. We contend that learning about one’s local watershed history and its environmental features may enable students to better comprehend the spatial traits, ecological features, and the environmental issues of the watershed in which they live. Thus, we designed, developed, and prototype-tested “Watershed Explorers”, a multidisciplinary VR exploration game aligned to the National Geography Standards [12], see Table I. The game focuses on promoting learners’ understanding of the spatial components of the Lehigh River watershed, focusing on how the watershed has changed over time [13].

II. WATERSHED LITERACY

The role water plays in one’s life is a learning goal in the USA [14]. Nevertheless, the topic of water is primarily focused on water as a natural resource and not so much as the medium of complex systems (i.e., watersheds). Environmental knowledge studies have reported that many adults and children fail to identify the correct concepts and understandings that define a watershed [3]–[5]. Thus, watershed-related concepts and understanding of its systemic functions remains unclear for many [8]. It is important to note that defining the term watershed is only one skill that watershed literate individuals need to have [15]. Additionally, watershed literacy skills include one’s ability to identify their local watershed and its connections with the ocean while recognizing that both natural processes and human activities affect the flow and quality of water in watersheds systems [15]. Furthermore, understanding geographic contexts of a watershed may serve to guide the interpretation of anthropogenic events in the past [12].

III. GAME-BASED LEARNING WITH DESKTOP VR

The potential of using video games and game-based learning (GBL) for education is well documented in the literature [16]–[22]. Digital game-based learning (DGBL) is a branch of GBL that encompasses digital entertainment media meant to promote players’ cognitive learning or skills with technology resources (e.g., computer games, mobile apps, and XR devices). Studies have demonstrated how DGBL can support the development of epistemological understandings [23], [24], positive attitudes and beliefs [25]–[28], as well as process skills and practices [29], [30]. VR learning games can engage learners in scientific practices, real-life problem solving, and reflection on their actions [31]. Among the motivations for VR use in education is allowing individuals facing cost prohibition [32], time constraints [33], inaccessible locations [34], risky activities, such as exploring cliffs and canyons [32], or hazardous training [35] to experience situations that would be otherwise impossible [36]. Desktop VR is an advantageous entry option for immersive learning since its virtual experiences can be delivered by computers, gaming devices, or any device with a Web browser and internet connection (i.e., WebGL interfaces).
TABLE I. THE NATIONAL GEOGRAPHY STANDARD ALIGNMENT TO WATERSHED EXPLORERS

<table>
<thead>
<tr>
<th>Grade</th>
<th>Using geography to interpret the past</th>
<th>Change in geographic contexts</th>
<th>Perception of geographic contexts</th>
</tr>
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<tbody>
<tr>
<td>5th-6th GRADE</td>
<td>▪ Identify physical landforms that affected overland travel during the expansion of the United States (e.g., mountain ranges, gaps, and rivers).</td>
<td>▪ Describe how the physical environment of a county or state was changed by processes of forest clearing, damming of rivers, or land leveling</td>
<td>▪ Describe how people’s perception of the environment changed over time from limitless exploitation to sustainability (e.g., pollution of rivers during industrialization).</td>
</tr>
<tr>
<td>5th-6th GRADE</td>
<td>▪ Analyze the significance of physical features that have influenced historical events (e.g., the role of hydrologic and/or topographic features of the Lehigh River Watershed, and the Appalachians in the settlement of the United States).</td>
<td>▪ Describe the changes in the spatial organization of cities over the past 200 years (e.g., the environmental effects of industrialization, river canals, and railroad systems).</td>
<td>▪ Explain how geographic perceptions impacted decisions of and actions by an individual, a group, or a nation (e.g., the perception of land uses and its values leading to the creation of cement, the construction of river dams, locks, towpaths, canals, and later, railroad systems).</td>
</tr>
<tr>
<td>12th GRADE</td>
<td>▪ Explain how physical geographical features and levels of technology influence the course and outcome of battles and wars (e.g., strategic localization of the Lehigh River in the industrial revolution, Bethlehem Steel’s role in the first world war).</td>
<td>▪ Analyze how technological changes in infrastructure have affected human activities in places, regions, and the environment of the Lehigh Valley over time (e.g., the effects of processes of technological change, development of the railroad spurring migration and influencing changes in land-use patterns with access to markets).</td>
<td>▪ Describe the changes in perceptions about a group, place, or geographic feature and analyze the effects of those changes (e.g., opinions about the role of the NJ Zinc plant in the Lehigh Gap area, attitudes towards and therefore treatment of superfund sites in the United States from late 1990’s to today).</td>
</tr>
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IV. THE WATERSHED EXPLORERS DESKTOP VR GAME

We developed “Watershed Explorers” using Unity real-time engine and built the game for WebGL platforms. The desktop VR game includes a GIS map interface of the Lehigh River watershed with labels, high-resolution 360º photos from the actual locations, 3D models of trail signs, historical imagery, and narrations regarding the environmental and historical significance of each explored area. “Watershed Explorers” was designed and developed with a series of design principles focused on local contexts and gaming features [13]. The intended audience for “Watershed Explorers” included a wide age range from adolescents to senior citizens.

The exploration game begins by providing players with the game’s context, the main goal of the game, a pretest measure, and the game tutorial. Players start the game in the D&L museum conference room and meet four avatars that serve as virtual tutors and tour guides throughout the immersive exploration. Della-the-mule is the D&L museum mascot and coordinates the exploration team. Lenni is the rivers and recreation specialist. Mira, the environmental educator of the group, describes the environmental importance as well as changes that occurred in the watershed area since the industrial revolution. Lance, a local historian, shares the main historical events of the Lehigh River during the past two centuries. After the avatars’ introductions, a narrated fly over animation of the Lehigh watershed map illustrates the path of their exploration down the river.

In sequence, the avatars introduce the controls of this point-and-click exploration game in a tutorial playthrough mode. The game environment contains 360º high resolution photos enriched with videos, historical imagery, trail information signs, and narration regarding the historical or environmental importance of each visited area.

Next, players explore the nine locations along the Lehigh River. Each location has two or three photospheres (i.e., immersive 360º photos). To keep advancing in this linear narrative-based game [24], players need to explore every photosphere completely by collecting the historical photos, watching regular and immersive videos, and reading the local information signs by clicking on their respective icons. Before moving forward to the next location, players answer one multiple choice question that summarizes the main aspect of the area. After exploring the final photosphere, players return to the D&L museum to report on their findings. Players achieve their main goal by recommending three locations to receive improvements that would increase tourism and community engagement along the Lehigh River. They also complete a watershed literacy posttest measure and provided demographic information that included gender and age. Upon data collection completion, the D&L game avatars award players with the title of Watershed Explorer.

Fig. 1. Watershed Explorers avatars in the D&L museum conference room. From left to right: Lance, Della (highlighted), Lenni, and Mira.
V. STUDY CONTEXT AND DESIGN

This study investigated the efficacy of the desktop VR exploration game “Watershed Explorers” as a curriculum enhancement activity to understand its impact on middle school learners’ understandings of watersheds by measuring changes in their watershed literacy scores. Implementation took place during the COVID-19 global pandemic in the summer of 2021. Participants had access to the study materials at https://go.lehigh.edu/explorers along with the game via a WebGL interface (i.e., a web-browser connected to the internet). The study’s participants were middle school-aged students (10–14 years old), living in the Lehigh River watershed and surrounding areas. Sixty-six participants completed the pretest, from which 35 (9 female, 25 males, and 1 other) completed both the pretest and the posttest. The following research question guided this feasibility study:

To what extent does playing the VR learning game impact middle school learners’ understandings of watersheds?

The participants completed a 9-item watershed literacy pretest-posttest content assessment measuring essential watershed understandings that individuals need in order “to be considered scientifically watershed literate” [15, p. 6]. Its nine closed questions included seven true/false and two multiple-choice selection items that assessed participants’ ability to:

- Define the term “watershed” (items #3, #4, and #7);
- Identify their local watershed, how they are connected to the ocean via streams, rivers, and human-made structures, as well as the functions that occur in a watershed (items #5, #6, and #9);
- Recognize that both natural processes and human activities affect water flow and water quality in watersheds (items #1, #2, and #8).

The data collection instruments were embedded in the game progression. The game interface (front-end) displayed the data collection instruments as required tasks of the game (see Fig. 2). As players submitted their responses, a C# script forwarded their input data to an online Google Form (previously created by the researcher) that automatically stored each participant set of responses across the rows of a Google spreadsheet.

A repeated-measures one sample t-test was conducted to check whether there was any difference between the students’ pretest and posttest watershed literacy scores. Although the measure had different formats of test items (i.e., true or false, multiple choice), each item had only one correct response. Thus, a new re-coded dataset was prepared as a data treatment procedure that dichotomized participants’ answers between incorrect (0) and correct (1). Total scores ranged from 0 to 9.

Four education technology and environmental education experts with experience in teaching and learning with VR technologies reviewed each measure to ensure face validity and content validity of the data collection instruments. After considering their feedback, we revised item prompts to better address the study’s research question and improved the visual representation of the maps for items 8 and 9 in the watershed literacy content assessment.

Despite the limited sample size, we investigated the psychometric properties of the Watershed Literacy measure by conducting a Rasch analysis using the partial credit model since the items had different rating scales. Next, we conducted a Confirmatory Factor Analysis (CFA) to ensure that the three originally conceptualized subscales “Define”, “Identify”, and “Recognize” were valid. The Rasch analysis was conducted using MINISTEPS, a free version of WINSTEPS computer program [37]. SPSS was used for the CFA.

VI. FINDINGS

The Rasch Analysis’ item reliability coefficient was .87 with a separation coefficient of 2.59 (i.e., a reliable measure with at least two different types of items). Findings from item infit and outfit analysis suggest low likelihood for multidimensionality since all nine items were within the conventional mean square (MSQ) fit ranges of 0.70–1.30 for multiple choice questions of mid/low stakes tests [38]. See Table II.

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Infit-MSQ</th>
<th>Outfit-MSQ</th>
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<tr>
<td>1</td>
<td>1.11</td>
<td>1.18</td>
</tr>
<tr>
<td>2</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>3</td>
<td>1.22</td>
<td>1.30</td>
</tr>
<tr>
<td>4</td>
<td>0.89</td>
<td>0.84</td>
</tr>
<tr>
<td>5</td>
<td>1.04</td>
<td>0.96</td>
</tr>
<tr>
<td>6</td>
<td>0.86</td>
<td>0.79</td>
</tr>
<tr>
<td>7</td>
<td>0.92</td>
<td>0.83</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>1.14</td>
</tr>
<tr>
<td>9</td>
<td>0.94</td>
<td>1.01</td>
</tr>
</tbody>
</table>

Note. N = 66

Fig. 2. Embedded data collection instrument. Item 7 and 8 illustrate the two different types of assessment questions of the watershed literacy measure.
Findings from the confirmatory factor analysis (Principal Components Analysis with Varimax rotation) aligned with our subscales. The 3 fixed factors requested to be extracted in SPSS accounted for 52.55% of the total variance (factor 1, 20.72%; factor 2, 18.64%; factor 3, 13.19%). Five items (#4, #5, #7, #8, #9) corresponded to the subscales as they were originally conceptualized and had factor loadings above .70 with little to no correlation with the remaining two subscales. Table III displays each set of items with their respective factor loadings.

We hypothesized that using the “Watershed Explorers” desktop VR game as a curriculum enhancement activity to promote watershed literacy would positively impact learners’ watershed-related knowledge after playing the game. The mean difference between the pretest and posttest scores of the entire Watershed Literacy (WL) measure was not statistically significant. When comparing the pretest-posttest mean scores of the WL subscales, there was a statistically significant difference with a medium effect size in Item 9 “Which number corresponds to the Lehigh River watershed?”, t(34) = 3.51, p = .001, d = .59. No statistically significant difference was found in items 1–8 in a pretest-posttest 2-tailed significance test (p > .05). Overall, the means of seven items slightly increased whereas the means of two items decreased. Table IV displays the descriptive statistics (mean, standard deviation, and mean difference) and pretest-posttest paired-sample t-tests for each of the means of the nine items of the Watershed Literacy measure.

Next, we investigated the mean difference for each item. There was a statistically significant difference with a medium effect size in Item 9 “Which number corresponds to the Lehigh River watershed?”, t(34) = 3.51, p = .001, d = .59. No statistically significant difference was found in items 1–8 in a pretest-posttest 2-tailed significance test (p > .05). Overall, the means of seven items slightly increased whereas the means of two items decreased. Table V displays the descriptive statistics (means, standard deviations, and mean differences) and pretest-posttest paired-sample t-tests for each of the means of the nine items of the Watershed Literacy measure.

### Table III. Results from a Factor Analysis of the Watershed Literacy Measure Items

<table>
<thead>
<tr>
<th>Watershed Literacy Item</th>
<th>Factor loading</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor 1: Recognize that both natural processes and human activities affect water flow/quality in watersheds</strong></td>
<td></td>
</tr>
<tr>
<td>8. Which town is most affected by the pollution of the abandoned mine?</td>
<td>.74 .00 -.13</td>
</tr>
<tr>
<td>6. Watersheds include running water, still water, groundwater, and surface water.</td>
<td>.68 .51 .10</td>
</tr>
<tr>
<td>3. Topography does not define and separate the watersheds.</td>
<td>.63 -.16 -.16</td>
</tr>
<tr>
<td><strong>Factor 2: Define the term “watershed”</strong></td>
<td></td>
</tr>
<tr>
<td>4. Watersheds consist of biological and physical components.</td>
<td>.09 .74 .10</td>
</tr>
<tr>
<td>7. A watershed is a land area that drains rainfall and snowmelt to creeks, streams, and rivers, eventually flowing into a large body of water.</td>
<td>-.06 .72 -.23</td>
</tr>
<tr>
<td>1. Everyone on Earth lives within a watershed.</td>
<td>-.21 .41 .38</td>
</tr>
<tr>
<td><strong>Factor 3: Identify one’s local watershed, how they connect to the ocean by waterways and built structures</strong></td>
<td></td>
</tr>
<tr>
<td>9. Check the number corresponding to the Lehigh River watershed.</td>
<td>.33 .07 .75</td>
</tr>
<tr>
<td>5. Smaller watersheds do not connect to each other forming larger watersheds.</td>
<td>-.25 -.05 .73</td>
</tr>
<tr>
<td>2. Watersheds are changed only by natural processes.</td>
<td>-.20 -.03 .41</td>
</tr>
</tbody>
</table>

Note. N = 66. Original (non-dichotomized) dataset. Factor loadings above .40 are in bold.

### Table IV. Watershed Literacy Measure’s Item Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre M</th>
<th>Pre SD</th>
<th>Post M</th>
<th>Post SD</th>
<th>AM</th>
<th>Paired t-test t(34)</th>
<th>p value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>0.34</td>
<td>0.48</td>
<td>0.51</td>
<td>0.51</td>
<td>0.17</td>
<td>1.53</td>
<td>.136</td>
<td>0.258</td>
</tr>
<tr>
<td>Item 2</td>
<td>0.40</td>
<td>0.50</td>
<td>0.43</td>
<td>0.50</td>
<td>0.03</td>
<td>0.26</td>
<td>.800</td>
<td>0.043</td>
</tr>
<tr>
<td>Item 3</td>
<td>0.49</td>
<td>0.51</td>
<td>0.37</td>
<td>0.49</td>
<td>-0.12</td>
<td>-1.00</td>
<td>.324</td>
<td>-0.169</td>
</tr>
<tr>
<td>Item 4</td>
<td>0.66</td>
<td>0.48</td>
<td>0.77</td>
<td>0.43</td>
<td>0.11</td>
<td>1.07</td>
<td>.292</td>
<td>0.181</td>
</tr>
<tr>
<td>Item 5</td>
<td>0.49</td>
<td>0.51</td>
<td>0.66</td>
<td>0.48</td>
<td>0.17</td>
<td>1.36</td>
<td>.183</td>
<td>0.229</td>
</tr>
<tr>
<td>Item 6</td>
<td>0.71</td>
<td>0.46</td>
<td>0.66</td>
<td>0.48</td>
<td>-0.05</td>
<td>-0.53</td>
<td>.600</td>
<td>-0.089</td>
</tr>
<tr>
<td>Item 7</td>
<td>0.66</td>
<td>0.48</td>
<td>0.66</td>
<td>0.48</td>
<td>0.00</td>
<td>0.00</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Item 8</td>
<td>0.51</td>
<td>0.51</td>
<td>0.54</td>
<td>0.51</td>
<td>0.03</td>
<td>0.24</td>
<td>.812</td>
<td>0.400</td>
</tr>
<tr>
<td>Item 9</td>
<td>0.11</td>
<td>0.32</td>
<td>0.43</td>
<td>0.50</td>
<td>0.32</td>
<td>3.51</td>
<td>.001*</td>
<td>0.593</td>
</tr>
</tbody>
</table>

Note. N = 35. *p < .01
TABLE V.  WATERSHED LITERACY MEASURE AND SUBSCALES DESCRIPTIVE STATISTICS AND PAIRED-SAMPLE T-TESTS

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>Post</th>
<th>AM</th>
<th>t(34)</th>
<th>p value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire measure</td>
<td>4.37</td>
<td>5.03</td>
<td>0.66</td>
<td>1.73</td>
<td>.093</td>
<td>0.292</td>
</tr>
<tr>
<td>Define subscale</td>
<td>1.80</td>
<td>1.80</td>
<td>0.00</td>
<td>0.00</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Identify subscale</td>
<td>1.31</td>
<td>1.74</td>
<td>0.43</td>
<td>2.27</td>
<td>.030**</td>
<td>0.383</td>
</tr>
<tr>
<td>Recognize subscale</td>
<td>1.26</td>
<td>1.49</td>
<td>0.23</td>
<td>1.05</td>
<td>.300</td>
<td>0.178</td>
</tr>
</tbody>
</table>

Note. N = 35. **p < .05

VII. DISCUSSION

This exploratory quantitative study investigated how middle school students’ understandings of watershed changed after playing “Watershed Explorers”, a desktop VR game used as a curriculum enhancement activity. Due to the COVID-19 global pandemic, the study implementation took place in summer schools. In the U.S., regular schools and summer schools have different goals, which impact their curriculum. Summer schools usually have students work on remedial activities to make up for any learning losses they had during the academic year. Although, the multidisciplinary game, “Watershed Explorers” was originally designed for informal learning, from adolescents (age 13+) to senior citizens, it was implemented with young learners (ages 10–14) from two summer school programs. It might be the case that some of the study participants had difficulties with the amount of reading. However, the young participants did benefit from using the desktop VR game as a curriculum enhancement activity to learn about their local watershed. These findings tend to indicate that VR integration into school curriculum may be a helpful learning tool. Therefore, our future plans also include developing a watershed curriculum learning unit using the VR game “Watershed Explorers”.

The findings from the Watershed Literacy content assessment partially support our hypothesis that the use of the “Watershed Explorers” game as a curriculum enhancement activity can positively impact middle school students’ essential understandings about watersheds. Players improved their ability to identify their own local watershed and its connections to the ocean by rivers, creeks, and human-made structures. This statistically significant learning gain in the “Identify” subscale was achieved despite the use of the desktop VR game as a curriculum enhancement activity. The unchanging scores of the “Define” subscale is corroborated by the literature as the concept of watershed is not considered common knowledge and is often misunderstood, especially among young learners [3–8].

There were some limitations to this study. First, despite the interest of school administrators and teachers, it was very hard to have students engage in this “no-stakes” learning activity during summer school. Second, the number of participants decreased between the pretest and posttest. Participant attrition occurred due to insufficient time to complete the entire game and network technology issues that occurred during gameplay. One teacher reported that a 50-minute class period was not always sufficient for some students to complete the whole experience in one sitting. It was also reported that three students experienced technical issues when completing the posttest. We believe that if the researcher were present during the implementation, time and technology related issues reported by the two teachers could have been addressed. Finally, using a curriculum enhancement activity is itself a limitation since we did not know the scope and sequence of the summer school curriculum of the participants. Future research should first interview teachers and analyze their adopted curriculum to identify where “Watershed Explorers” could fit best in a coherent local sequence for the school curriculum.

From a methodological perspective, the limited sample size number did not jeopardize this prototype implementation study given its exploratory nature (i.e., not intended for generalization). However, if the number of participants were larger, our Rasch analyses could have explored the difference between participants’ ability levels as well as the role of guessing in the Watershed Literacy content assessment. This would further support a better psychometric measure for the next iteration of the instrument.

ACKNOWLEDGMENT

We wish to thank Farah Vallera, Tammie Peffer, Dave Anastasio, and Tom Hammond for revising and providing feedback on the watershed literacy measure. We also thank Jenn Nester for assistance with the study implementation, Joan Fu for providing statistics advisory, and Thayná Bertholini for proofreading.

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REFERENCES


Flood Adventures: A Flood Preparedness Simulation Game

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Abstract—Knowledge of how to prepare for flooding remains an important educational need as illustrated by the devastation caused by recent flooding events across the USA and in other global locations. To address this need, we are developing *Flood Adventures*, a two-stage VR learning game with best practices for flood preparation focusing on how individuals can prepare for flooding and communities can mitigate flood risk. We present our VR game learning model that guides our design and development work. Our prototype development work on the first game stage that focuses on flood preparedness is presented. We conducted usability testing with the initial prototype version of the game with twenty-four adults. Findings from our usability testing found that players used spam clicking strategies during game play. Recommendations to enhance the game are presented.

Index terms—flood preparedness, virtual reality, learning game, flood risk

I. INTRODUCTION

As global temperatures rise and the hydrologic cycle intensifies [1], people and property are at a higher risk to flooding events [2]. Knowledge of how to prepare for flooding and where to find forecasts and preparedness information remains an important educational need as illustrated by the devastation caused by recent flooding events across the USA and in other global locations. It is important that people know what actions to take when a flood is forecasted and understand the risk flooding poses to infrastructure and lives. Game-based immersive VR learning environments can help individuals learn about best practices for flood preparation and how individuals and communities can prepare for and mitigate flood risk.

Our team hypothesizes that learning about flooding with VR can have a positive impact on engagement and learning, particularly in informal learning environments and at home. Engagement is critical to learning in informal STEM education. Research shows that during informal STEM education, learners are most engaged by experiences that offer interactivity [3]. VR learning games are one way to provide this interactivity and engagement. Features such as active control of the user experience, naturalistic, yet safe environments, and realistic representation of real-world situations can increase engagement and learning [4]. The VR experience can also provide a sense of authentic immersion and presence; users can virtually ‘be’ at specific geographic locations that are dangerous [5]. Furthermore, headset VR can focus users’ attention on learning tasks in a game [4]. Our aim with a new Flood Adventures VR game prototype is to enhance the quality of visitors’ experiences in informal environmental education centers while improving understanding of flood preparation and mitigation of flood risk.

II. BACKGROUND AND THEORETICAL FRAMEWORK

Our VR game learning model (Fig. 1) focuses on elements that lead to engagement and learning with VR game-based experiences. Engagement can be defined as one’s focus, participation, and persistence within a task, and therefore, is related to adaptive or self-regulated learning [6]. Engagement is what happens during a task and is the result of the interaction between the learner and the characteristics of both the task itself and the supporting environment. Dorph et al. [6] discuss three dimensions of engagement: (1) behavioral engagement that focuses on what a person involved in a learning activity would be doing (e.g., actively participating in a learning task); (2) cognitive engagement that focuses on thought processes or attention directed at processing and understanding the content in a learning task; and (3) affective engagement that includes one’s emotions that are experienced during a science activity. Research suggests that a combination of these three aspects of engagement supports learning [7]. In addition, agentic engagement, a fourth and more recent dimension of learner engagement, involves one’s proactivity and valuable contributions into the received instructional sequence [8]. All four forms of engagement can be enhanced by VR learning games.
Our project builds on two theoretical frameworks: (a) Malone’s theory of intrinsically motivating instruction [9], and (b) Science Learning Activation Theory [6], which supports our design of engaging VR game-based activities for learning. Malone’s theory of intrinsically motivating instruction [9] contends that intrinsic motivation is created by three qualities: challenge, fantasy, and curiosity. A main component of Science Learning Activation Theory [6] contends that the activated science learner is fascinated by natural and physical phenomena. A learner can have emotional and cognitive attachment/obsession with science topics and tasks that serve as an intrinsic motivator towards various forms of participation.

The model inputs (Fig. 1) derive from the published literature pertaining to VR and game-based learning, including (a) perceived usefulness of learning with VR, (b) VR affordances, and (c) flexible game design features for individual and social learning. Previous research has identified perceived usefulness as an important component that influences learners’ interactional experiences when using educational technology [10]. Perceived usefulness refers to the degree to which a VR user believes that using a platform will enhance their performance [11]. Recent VR implementation studies have found that perceived usefulness is important for promoting cognitive benefits and affective learning in a VR lesson [11], [12]. The VR affordances of immersion and presence are the main area of VR research studies primarily with headsets [13]. Immersion is the level of sensory fidelity that a VR system provides and describes the experience of using VR technology [14]. Presence is a user’s subjective psychological response to a VR system where the user responds to the VR environment as if it were real [15].

Flexible game design features for individual and social learning are design principles that draw from the research literature on designing learning for informal science education environments and the affordances that gamified VR can provide. These include:

- **Engage learners in challenging tasks that are intrinsically rewarding.** Distinct challenges within a learning game keep players engaged and challenged. Designing for the right challenge-skill balance promotes engagement and an intrinsically rewarding experience for the learner [16], [17].

- **Promote curiosity.** Curiosity involves intrinsic motivation to learn and explore. Exploration, task simulation, and social simulation games with virtual characters have been found to stimulate curiosity [18].

- **Provide a strong narrative.** A game designed for informal use requires strong narrative elements to generate excitement, interest, or enthusiasm for science learning. Game-based narratives use questions, problems, or missions to enhance learners’ motivation [19].

- **Provide supportive guidance and motivational feedback.** Guidance in the form of advice, feedback, prompts, and scaffolding can promote deeper learning [20]. Providing guided exploration and metacognitive support also enhances learning for transfer in informal settings [21]. Support is also enhanced by different forms of engaging feedback such as badges or points [22].

- **Engage in generative learning tasks to stimulate reflection within and among users.** Reflective learning is a generative learning strategy that involves actively reflecting upon one’s own understanding of the material.

![Fig. 1. VR game learning model.](image)
and generating inferences [23]. VR learning that incorporates generative learning strategies can be beneficial for promoting motivation and learning [24].

III. Flood Adventures: Prototype Design and Development

Guided by VR learning and game design principles, we are developing a multi-stage (level) VR game for adolescents and adults to learn about flood preparedness and community resilience planning. These authentic issues make science learning engaging since players need to feel the relevance and authenticity of the learning activity to their personal lives in some way [25]. The game is being designed for diverse populations and will be relevant to many people in the USA since millions are exposed to flood risk [26]. This should help players identify with flooding issues in personally meaningful ways to promote connections between science knowledge and their own lives. The game also uses combinations of imagery, 3D visualizations, animation, audio, and text to enhance learning, promote transfer, and foster sense-making of flood risks. We are using the Quality of Education in Virtual Reality Rubric [27] to guide our development process for learning goals, content development, pedagogy, metacognitive prompts, feedback, interface design, sound, language, navigation, engagement, ensuring content is culturally appropriate, and other VR design features.

Flood Adventures will take place in two game stages (levels). The first stage focuses on flood preparedness and the second stage focuses on community resilience planning. Each game stage is designed to take 15-20 minutes to complete. The game experience will begin with a brief three-minute video to inform players how global climate change can result in a higher risk of localized flooding events that threaten lives and property. We present our development work to date on the first game stage.

Game stage one begins at a house located near a creek. The house includes multiple rooms with 50 household items (Fig. 2). The player starts in the garage and a tutorial explains how to move, pick up and place objects into an inventory system (this is analogous to what one is carrying), and then put the gathered objects in the household’s car. A weight system is employed that slows down the player’s movement as they carry more object weight. The tutorial ends with the player going to the living room where a flood emergency warning goes off in the house and their smartphone. The player learns that the nearby creek is flooding and hears “get all your essential items and evacuate the area immediately.”

The scene changes to the area outside showing a nearby creek and surrounding area (Fig. 3). A major thunderstorm occurs, water begins to flow faster in the creek, and debris start to rapidly flow downstream as the water level rises. The water begins to rise over the banks of the creek and approaches the house (Fig. 4).

The scene then shifts back to the house where the player is given three minutes to gather items in the house to place in the car. The scene ends abruptly at three minutes with a cut scene showing the creek flowing over the bank and inundating the house. Feedback is given to the players about how many of the items they gathered were essential (needed that day), very important (needed it in the next few days in case you cannot get back into the house), and items that are useful, and not very important for daily survival. A point system ranks each of these four item categories. This game segment is designed for the players to initially fail and receive a low score. We envision that during this game segment, most players will not have appropriate background knowledge to differentiate between items that are essential or very important compared to items that are useful or not needed during a home flood evacuation scenario. Then, specific reflective prompts appear based on the player’s decision-making choices (what they chose to take with them when evacuating) and will be reflected in a game score. Designing to have the initial attempt fail is meant to creating a learning opportunity for the player and highlights the importance of the tasks they must do in response to a flood threat.

The game continues with a loud TV sound. The player wakes-up and realizes it was just a dream. The player slowly walks to the living room to turn off the TV. Suddenly, they notice the content of the TV broadcast: an interview with a flood preparedness and resilience expert from the local nature center. She would be teaching the player how to prepare a “flood emergency kit.”

The game continues with a short video from the TV in which the player learns about recommended items to have ready in case a flood occurs, the importance of preparing an evacuation route, and the dangers of driving into standing or rising water. During this game segment, players have time to gather essential items in the house and place them in a “flood emergency kit” container. Reflective prompts direct players to think about which items are essential and very important to place in the container. Feedback on the items’ importance appears immediately after each item is placed in the container. The weight system keeps players from carrying too many heavy objects at one time. If the player’s carry load exceeds twenty pounds, the player’s movement slows down. This game segment concludes when they have prepared the container while reflective prompts encourage players to think about other very important items to gather if a flood occurs.

The next game segment begins with the flood emergency warning going off in the house. The player has three minutes to gather household items that now includes their “flood emergency kit” container and load them into the car and drive off. Feedback is provided and the intent is that the player will receive a much higher point score based on their new decisions. Reflective prompts focus on the decision-making choices. Finally, players have the option of either repeating this segment to improve their performance or moving on to game stage two.

IV. Prototype Testing and Next Steps

We conducted a usability study of the prototype house and its functionalities (movement and ability to pick up objects) with twenty-four adult participants 20-49 years old that played a desktop VR version on a PC laptop. Each player was informed that a flood was approaching the house and they had three minutes to grab as many essential items as they needed and were to place them into the car located in the house’s garage. After the participants completed the task, we asked them to provide us
with feedback to enhance the game and if they enjoyed playing it. All participants were able to successfully move throughout the different rooms of the house and pick up objects. The participants reported that Flood Adventures was “so cool” and a “fun game.” Some participants commented that they enjoyed the cat that walked around the house. Some participants reported that their movement was smooth and did not lag. During the usability testing sessions, we observed that many players used spam clicking strategies [28] to complete the game. That is, they were interacting with the user interface through quick sequences of mindless and random clicks during gameplay.

The prototype testers had many recommendations for improving the game. One player suggested that the feedback system provide a detailed explanation for their scores. Another player recommended providing more detailed game instructions. One participant stated it was unclear which items in the house could be picked up. One player commented that the game needed to prevent users from spam clicking. Other recommendations from players included enhancing the lighting in the rooms, using different textures on the floors of each room, providing the functionality to open the cabinets, changing the direction of opening the door into the garage, and using a more realistic looking cat or including a dog in the house.
We are currently refining the prototype of game stage one in the Unity environment based on our prototype implementation feedback. The house now has different textures on the floors of each room and enhanced lighting. We have developed a differential point system for the four different item types that are placed in the house based on their importance during a flooding event: essential (needed that day), very important (needed it in the next few days in case you cannot get back into the house), items that are useful, and not very important for daily survival. In addition, we are developing a more detailed feedback system to provide players important dialogue prompts to consider while they are gathering objects in the house.

After further revisions to the prototype are made, we will conduct another round of usability testing with a desktop VR version of the game and make revisions based on testers’ feedback. After the last iteration of the desktop VR version, we will convert the game for headset VR implementation and conduct further usability tests. Additional prototype implementation data will inform revisions to this first stage of the game. Then, the revised headset VR version will be pilot-tested at two informal environmental education centers. After our iterative development process concludes, we will begin development on the second game stage which is a flood hazard mitigation, planning, and decision-making simulation game that takes place on a community level perspective.

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Enhancing K-16 Science Education with Augmented Reality: A Systematic Review of Literature from 2001 to 2020

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Abstract—This study conducted a systematic review of 20 years of literature on the usage of augmented reality (AR) in K-16 science education. A total of 89 articles were selected as the research sample pool of this review after initial literature searching and manual filtering. The research findings were analyzed and synthesized through five interrelated aspects of AR-supported instruction: metadata, research methodologies, instructional contexts, instructional design, and technological features. The results revealed the trend patterns in AR-supported science education in terms of publication, pedagogical assumptions, and technological affordances over time. In addition, we reported the contextual factors in AR pedagogies and instructional functions. Finally, practical implications for teachers and AR program developers are proposed and discussed.

Index terms—augmented reality, science education, systematic review, instructional design

I. INTRODUCTION

Augmented reality (AR) provides real-time interaction and focuses on supplementing reality through virtual information superimposed upon or synthesized real objects and coexisted in the same environment [1]. The great potential of AR for science education has attracted researchers’ attention recently, which has led to an increasing number of empirical studies investigating its application in science classrooms.

However, those studies were conducted in various educational contexts with scattered and inclusive results being reported, highlighting the need for a systematic review of relevant literature. To our best knowledge, there are three systematic reviews in the literature: Cheng and Tsai (2013) [2] attempted to re-coin two types of AR and pedagogically examined AR-related studies in science education. Goff et al. (2018) [3] focused on informal science education and conducted a review of design elements, technological devices, and reported outcomes. Arici et al. (2019) [5] conducted a bibliometric mapping analysis and discussed the research methodology through content analysis.

Despite the scholarly contribution of the aforementioned systematic reviews, there are also some noticeable limitations of the review findings. First, while the topics of pedagogy, technology, and research methodology have been emphasized in different reviews respectively, there has been a lack of comprehensive review that explores the relationship among the three topics. Second, despite the importance of student age for science education, comparative analysis across different educational stages was rare in the literature. Lastly, the most recent comprehensive review was conducted 10 years ago [2], there is a need to synthesize key research findings during the last decade. Therefore, an up-to-date systematic review of AR-supported science education in the K-16 sectors is in urgent need.

To close this research gap, we focused on AR-supported science education literature in K-16 in our systematic review, and critically analyzed the empirical studies published in the past 20 years (2001-2020) in terms of publication trend, instructional design, technological features, and research methodology over the two decades. Specifically, the present review poses the following questions:

1. What patterns in research publication can be identified from the metadata?
2. What pedagogies and instructional affordances have been utilized in AR-supported science education?
3. What technological features of AR have been used in science education and how are they evolving over time?

II. METHOD

A systematic review approach was used to locate, select, and analyze the articles which were published from 1 January 2001 until 31 December 2020. Three main stages (1) initial literature search, (2) manual filtering, and (3) analytical coding were covered in this systematic review.

A. Initial Literature Search

The initial literature search was conducted using Scopus as research database. As the largest abstract and citation database of peer-reviewed literature, Scopus delivers a comprehensive overview of the world’s research output in the fields of science, technology, medicine, social sciences, and arts and humanities. Thus, this selected database has the characteristics of both a wide range and high-quality content, which can fully meet the needs of our research. The reason for not using other databases to supplement the literature is that the search results of other databases basically overlap the literature retrieved in Scopus.

The initial literatures were searched by using an arbitrary combination of two sets of search strings. The first cluster
contains ‘augmented reality’ and its abbreviation ‘AR’; the second cluster is closely related to education, such as ‘learn*’, ‘teach*’, ‘education*’, ‘class*’. A total of 3182 articles were retrieved during this stage.

B. Manual Filtering

At this stage, we manually filtered the articles according to the following criteria: (1) Focus on AR. VR and MR were excluded. (2) Grade level was K-16. The contexts of special education and professional development were removed. (3) Peer-reviewed studies. Publications including reports and dissertations were excluded. (4) Empirical research or design case. Specific types of empirical research include experimental, quantitative, qualitative, mixed method, survey research, and design-based research. In addition, the reason why we included the design case studies was that we considered the design case studies were still highly relevant to education and offer technology code data, though they reported design and development of systems or apps in education without conducting empirical research. (5) Conducted in the context of basic science. The articles must have been specifically related to basic science education, such as physics, biology, chemistry, environment, and astronomy.

The manual filtering process spanned about 8 months and involved 7 researchers specializing in educational technology. The controversial parts were discussed in weekly meetings, which lasted 1.5 hours each. After manual filtering, a total of 89 articles were selected as the research sample pool of this review for further analysis.

C. Analytical Coding

After identifying the research sample pool of this review, we gathered five categories in each article: metadata, research context, design, and technology. Table 1 illustrates the details of AR coding manual. The full manual protocol can be accessed from https://doi.org/10.17632/8nvnnmy9j3.1.

### Table 1. Details of AR Coding Manual

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metadata</td>
<td>Title</td>
<td>Full title of the study</td>
</tr>
<tr>
<td></td>
<td>Authors</td>
<td>Authors' names</td>
</tr>
<tr>
<td></td>
<td>Year</td>
<td>The year the study is published</td>
</tr>
<tr>
<td></td>
<td>Source</td>
<td>Information about the journal/book/URL</td>
</tr>
<tr>
<td>Research</td>
<td>Empirical Type</td>
<td>Experimental/quantitative/qualitative/mixed/survey/design-based research</td>
</tr>
<tr>
<td>Context</td>
<td>Location</td>
<td>Country or region where the study was conducted</td>
</tr>
<tr>
<td></td>
<td>Grade level</td>
<td>Primary/secondary/middle/high school/education/county</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>Teacher training: no/yes</td>
</tr>
<tr>
<td></td>
<td>Setting</td>
<td>Formal/informal/unrestricted</td>
</tr>
<tr>
<td>Design</td>
<td>Pedagogy</td>
<td>Inquiry-based/game-based/collaborative/trial-error/direct instruction/experiential learning</td>
</tr>
<tr>
<td></td>
<td>Level of inquiry</td>
<td>Lecture-based/interactive/inquiry oriented</td>
</tr>
<tr>
<td></td>
<td>Scaffolding</td>
<td>No scaffolding/manuals/computer/teacher &amp; student</td>
</tr>
<tr>
<td></td>
<td>Assessment</td>
<td>No assessment/traditional/AR/mixed</td>
</tr>
<tr>
<td>Technology</td>
<td>Human-Computer Interaction</td>
<td>Natural: voice/command/magnetic/motion/haptic/location-based</td>
</tr>
</tbody>
</table>

III. Results and Discussions

A. Publication Trends

Fig. 1 shows the number of AR publications in science education from 2001 to 2020. As seen in Fig. 1, there was a significant increase in research publication since 2014, corresponding to the major advancements in AR technology: Google Glasses featured by various AR features was launched in 2013 in the U.S. market and sparked global interest in AR. Fig. 1 also shows that the overall trend was increasing and research in AR-supported science education has intensified during the last three years, projecting the continual growth in research interest towards this field of study.

A total of 69 empirical studies identified the country or region in which the study took place. 97.1% of them were in Asia (35), North America (13), and Europe (19). Specifically, Taiwan had the largest number of publications (n=26), followed by the United States (n=13) and Spain (n=5).

![Fig. 1. Number of articles published by year.](image)

Among the sample pool, there were 80 empirical studies and 9 design cases. The research methods applied in empirical research include experimental, quantitative, qualitative, mixed method, survey research, and design-based research. Among them, experimental studies accounted for the majority (n=45), which commonly adopted the grouping method and explored the effectiveness of AR application in instruction by comparing the learning effect, learning attitude, and behavior pattern of learners in AR-based learning group and traditional group. The second was quantitative study (n=16), which did not adopt the form of grouping, but collected the quantitative data for analysis after students experienced AR. Qualitative studies (n=4) mainly collected data through interviews or observations. Mixed method (n=6) integrated quantitative and qualitative data. Survey research (n=4) directly obtained teachers' and students’ attitudes towards AR teaching through the form of questionnaire, and then analyzed its effect. It is worth mentioning that in coding, we especially distinguished design-based research (n=5) from design research (n=9). Because the former conducted further empirical research on the product performance or teaching effectiveness after product design, while the latter only referred to design and development of
systems or apps in education and the validity needs to be tested by empirical study in the future.

B. Instructional Contexts

We further tallied the number of studies by disciplines and key educational stages in Table 2. AR was commonly applied to teach the following disciplines: biology, physics, chemistry, geography, and astronomy. Moreover, a few studies (n=3) took place in science classes without specifying its disciplinary field.

TABLE II. DISCIPLINE DISTRIBUTION OF AR APPLICATION IN SCIENCE EDUCATION

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Primary education</th>
<th>Secondary education</th>
<th>Higher education</th>
<th>Mixed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics</td>
<td>5</td>
<td>9</td>
<td>6</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Geography</td>
<td>4</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Environment</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Chemistry</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Biology</td>
<td>12</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Astronomy</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>29</td>
<td>27</td>
<td>5</td>
<td>89</td>
</tr>
</tbody>
</table>

In primary education (Grade 1-6), AR was commonly used to teach biology. In contrast, there was no study investigating AR application in chemistry education since chemistry is not commonly offered in primary schools. In secondary education (middle school and high school), physics and chemistry were the common disciplines for AR-supported instruction. In most experiments of physics, AR was used in the learning process of electromagnetic knowledge. Zimmerman et al. (2016) [6] indicated that AR technology could solve the problem of insufficient laboratory equipment or difficult simulation of experimental conditions. For example, Kapp et al. (2019) [7] used paper props to simulate instruments on the circuit and used AR to present the movement direction of the electron motion. In most experiments of chemistry, AR was used to present three-dimensional chemical molecules. Additionally, Cai et al. (2014) [8] mentioned that AR-based instructional tools were more effective for students with poor grades. In higher education, AR has been an embedded feature of many experimental platforms that were used to facilitate a deeper understanding through open exploration and interactive simulation. For example, augmented reality sandbox provides real-time geographical terrain changes by projecting an electronic topographic map onto a traditional sandbox when students manipulate the sand [9]. Popular disciplines for AR application in higher education included geography, physics, and chemistry, while AR was rarely used in environment and astronomy education.

C. Instructional Design

1) Pedagogy

To explore the evolving trend in the pedagogy of AR-supported science education, we conducted a comparative analysis of the relevant AR literature based on time periods and educational stages. The results were plotted in Fig. 2. The most striking change was the booming popularity of direct instruction as the pedagogy for AR-supported science education. From 2001 to 2015, there were merely 4% of the published studies reporting AR interventions featured by direct instruction, whereas the proportion increased to 44% between 2016 and 2020. Additionally, collaborative learning was not as popular as expected, witnessing a 17% drop from the previous period. Subsequently, inquiry-based learning and game-based learning have also declined. We speculate that with the development of technology, AR applications were able to present instructional resources with greater fidelity and vividness, thus AR has been used more commonly to deliver instructional content directly. Furthermore, with the popularization of AR, the main terminals used by AR have changed from desktop computers to mobile phones and tablets, and combined with the implementation of education informatization, most schools can ensure that each student has access to AR equipment, making independent inquiry and learning more convenient.

![Pedagogies applied in AR-based science education. (a) Major pedagogies during the period 2000–2015; (b) Major pedagogies during the period 2016–2020; (c) Major pedagogies in different educational stages.](image)

2) Scaffold and Training

Due to the novelty of AR as an emerging technology, the importance of scaffolding needs to be emphasized during the learning practice. As a result, we analyzed the scaffolding design in AR-supported science education and presented the key findings in Fig. 3. It appears that teacher guidance and computer-based tools played an important role in primary and secondary education. However, students received guidance mainly through computer-based tools in higher education. It reflects that teacher still took a leading role when AR was introduced into science education in primary and secondary schools. While considering that college students in general have
stronger independent learning ability, they could carry out learning operations with computer-based tools. Yet, no matter in which educational stage, nearly half of the instruction in the research did not provide scaffolding, which might have left students confused during self-directed learning with AR applications, and likely deviated from the designed learning process.

![Scaffolding Mode](image)

**Fig. 3.** Scaffolding features in AR-based science education.

Furthermore, we examined whether teachers and students received relevant training before engaging in AR-supported instruction. The results show that a few studies (2.5%) mentioned teacher training. However, in many studies researchers took the role of teachers and thus had a certain understanding of AR. The majority of published studies (78.5%) had no professional training for students. Regarding some studies where the teacher would briefly explain how to use the AR equipment for 5-10 minutes, they were not considered as student training, as those studies were not dedicated to instructional phase to prepare students for the upcoming AR intervention. The lack of training before an AR intervention may result in greater barriers for students to use the AR equipment properly and get adjusted to the new mode of instruction, which may lead to unsatisfactory learning experience and poor learning outcomes.

**D. Technological Features**

1) **Human-computer interaction**

Since one of the characteristics of AR is real-time interactivity [1], this part aims at better understanding how human-computer interaction (HCI) is implemented in instruction. We collected various types of HCI used by AR and divided them into two categories: artificial and natural interaction, which were respectively represented by cool and warm colors in Fig. 4. Artificial interaction means that learners need to move, rotate, and scale AR content with the help of additional devices (e.g., mouse, controller, trigger image, and QR code). In contrast, natural interaction means that learners can interact with AR content directly through body motion, gestures, voice, position changes, etc.

As is shown in Fig. 4, in practical application, the scan was a common form of artificial interaction, while natural interaction had more diverse forms. In terms of trends, there was a slight increase in the artificial interaction (53% to 57%), with the overall proportion larger than natural interaction. We suspect that this was because of the ease of using technology for students. In other words, although the natural interaction could provide students with a better sense of authenticity, it might take students more time to adapt to the interactive way and induce a relative drop in confidence [10]. However, in the last period (2016-2020), new interactional ways (voice command and magnetic) added to natural interaction. Even though the number of these new ways was relatively small, it still reflected the innovation trend of natural interaction. Additionally, in order to simply categorized the developments of AR, modern-day AR was divided into two types: image-based and location-based AR [2], [3]. Whereas the data revealed that location-based AR has not been fully utilized as expected. On the contrary, image-based AR (interact by scan and motion) was highly valued.

![HCI (2001-2015)](image)

**Fig. 4.** The types of human-computer interaction (HCI) during interaction with AR object. (a) Major HCI during the period 2000–2015; (b) Major HCI during the period 2016–2020.

2) **Presentation medium**

We attempted to analyze the presentation medium in the use of AR from the perspective of pedagogy. Table 3 lists the number and proportion of common AR presentation mediums in different pedagogies.

The table shows that 3D objects and 2D image were still the most popular types of presentation medium. In the meantime, text also played an important role as a tool for conveying more detailed information. Regarding the impact of pedagogy on presentation medium, inquiry-based learning and direct instruction both extensively used mediums, but the role and requirements of medium were different. In inquiry-based learning, students interact (e.g., select, combine, splice, etc.) with the medium to obtain further processed information [11], [12]. In this case, designers and learners could less care about the details of mediums, and instead pay more attention to interaction and symbolic meaning. In direct instruction, the main role of presentation mediums was to present content and transfer knowledge [13], [14], therefore, the acceptability of knowledge and the quality of delivered content will greatly affect learning outcome. When practice-based pedagogy (Trial-error and experiential learning) was conducted, it needed to fully invoke presentation mediums to create an experiential environment and required students to respond in time. It was unexpected that in practice-based pedagogy, data was not taken
into account, even though data could give students a better grasp of their practice.

### TABLE III. PRESENTATION MEDIUM IN DIFFERENT PEDAGOGY

<table>
<thead>
<tr>
<th>Indicator</th>
<th>I*</th>
<th>G*</th>
<th>C*</th>
<th>D*</th>
<th>T*</th>
<th>E*</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text</td>
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<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Data</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>2D image</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>9</td>
<td>1</td>
<td>6</td>
<td>31</td>
</tr>
<tr>
<td>3D object</td>
<td>11</td>
<td>3</td>
<td>5</td>
<td>18</td>
<td>2</td>
<td>5</td>
<td>44</td>
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<tr>
<td>Video</td>
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<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Animation</td>
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<td>3</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
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<td>17</td>
<td>47</td>
<td>5</td>
<td>24</td>
<td>139</td>
</tr>
</tbody>
</table>

* I: Inquiry-based; G: Game-based; C: Collaborative; D: Direct instruction 
** T: Trial and error; E: Experiential learning

### IV. CONCLUSION

This study systematically reviewed 20 years of research on AR-supported science education in K-16. Based on the review results of 89 selected articles, tentative answers can be provided to the three research questions: (1) The research publication trends of the selected research studies revealed that AR is booming in science education. Moreover, AR is utilized in different disciplines according to different educational stages. (2) Inquiry-based learning and direct instruction were the two most popular pedagogies, while the latter had a booming growth. In terms of scaffolding and training in AR intervention, the instructional phase to student or teacher training was often either missing or briefly explained. (3) In artificial HCl, scan was the most important interaction mode, and the increasing types of natural HCI reflected the innovation trend of interaction. 3D object and 2D image were still the dominant forms of presentation medium. When combined with different pedagogy, the main functions and requirements of mediums were different.

Some practical implications for teachers and researchers also are furnished. Firstly, teachers should assess learning tasks carefully before adopting AR technology in teaching. AR is considered to be more suitable for concretizing abstract knowledge and substituting dangerous experimental equipment and materials with digital simulation. Secondly, AR is only one component of instruction that serves specific pedagogical purposes such as content delivery or digital simulation. We recommend combining it with traditional instructional approaches to maximize its learning affordances. Therefore, instructional designers still need to carefully design other key learning activities to integrate technology and teaching. Furthermore, scaffolding and training were recommended in AR implementation, thus the students’ identity could be enhanced from the recipient to creator in the iterative process. Finally, location-based human-computer interaction should also be emphasized, and it would be interesting to explore presentation mediums that stimulate multiple senses other than vision.

### ACKNOWLEDGMENTS

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### REFERENCES

An Explore of Virtual Reality for Awareness of the Climate Change Crisis: A Simulation of Sea Level Rise

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Abstract—Virtual Reality (VR) technology has been shown to achieve remarkable results in multiple fields. Due to the nature of the immersive medium of Virtual Reality it logically follows that it can be used as a high-quality educational tool as it offers potentially a higher bandwidth than other mediums such as text, pictures and videos. This short paper illustrates the development of a climate change educational awareness application for virtual reality to simulate virtual scenes of local scenery and sea level rising until 2100 using prediction data. The paper also reports on the current in progress work of porting the system to Augmented Reality (AR) and future work to evaluate the system.

Index Terms—virtual reality, climate change, environmental education, human-computer-interaction, augmented reality

I. INTRODUCTION

Climate change is accelerating, bringing the world ‘dangerously close’ to irreversible change [1] and even potentially affected the psychological wellbeing [2] of people around the world. However, large portions of the public still believe that global warming is not happening [3], and only a minority believe it will impact them and their families severely over the next fifteen years [4]. This has much to do with the fact that the effects of climate change are “gradual” rather than “immediate”, which may make people feel undecided or uncertain [5]. A substantial segment of the public ignore the urgency of climate change because of its inconspicuousness. This paper details a unique case study that has targeted a population where within 50 years their homes will be under water. This is within their or their children’s lifetimes so has a direct effect on them but still many are skeptical. It is hoped that through visualization in a VR application which dynamically simulates the sea level rise, finally it will become apparent how serious the problem is. For the families within this target group, this education will aid them in making the difficult but necessary decisions for their future and their children future.

Compared with traditional media and educational media, Virtual Reality (VR), as an emerging science and technology, has an incomparable capability of information transmission due to its immersive nature. In 2018, Markowitz, D. M. et al. [6] tested the efficacy of immersive VR as an education medium for teaching the consequences of climate change (Fig.1), and got positive results that displayed more positive attitudes toward the environment after comparing pre- and post-test assessments.

Fig. 1. Markowitz, D. M. et al. [6] are testing their project.

While Markowitz et al. tried to simulate an immersive underwater world to show the process and effects of rising sea water acidity, this work is targeted at a much more local level. Specifically a local residential area, Portrane (a seaside settlement located in North County Dublin, Ireland). The aim of this work is to give a Virtual Reality experience of sea level rising along the coast within the residential environment. This work mirrors work in VR [7] that has been used to highlight sea level rise in another coastal communities such as Santa Cruz, California.

Section 2 gives the development and implementation of the application. Section 3 will discuss the experiments so far that have taken place and the plan of future ones. It also highlights future work including a demonstration of an Augmented Reality application that was ported from the VR project. Conclusion will be given in section 4.

II. VR APPLICATION DEVELOPMENT AND IMPLEMENTATION

A. Application design with Unity3D and Oculus Quest

360° immersive video applications offer the potential to provide vivid experiences especially in Cultural Heritage ed-
ucation which has been proven in past studies [8], [9]. This project origins come from a 360-degree fixed scene that is combined with a 360 video and a simulated 3D ocean model (Fig.2). This initial demo was developed to illustrate the simple sea level changing at a fixed view point and it can run on both mobile and Head-Mounted Device (HMD) like Oculus Quest and provide elementary immersive scene. But the fixed point limitation could not provide an immersive experience and a large number of panoramic video shooting and complex simulation of sea level change would have been required for every new viewpoint, and this tech is less responsive, less interactive than virtual reality [10]. Therefore, we chose a VR application with virtual scenes as a better solution.

Users can pick any one of 5 point of interests to explore the virtual scenes, view the ocean level in specific year and learn about the corresponding ecological information (Fig.4 (c)&(f)) for each different point of interests. The information shows as text, audio and video, contains special local ecosystem, local characteristics, species, the impact of climate change and how to make environmental protection. The controlling of ocean level rise simulation is designed as a slider for a easy and dynamic show of the sea level height. Specifically, the slider bar is designed to be divided into 80 consecutive points, each of which represents a year and pass a value for which a simulation model of the ocean will take in and rise to its corresponding position, users can also directly jump to 2021, 2050 or 2100 using the buttons below the slider bar (Fig.4 (c)&(d)). In addition, a rotating compass is also added to the upper right corner of the user interface based on the geographical direction of the real world to indicate the direction in the virtual environment, helping users to better connect the virtual scene with the information in the real scene. Immersion in consideration, the lower left corner of the user interface adds a "hide UI" button, the user can at any time through the button to hide in addition to the button all the interactive interface, and click again to display, in order to in a selected years of rising sea levels scenarios to achieve better immersive experience.

Fig. 2. The 360-degree scene viewer based on punctuation video and ocean model.

This application is developed with Unity3D game engine [11] and can run on the Oculus Quest platform [12] (Fig.3). Oculus Quest 1 is the device used for development and it provides 1440 × 1600 resolution and the max offers a maximum refresh rate of 72fps. As a VR all-in-one headset machine, it doesn't need external computing or rendering support, but uses a Qualcomm Snapdragon 835 SoC with 4 GB of RAM (Three of the four 2.3 GHz CPU cores of the chip are reserved for software) and a Adreno 540 GPU to compute and render by its own, this is close to the graphics power of mid-low end mobile phones on the market. The controllers of Oculus Quest can provide all the interaction requirements in this application.

Five points of interests in the beach area of Portrane were picked to be included, and based on each a virtual scene with residential views was built. These points were chosen due to their previously identification as points of scenic beauty in the area. The home menu page provides a map with these 5 points of interests (Fig.4 (b)). The user interface interaction is based on the virtual laser that starts from the right controller and achieve the operations through the interactive buttons on the user interface pointed by the laser, in actual operation, users can achieve interaction by push button "A" on right controller when the laser hit the button on the interface.

Fig. 3. Using Oculus Quest Head-Mounted Device (HMD) to run the application and make interaction with user interface.

B. Scenes and Ocean Simulation with Geography Information System

For the sea level simulation of each point of interest, before generated the ocean model, this project combined the prediction data files with local Digital Elevation Model (DEM) in QGIS (an Open-source cross-platform desktop geographic information system), based on overlapping regions and geographical location coordinates to determine the results of sea level rise simulation (Fig.5).

Afterwards, on the generated terrain model with DEM, the texture from satellite imagery is added to help constructing the residential objects (Fig.6). Then with reference to local photos and the specific locations marked from satellite imagery texture, the buildings and plants of the community were
modeled and put on the terrain model to constitute the land models part. After land models were finished, the ocean models generated with animated sea surface visual effect can dynamically be changed to the position specific year from 2021 to 2100 generated according to the relative positions obtained from the geographic information system (Fig.7).

Finally, to achieve a fully integrated scene, additional relevant geographical and ecological information was added to the sub-panel, along with sound simulation of the changes in the sound of waves rising and falling with the sea level, which further enhanced the user’s sense of immersion. The importance of sound in human-computer-interaction is often ignored but critical when you are fully immersing a user within a virtual space [13].

III. EXPERIMENTS AND FUTURE WORK

Because of the Covid-19, only one initial feedback session was done with our council partners which included around ten people under strict COVID restrictions. The feedback season was in Fingal county council building in Swords, Dublin, Ireland and no participants tested positive for COVID subsequently, this does not definite prove that our safety regime was successful but helped advise us in our preparation for an experiment with both local residence and members of the public in the future. The feedback session used a
CX 1 CleanBox which uses Ultra violet(UV) light to clean a Head Mounted Display(HMD). The HMD’s used in this experiment where also pretreated with an Superhydrophobic nanoparticle solution that allowed them to be cleaned just using UV between users. All full experiment is planned in Q2 of 2022. This experiment will be conducted with local residents in Portrane to test whether they can have a clearer understanding of the climate change education and how their attitude towards climate change would change assisted by virtual reality, with the control group of individuals who will not be directly effected.

 Meanwhile, based on the user interface and the predicted geographic location information of ocean, an Augmented Reality mobile application is under developing now (Fig.8), it is also developed with Unity3D game engine and uses ARFoundation and Global Position System (GPS) to realize the plane detect and simulated ocean model placement in actual location of Portrane. The user interfaces and application structure logic are migrated from VR project in order to ensure the function consistency of the projects. This application will be tested in 2022 and further experiments will be conducted to allow for a comparison between the VR and AR versions of this application.

The experimental survey content is being designed in order to learn the advantages and disadvantages of such platform transplantation from user feedback, as well as what specific adjustments should be made to the user interface design at the human-computer interaction level to adapt to the operation scenarios of AR and VR respectively. Xuanhui Xu et al. [14] (Fig.9) designed a experiment questionnaire based on a project of achieving the conversion of a veterinary teaching workstation VR tool to mobile devices and initially explores the performance, this is a very good demonstration and can be used to conduct experimental investigations based on this design.

![Fig. 8. AR mobile application demo. (a) menu page of the app, (b) navigation function that can lead the user to the preset target position of selected point of interests, (c) ocean simulation function that generates the ocean model to cover the real sea surface to show the sea level rise prediction, (d) inherited from the VR version of the information display function.](image)

Fig. 8. AR mobile application demo. (a) menu page of the app, (b) navigation function that can lead the user to the preset target position of selected point of interests, (c) ocean simulation function that generates the ocean model to cover the real sea surface to show the sea level rise prediction, (d) inherited from the VR version of the information display function.

Fig. 9. Experiment questionnaire design from Xuanhui Xu et al. [14].

Uses this approach based on quantitative analysis of the feedback data, an evaluation will be then conducted to assess application applicability to help more intuitively bring the urgency of the climate change crisis to people who will be effect in the next 50 years.

**IV. Conclusion**

Education is critical to raise awareness on climate change [15], and to help the public understand sometimes quite complex concepts within Environmental Sciences, visualization is the key. This work has illustrated how an environmental AR/VR educational application can be created and how an initial feedback session was conducted during strict COVID restrictions.

Currently the next step for this project is to evaluate an AR version of the application and subsequently explore if VR and/or AR is a superior medium than other mediums for climate education.

**ACKNOWLEDGMENT**

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**REFERENCES**


Work-in-Progress—Developing an Undergraduate Geology Virtual Field Environment

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Abstract—This work-in-progress paper documents the development of a desktop-based virtual field environment (VFE) to enable students and park visitors to explore the geological processes that have shaped Rock Bridge Memorial State Park, Columbia, Missouri, USA. Our rapid design process utilized a suite of pre-existing tools, allowing greater focus on the intended learning goals. Prototype implementation revealed limitations on integrating assessment into the VFE and has guided further development utilizing the educational platforms ThingLink and Articulate Storyline. This VFE addresses a paucity in virtual scientific education experiences relating to regional geology within the US midcontinent.

Index terms—virtual field environment, public engagement, photogrammetry, geology, field trip

1. INTRODUCTION

Field education is a fundamental component of many undergraduate geology programs, ranging from short day trips to immersive multi-week courses. Learning in the field is considered highly valuable for students, resulting in cognitive gains in critical thinking and higher-order thinking skills while preparing students for their professional careers [1]-[3]. However, field education is not without limitations. Large class sizes, budgetary constraints, inclement weather, and inaccessible field sites have led to the cancellation and discontinuation of field education opportunities. Although the benefits of field education are generally agreed to outweigh the limitations [3], virtual counterparts to in-person field opportunities [4] afford students a place to digitally practice field techniques, listen to lectures in context, and explore places they could not otherwise visit [5].

The Department of Geological Sciences at the University of Missouri-Columbia has faced similar limitations over the decades when conducting a mandatory field trip to Rock Bridge Memorial State Park (RBMSP) for the introductory geology curriculum. Inclement weather, inaccessible walkways, and global pandemics have ultimately resulted in the field trip being substituted with a traditional lecture or canceled altogether. To counter this, we have developed a desktop-based virtual field environment (VFE) of RBMSP to address these complications while allowing for an interactive experience using pre-existing learning tools. Where the in-person field trip follows a linear path and progression of ideas, similar to that, we set out to create a self-guided inquiry-based VFE that allowed students to navigate freely through the park. This self-guided inquiry differs from virtual field trips (VFTs) that replicate the linear nature of in-person field trips [6]. Inquiry-based learning has been found to lead to increased comprehension of the material by presenting multiple modalities of content which can improve higher-order outcomes in geology [7]. In our approach, we combine the various modalities of information with an in-situ place-based focus to further enhance learner comprehension.

Our VFE leverages immersive technology using 360° images to recreate a 3D representation of the field site wherein students can explore overlain and interactive content. Moreover, the VFE is designed to meet an enhanced version of the learning objectives from the in-person field trip and replicate the learning experience of exploring the exemplar karstic system hosted within the crinoid-rich limestone of RBMSP. As with the in-person field trip, the VFE ties together important geological processes, such as depositional environments, paleontology, weathering and erosion, fluvial drainage, and karstic subterranean systems. Our student learning objectives include being able to (i) communicate what a fossil is and its importance to the formation of the host limestone; (ii) relate the underlying geology to the observed topographic features; and (iii) place the major geologic events involved in the formation of RBMSP in chronological order. Both the VFE and in-person field trip provide students with a broader context of the region, in space and time, by juxtaposing evidence of past paleoenvironments with present-day landlocked geography to improve student comprehension of landscape evolution in Deep Time. We posit that using a suite of pre-existing tools will enable us to focus on aligning higher-order objectives more efficiently to learner outcomes while reducing overall development time. Additionally, using local sites can improve exposure to geological concepts to inform beyond introductory courses and broaden public engagement. Herein, we document progress made towards developing a geology specific VFE and discuss the broader significance interactive technologies such as this have in communicating geological principles to a range of audiences.
II. DEVELOPMENT

Initial scaffolding of the VFE was developed in ThingLink (https://www.ThingLink.com), an online education platform specializing in interactive visual media. This platform hosts a series of 360° photographs from key stops throughout the park, forming the fundamental framework of the VFE. While usable with a mobile headset like Google Cardboard, we opted to focus on the virtual desktop option to better support the variety of content we embedded into the experience. Each stop consists of annotations, or ‘hot spots,’ including text descriptions, informational images, and embedded web content. Notably, ThingLink has incorporated Microsoft’s Immersive Reader to read aloud and automatically translate all text media within the VFE. In addition to 2D media, specimens of rocks and fossils commonly found within the park in the department’s collections were reproduced as 3D models using an in-house photogrammetry set-up.

While ThingLink can be embedded into learning management systems (LMSs), built-in assessments are limited to conditional short answer questions that must be answered correctly to advance through the virtual tour. Data regarding these answers are not stored within ThingLink and cannot be linked to an LMS (e.g., Canvas). We informally deployed a prototype of the VFE in Fall 2021 (owing to bad weather), wherein the ThingLink tour was embedded in a Canvas quiz and followed by a summative assessment. Upon opening ThingLink, students arrived on a landing page with a map, list of sites, and legend for ‘hot spots’ they were encouraged to investigate (Fig. 1).

The tour was unguided, and students could click on sites on the map to navigate to any location and explore, though the assessment was tied directly to specific locations. After selecting a site on the map, students arrived at a 360° image of that location containing multiple ‘hot spots’ (Fig. 2.) that included information to complete the assessment in Canvas. While we did not formally collect feedback from this prototype testing, we noted that the assessments within our ThingLink tour were insufficient to test student higher-order thinking to meet our learning objectives.

To address the assessment limitations of ThingLink and incorporate additional interactive and immersive content, we have utilized Articulate Storyline, an educational platform that can directly integrate into an LMS. Articulate Storyline enables us to provide stealth, formative, and summative assessments (Fig. 3.).

By integrating assessments within the VFE, we can create a more active, constructive, and authentic meaningful online learning experience [8] and allows for higher-order connections that can be lacking within VFEs [9]. By itself, Articulate Storyline is somewhat limited in its interactivity with 360° images, particularly with the functionality of annotations. Therefore, we opted to embed content from ThingLink to take advantage of the operational diversity afforded by the platform and the assessment capabilities of Articulate Storyline. Combining the two programs has formed the basis of our suite of pre-existing tools to rapidly develop an interactive VFE that incorporates multiple forms of assessment to accompany different interactive exercises.

III. OUTSIDE SIGNIFICANCE

The joint venture between interactive technologies and spatial sciences bridges the outdoor world and the classroom forgoing potential barriers imposed by in-person field trips. Several VFTs and VFEs have been developed to highlight geological and paleontological areas of interest across the United States and can be accessed through multiple repositories [10], [11]. However, many specifically showcase geologically...
complex areas or are associated with select institutions (i.e., museums or colleges). This gap in VFT/VFE offerings means students are limited to visiting sites that may be unfamiliar to them and exhibit no relation to their regional geology. Particularly for introductory courses, developing a sense of familiarity with ‘backyard geology’ should help to reinforce learning objectives by connecting knowledge obtained in the VFE to what students see every day in their surroundings. This idea of ‘backyard’ geology supports the underlying principles of place-based education that learners need to relate to concrete and identifiable facts over ideas [12]. While our VFE addresses the formal educational needs of the Department of Geological Sciences at the University of Missouri-Columbia, it also serves to bridge the geographic gap in the representation of VFE offerings across the US midcontinent [10]. Future work includes testing the VFE in a large introductory geology course and using the feedback to develop elements for an audience beyond formal education.

We intend to further extend the reach of the VFE to broader audiences to develop formal and non-formal educational resources that engage participants in learning that Earth’s surface and inhabitants change through time [13]. This is imperative in fostering the scientific literacy of our planet and its resources within our communities. In addition, because open-source VFEs are not limited by geographic location or accessibility, they provide a means of raising awareness concerning the significance of global geological and paleontological heritage.

ACKNOWLEDGEMENTS

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Workforce Development & Industry Training (WDIT)
An Augmented Reality Training Application for Service and Maintenance of a Medical Analyzer: A UX Approach to Usefulness and User Satisfaction

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Abstract—This paper presents an experimental study on a mobile augmented reality application for immersive training of field engineers in service and maintenance of a medical analyzer (AQT90FLEX). Based on approaches from user experience design, we developed an AR training application with the aim of high level of relevance, ease of use, usefulness, user satisfaction, and learnability. Sixteen field engineers from the multinational company Radiometer participated in the study. The procedure was divided into three iterative stages: design, prototype, and evaluation. The methods consisted of questionnaires, interviews, and co-creation. The questionnaire was inspired by the technology acceptance model. The findings revealed that all the field engineers expressed positive feedback in terms of being able to see, train, and practice on the AQT90FLEX analyzer. Especially the usefulness and user satisfaction were positively evaluated. This study also shows the importance of using mixed methods, both qualitative and quantitative approaches, in order to develop an AR training application for field engineers across the world.

Index Terms—Augmented Reality, UX, medical analyzer, technology acceptance, content analysis

I. INTRODUCTION

The accelerated evolution of augmented reality (AR) has brought forth new possibilities for developing innovative applications and has diversified the modalities of interacting with them. AR has become a fast-growing interactive technology for improved training and learning within various applications [1], [2], [3], [4]. AR blends real-world and digital information [5], with a live view of a real-world environment whose elements are augmented by computer-generated content, such as sound or graphics [6]. This combination of the real world and virtual world has been applied for a wide variety of functions, especially in education and health care [1]-[7]. AR can display a physical environment that encompasses learners with virtual interactive information, which could enhance learners’ perspective and sense in real-time interaction [7]. However, when designing AR applications, important user aspects sometimes are overlooked, which has already been problematized by other scholars [8] - [11]. One of the major challenges when designing AR technologies is to match the users’ motivation, attention, and interest with perceived usefulness, learnability, and user satisfaction within a very specific context [9] – [11]. This study is applied research with the following research question: How can a mobile AR application be designed and developed for immersive training of Radiometer’s field engineers in service and maintenance of AQT90FLEX medical analyzer with a high level of relevance, ease of use, usefulness, user satisfaction, and learnability?

The mobile AR application is defined as a minimum viable product (MVP) for online training experience for the field engineers at Radiometer to perform maintenance on the AQT90FLEX, an immunoassay analyzer. The AQT90FLEX analyzer is based on the quantitative determination of time-resolved fluorescence to estimate the concentrations of clinically relevant markers on whole-blood and plasma specimens to which a suitable anticoagulant has been added. It is intended for use in the medical industry, such as in point-of-care and laboratory settings. Radiometer is a Danish multinational company that develops, manufactures, and markets solutions within healthcare, especially blood sampling and other diagnostic tools. The company was founded in 1935 in Copenhagen, and today it has more than 3,200 employees and direct representation in more than 32 countries.

The Covid-19 pandemic has influenced the delivery of training for the service and maintenance of AQT90FLEX, being reduced from 5 days of face-to-face training to 5 hours of online training. The online training delivery led to a decrease in the quality of the training due to the lack of visual representation of guidelines for service and maintenance of the device and practical exercises. An AR application could bridge this knowledge gap and increase the functional and visual representation of the training materials, making it an online training experience that could replace face-to-face training even after the pandemic. In this specific context, AR can supply two significant advantages. First, the AR solution is capable of recognizing images immediately through the camera on a mobile device by focusing on the service and maintenance of AQT90FLEX. Second, the AR solution is capable of immediately projecting information concerning the service and maintenance of AQT90FLEX to provide visual help and guidance concerning the most important aspects. Potentially, the AR solution could even decrease the costs associated with the training; especially the travelling costs, as the field engineers are spread worldwide.
II. PREVIOUS WORK

A prevalent and significant number of use cases of AR technology is encountered in education and training across various subject areas in both a formal and informal context. There is significant research on AR capabilities within the healthcare industry, addressing the opportunities AR has, especially to improve or replace some conventional training methods [11], [12]. AR has been found useful and with strong affordances in healthcare education and training [4], [9], [13] due to its potential to make the learning process easier [12], decrease the time for training [19], provide trainers an outlet for assessment, and increase success rates [14]. Research has shown AR is cost-effective training in which everyone can practice real-world tasks [15], reduces human errors [17], provides feedback and navigation, provides remote assessment and training [12], and increases learners/employees’ engagement and motivation [20]. Research has already highlighted the importance of considering the user experience (UX) when designing and developing mobile augmented reality (AR) applications [8] - [11]. However, examples in the literature of a UX methodology used within an applied AR online training for internationally widespread field engineers are limited. The novelty in this study is the target group of geographically spread field engineers, for which the AR application needs to have highly accurate design details within a highly specific and complex training context. In the literature, UX is used as well as defined quite differently [8]-[9], with no coherent taxonomy. For this study, we define and apply UX within the ISO standard for human-centered design for interactive systems [21], in which the focus is on users’ perceptions and responses that result from the use and/or anticipated use of a system (in this case, the mobile AR application). The users’ perceptions and responses include their preferences before, during, and after use [21]. The UX approach also emphasizes the importance of the users of the technology, rather than designing the technology itself [29]. The usage, user perspectives, and benefits for industrial AR applications were already described back in 1997, when Azuma introduced potential AR applications, which also included service and maintenance [36]. Despite Azuma’s focus on the technology [36], there are some early interesting user elements in an AR technology context, such as simplicity, resolution, safety, no eye offset, and flexibility. Even more important might be the description of how to reduce complexity with the need to accept the fact that the AR system may not be robust and may not be able to perform all tasks automatically [36]. Due to hardware and software advances AR has been used more and more frequently, also in industrial contexts, including using HMD’s (Head-Mounted Displays), wearable smart glasses (e.g., Microsoft Hololens 2), and mobile devices such as smartphones or tablets [20, 37-39]. One of the most important takes from the past research in the context of service and maintenance, is the necessity for developing a mobile AR application. Service and maintenance are inherent as mobile and needs flexibility [36, 41], and requirements [36, 40]. We agree with Jetter al., [40] already pinpointing those studies in the field of industrial AR applications are focusing on single industrial process. This is also due to each of the respective industrial areas and single product phases having their own requirements, limitations and consequently performance driver [40]. Therefore, it is also important not neglect the users’ perceptions and responses that result from the use and/or anticipated use of an industrial AR application. The users’ perceptions are important as to improve the AR application/system with complex interactions, perceptions, interpretations, and learnings in various and broader contexts.

III. METHODS

A. Participants and Ethical Considerations

Sixteen field engineers voluntarily participated in this study. All the participants were from the Technical Service Department at Radiometer. The participants were from countries where Radiometer commercializes the AQT90FLEX analyzer. There were 12 participants from Europe, and 4 from Australia. All participants gave informed consent, and they were informed that they could withdraw from the study at any time. In addition, all participants were provided with anonymized ID numbers, and all data were labeled with these IDs. We applied special considerations when recruiting participants across countries, in accordance with the international code of conduct [22] and ethical approval from Radiometer.

B. Procedure

The procedure was divided into three stages: design, prototype, and evaluation. Each of the phases included different methods.

Design: A 20-item questionnaire that included 15 open-ended questions was developed with the purpose of identifying user characteristics. The questionnaire included demographic information, work experience, tool set skills, AQT90FLEX training experience, and preferred learning styles. All 16 field engineers replied to the design questionnaire. Furthermore, within the design process, seven field engineers were interviewed in depth to identify the possible features of and use cases for the AR training. At the end of the design stage, three co-creation sessions were conducted [23] with two groups (Group A had 3 participants, Group B had 5 participants), lasting 90 minutes each. Based on the questionnaire, interviews, and co-creation, there were outlined personas, application features, and design considerations.

Prototype: The prototype development was within an iterative process, and it included pilot testing, conducted with field engineers in Denmark (n = 6). The pilot testing included usability testing (with used observations and questionnaires) with a follow-up interview with discussions for improving the designed AR experience. The improvements especially included reduced waiting time in the application, text subtitles, implementation of a help menu, and minor bug fixes.

Evaluation: The evaluation of the application was conducted using a questionnaire and follow-up interviews (n = 7). The participants received a questionnaire for the assessment of the ease of use, visual interface, user satisfaction, learning outcome/usefulness of the AR application, and the application’s learnability. On 5-point Likert scale, the participants could choose between strongly disagree, disagree, neutral, agree, strongly agree. The theoretical framework behind the questionnaire was inspired by the technology acceptance model (TAM) [24] – [25], which emphasizes technologies and the ways users (in this case field engineers) come to accept and use (AR training) technology. The TAM suggests that when users are presented with a new technology, a number of factors influence their decisions regarding
how and when they will use it; notably, these include perceived usefulness and perceived ease of use [24], as well as satisfaction, and general perceptions [25]. Using TAM as in evaluation of AR tools for industrial applications is already performed by other scholars [40]. TAM can be used as an indicator of the users (AR-technology) acceptance, as the users only briefly interact with the application [24] in a pre-adoption process. The foundation in TAM is that ‘perceived ease of use’ and ‘perceived usefulness’ are antecedents of ‘behavioral intention to use’, which consequently leads to ‘usage behaviour’. Perceived usefulness is defined as the degree to which an individual believes that using a particular system would enhance his or her job performance [24], while the perceived ease of use is described as the degree to which an individual believes that using a particular system would be free of physical and mental effort [24]. The basic relationships of the TAM model have been well-investigated and validated by various meta-analysis [24, 25]. The questionnaire was followed by interviews with seven field engineers to gain further in-depth insights into their AR experience.

C. Data Analysis

Researchers analyzed the questionnaires using cumulative frequency (i.e., the total number of answers to specific questions). They analyzed the interviews using traditional coding [30], and content analysis [31]. The traditional coding followed four steps: organizing, recognizing, coding, and interpretation. They transcribed the interviews verbatim to be organized and prepared for data analysis. The researchers read the transcripts several times to recognize the concepts, which also included a general sense of the information and an opportunity to reflect on its overall meaning. There was found 17 themes. Researchers then categorized and interpreted each interview statement by following an interpretation and content analysis of positive and negative statements within each of the 17 themes.

IV. DESIGN AND IMPLEMENTATIONS

The AR application was built for both Android and iOS. For recognizing and tracking objects, we used the Vuforia AR [26] engine for Unity3D. Vuforia uses computer vision technology to recognize and track planar images and 3D objects in real time. The final application (Fig. 1) consisted of troubleshooting, hands-on library, and how-it-works features, as well as a video module. In this paper, we will focus only on the troubleshooting feature within the specific AR training for the AQT90FLEX analyzer.

The troubleshooting consisted of three steps: (a) retrieving and saving a service dump file, (b) determining the error code from the ACT90FLEX analyzer, and (c) inserting the code in the AR application (Fig. 2).

![Fig. 2. Interface of entering the error code.](image)

It took some effort to create an object for declaring the error code specifications (Fig. 3), which on a later stage should be used in the dictionary of objects to determine the displayed information (after the input of the error code). There was also included feedback, if the field engineer inserted a wrong/not recognized error code.

![Fig. 3. Error code specifications.](image)

After inserting the detected error, the application displayed the reason an error might occur as well as the service action needed. In this paper, we will follow error code 1267 as an example, accompanied by a service action involving a needle-wash procedure. Error code 1267 has 12 steps, each of which is an activity the field engineer should follow in solving the error. Each of the 12 steps can be individually played, and there is no dependency or need to wait for the animations to be finished before going to the next step. This freedom of movement between activities was considered to target specific steps in their training exercises or maintenance activities.

In Step 1 (Fig. 4), the field engineer using the AR training application was asked to open the back of the analyzer, provide a back view, open three screws at the top, and open two screws at the bottom, followed by some safety information.

![Fig. 1. Front page of the AR application.](image)
In some of the steps, the AR representation of the training activities included further information and helpful media elements (Fig. 5), including videos, text box instructions, 3D models, figures, tables, and pictures.

Most 3D models used were representations of the AQT90FLEX analyzer and its various parts (e.g., the inlet wheel and the needle wash unit; Fig. 6). Different independent 3D models were also implemented for use (e.g., the front cover, back cover, and screen). The lack of accuracy of the 3D models led to a time-consuming amount of work for some fixes to be implemented for improving similarity.

Other 3D models were easier to implement, such as the screwdriver, the tube, the cotton swab, and the recipient beaker (Fig. 7), which were freely accessible online and could be perceived being less context specific.

The overall design of the AR application was inspired by Donald Norman’s six UX design principles [28] including visibility, feedback, constrains, mapping, consistency, and affordance.

Visibility is about the users need to know what all the options are and know straight away how to access them. The AR application was developed to have the most important elements in sight when the field engineer was performing the training sessions. This could be with e.g., the screwdriver or cotton swab (Fig. 7) as within the training in step 1 (Fig. 4). However, this was also one of the most difficult design principles to implement, as the users’ preferences and context could be very different.

Feedback is the principle of making it clear to the field engineers what action has been taken and what has been accomplished. Therefore, we made it clear for the field engineers at which step they were at now, and what to do next. This was implemented in the AR application as “Step X of Y” in the lower-left corner of the screen (Fig. 4 and 5) and providing leftwards and rightwards arrows in order to indicate a moving step back or forward (Fig. 4 and 5). Further, there was indicated text of what to now, and what to next (within the specific step) (Fig. 4 and 5).

Constrains is about limiting the range of interaction possibilities for the field engineers to simplify the interface and guide them to the appropriate action. The constraints are clarifying, since they make it clear what can be done. An example of one of the constraints is the input of the error code (Fig. 2); which also provided a systematic procedure, process, and identification.

Mapping is about having a clear relationship between controls and the interactions and behavior. This was implemented in the AR application by clear icons, e.g., the leftwards and rightwards arrows (Fig. 8), and the “house” in the lower right corner for main/home menu (Fig. 8). Further, there was implemented an icon for troubleshooting and help support call in upper right corner (Fig. 8). The well-known icons allowed the field engineers to know where to go to.
Also, the home/front page (Fig. 1) with its structured and systematic approach in four boxes was designed to provide a clear mapping.

Consistency is about to restrict a particular form of user interaction with an interface. The consistency was implemented by having similar operations and similar elements for achieving similar tasks in the AR application. Different error codes followed the same overall stepwise procedure, and within the same design. This could potentially be very important, as this AR application was new, and not used and tried out before.

Affordance refers to an attribute of an object that allows people to know how to use it. Besides the implemented well-known icons in the mapping, we also provided a “how it works” (Fig. 1), a tutorial accessible from the front page. This was implemented in order to get the field engineers high affordances within this new technology development.

V. FINDINGS

A. Ease of Use, Visual Interface, User Satisfaction, Usefulness, and Learnability

The AR training application was positively evaluated. In particular, the usefulness and user satisfaction were perceived as high, both from the questionnaire results (Table 1) and the interviews (Table 2). The usefulness items in the questionnaire covered questions concerning perceived enhanced skill level of performing the tasks as well as whether the AR training application was a valuable training tool and whether the AR training could improve the skills transfer between experience and everyday work tasks. The usefulness had a mean of 4.3 (SD = .50) from the questionnaire (Table 1), and the user satisfaction had a mean of 3.8 (SD = .90) (Table 1). The user satisfaction covered questions such as, “I enjoy the time I spend using the AR training application,” “I am satisfied with how the activities are presented by the AR training application,” and “I would recommend this AR training application to my colleagues.”

TABLE I. FINDINGS FROM THE QUESTIONNAIRE (N=7)

<table>
<thead>
<tr>
<th>Items</th>
<th>Range (min-max)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of use</td>
<td>2.83 – 4.83</td>
<td>3.63</td>
<td>.55451</td>
</tr>
<tr>
<td>Visual interface</td>
<td>3.00 – 5.00</td>
<td>3.78</td>
<td>.55277</td>
</tr>
<tr>
<td>User satisfaction</td>
<td>2.00 – 5.00</td>
<td>3.81</td>
<td>.89925</td>
</tr>
<tr>
<td>Usefulness</td>
<td>4.00 – 5.00</td>
<td>4.33</td>
<td>.50000</td>
</tr>
<tr>
<td>Learnability</td>
<td>3.00 – 4.50</td>
<td>3.58</td>
<td>.46771</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>3.83</td>
<td>.595</td>
</tr>
</tbody>
</table>

It is interesting that in spite of the positive usefulness and user satisfaction ratings, the learnability was evaluated with the lowest score (M = 3.6, SD = .48; Table 1). The learnability was evaluated positively, but participants included further suggestions for improvement, including in the interviews. In the questionnaire, it also appeared difficult to ask the right questions within the learnability because the learnability comes with many individual preferences and specific context, which might be difficult to cover and answer in a questionnaire. The questions asked in the questionnaire concerning the learnability aspect were, “It takes too long to learn the functions in the AR training application,” “The AR training disrupted the way I normally like to arrange my learning/work,” “There is not enough information provided on the screen,” and “The AR application presents the information clearly and understandably”. The wording “too long to learn,” “disruption,” “normally,” and “enough information” might be very differently perceived as well as used/interacted with in various contexts. The ease-of-use item (M = 3.6, SD = .55) mainly covered questions concerning usability: understandable and ease to use buttons, icons, menus, settings, instructions, and error/mistake codes. The visual interface item (M = 3.8, SD = .55) covered questions concerning perceived visual interface consistency and the aesthetics of the interface.

The positive results concerning the usefulness and user satisfaction items were validated by the interviews. From the interviews, four themes within the usefulness item and three themes within the user satisfaction item were categorized, and participants made no negative statements within either the usefulness or the user satisfaction items (Table 2).

TABLE II. FINDINGS FROM THE INTERVIEW DATA

<table>
<thead>
<tr>
<th>Items</th>
<th>Themes</th>
<th>Negative</th>
<th>Neutral</th>
<th>Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of use</td>
<td>User flow</td>
<td>2</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>AQT recognition</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Content</td>
<td>8</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Visual interface</td>
<td>Aesthetics</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Animation</td>
<td>1</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Media</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>recommandation</td>
<td>0</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Text</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>User satisfaction</td>
<td>Content</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Enjoyment</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Media</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Usefullness</td>
<td>Multipurpose</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Accessibility</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Service</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Learnability</td>
<td>Learnability</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Despite the positive comments, the interviews revealed that the AR application could be improved, especially the ease of use and elements with the content as well as the advanced query tool (AQT) recognition. The comments for the content improvements mainly concerned difficult field engineering terminology, which in a few places was incorrect. The comments regarding the AQT recognition indicated a problem recognizing the medical device and identifying the optimal distance to keep from the device from triggering the recognition. The reasoning behind the
issues recognizing the AQT was the use of iPhones for testing that appeared to cause problems related to keeping the dimension ratio/animation accuracy. The interviews revealed the field engineers were generally positive about the AR application, especially the training for the AQT90FLEX analyzer because it is one of the most complicated machines. Further, almost all the field engineers expressed being more comfortable fixing the analyzer with the AR application because they rarely do maintenance on this specific analyzer.

B. User, Context and Technology

Interactions, perceptions, learning activities, and learning outcomes, can be revealed within three overall factors (user, context, and the AR system) as part of a user experience in the developed AR training application. In between the factors there are not only interactions, but also various perceptions and behaviors, learning outcomes dependent on some sub-elements within each factor. Fig. 9 shows a model of the factors and sub-elements revealed by the participants. The model is inspired from [32] and [44], also described within a user experience perspective. However, we have added to and modified the model with the user inclusion of learning styles, co-presence, interruptions, experience, involvement, novelty, aesthetics, technology acceptance and trust [33], and specified elements within the AR training system.

Another element frequently mentioned was a common accommodator and converger [34] learning style, with much emphasis on the hands-on:

“We tend to learn much faster when the hands-on experience is included in the training.” (FE: K1)

“I tend to actually like to try something before I step into the field.” (FE: A3)

“Some engineers learn by doing, not listening.” (FE: K2)

In the user category, some of the sub-elements that impacted interactions and perceptions include the degree of co-presence from others (how many and whom), the degree of motivation, mental state, emotions, attitudes, knowledge (e.g., IT skills and knowledge), expectations, involvement, novelty, aesthetics, technology acceptance and trust, and geography/cultural differences. It was commonly mentioned that doing service and maintenance training is not an isolated individual task, but can often be in co-presence and collaboration with others; both e.g., trainees (young professionals), help support, other employees, and clients. Involvement is a psychological state experienced as a consequence of focusing one’s energy and attention on a coherent set of stimuli or meaningfully related activities and events [35]. Involvement depends on the degree of significance or meaning that the individual field engineer attaches to the ongoing stimuli in the AR training. The involvement can though also be challenged by interruptions, e.g., phone calls, missing elements, or physical conversation interruptions.

The context of the training can be very different, including both remote and physical/location-based training, and be in different social contexts as well. The field engineers were very specific in terms of the different requirements they would like in the AR system; including e.g., the right objects, the ability to zoom in and out, a high degree of realism and quality, good usability, as well as the possibility for having it as shared experiences.

VI. LIMITATIONS

The main limitation of this study is the imperfect study design with a small sample size, lack of randomization, missing proper baselines, and the lack of control groups. In that regard, we had difficulties reporting the specific learning and training effects of the designed AR application. However, an imperfect study design is a very common limitation in many other AR training studies [1], [4], [16], [17], [18]. Future work is needed to create significant evidence of and insight into the training and learning outcomes of AR. The exact methods of interaction with the field engineers were difficult to describe in detail due to being within an iterative design process within a very context-specific AR application. Therefore, even though we followed a rather systematic methodology, it is difficult to repeat the study. Thus, we should be careful about concluding the cause of any effect was due to the AR technology. Further, as within many other experimental technology studies, we also need to consider the novelty effect. Many AR studies (including this one) are not longitudinal enough to exclude these novelty effects.

Many scholars across disciplines have used the Technology Acceptance Model (TAM) in many different contexts [47], [48]. In spite that the TAM model [24, 25] was useful in this study, there are some limitations towards the model, which should be
considered. One limitation of the TAM is the variable of user behavior, which is evaluated through subjective means like behavioral intention and interpersonal influence [45]. We mitigated this limitation and critique towards the TAM model by including not only TAM-questions in the questionnaire, and especially by used interviews. The interviews provided lots of further beneficial insights and complexity – in contrast to the simplicity of the TAM model. The insights from the interviews included (as it appears from the quotes) also some subjective reflections towards (engineering) norms and personality traits. Another limitation in the TAM is the missing external variables [46] like age, education, and skills, which was mitigated by asking for exactly those variables. However, with sixteen field engineers included in the study, one should be very careful of making statistical analysis on these external variables.

VII. DISCUSSION AND CONCLUSION

The existing literature on mobile AR training is covered within many design guidelines and frameworks, such as the mobile augmented reality education design framework [7]. However, there is often a lack of clear basis on learning theories [3], [11] combined with an approach or process to guide the design path [27]. We suggest taking greater advantage of UX approaches, including co-creation and other related methods to improve the AR training. With the developed AR training application in this study, all the field engineers expressed positive feedback in terms of being able to see, train, and practice on the AQT90FLEX analyzer. A reason for the positive evaluation of the AR training application, especially within the usefulness and user satisfaction items, could be due the high degree of effort to include the users (i.e., field engineers) at a very early stage and throughout the entire design process. Further, much effort was made to design the AR application based upon an explicit understanding of the users, tasks, and environments. In the literature, there seems to be some challenges with matching design ideas, implementation, and data quality in AR studies. The big question is how to incorporate elements concerning users, contexts, and AR systems, as well as gathering the right data for the research questions/theories within a new AR field of technological development. One of the major challenges when designing technologies for users is to match users’ motivation, attention, interest, and need with the context and technology. It is important to motivate the field engineers to use this AR training system on a more regular basis or as part of everyday work life. An important element in this motivation could be to continue the co-design of the AR training system with design input from the field engineers. Moreover, there could even be harder questions concerning ways to provide better research designs in a field/company context, where the given user groups come with diverse variables (e.g., motivation, learning styles, skills, or feedback opportunities). Even if one has the right data and a good research design, the data might still hide conclusions. This experimental study has shown an extremely complex AR training application for field engineers across the world requires mixed methods using both qualitative and quantitative data throughout the entire design process. Logdata, analysis of variance, high F-scores or standard deviation are not enough to understand in full the users’ perceptions and behavior in AR training facilitations.

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REFERENCES

Construction Workforce Training Assisted with Augmented Reality

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Abstract—As augmented reality evolves, many use cases for the technology have emerged in the construction industry. Training new practitioners in the industry is an ever-growing challenge because a significant number of seasoned practitioners are leaving the workforce. Every year the construction industry is faced with fewer skilled trade workers that can train their replacement. While construction students obtain most of their theoretical knowledge in the classroom, there is a lack of resources to instruct and train trade workers. Using augmented reality for instruction and training has many applications in other industries and can be used to approach the issues that the construction industry faces. In this research, a comparison was analyzed between construction management students that learned from two-dimensional paper construction drawings to those that used an augmented reality assisted instructional device. Both sets of students were instructed on how to properly layout and erect a wood framed wall. Overall findings indicated that the students that used the augmented reality device made fewer mistakes during the exercise than the students using the paper plans. Further, the researchers collected NASA Task Load information from the students to gauge their perceived effort using the augmented reality device. The findings indicated an increased performance perception with less overall effort during the study. These findings support a case for the use of augmented reality as a support tool for workforce training—especially at a time in the construction industry when there are so few to call upon to do the training.

Index Terms—workforce, training, construction education, augmented reality

I. INTRODUCTION AND BACKGROUND

In the construction industry, productivity is an important driver for the economic success of a construction firm. However, errors due to inexperience are the most prevalent [1]. While there are some errors that can be attributed to outside factors, practitioners that recognize training as a way of addressing the acute issues are often more successful [2]. Because of this, in the US, the industry suffers from falling productivity rates when compared to similar nonfarming industries [3]. Recent technological developments in computer-aided building information modeling (BIM) are providing new ways for others to understand the construction products of the built environment [4]. This technology is also useful for students of the built environment as they make associations between viewing modeled information and comparing that with what they are studying on two-dimensional (2D) paper construction plans. Pairing BIM technology with augmented reality (AR) allows students to view building information at a scale that they are unable to mimic unless they were on an actual construction project site. Visitation to construction project sites can often be challenging and a safety risk for the students [5]. At the moment the construction industry is demanding more qualified students (future practitioners) than are available. This need is difficult to satisfy when highly qualified practitioners are departing the industry faster than the new practitioners enter it; creating a skills gap that needs to be addressed. There is a fundamental resource issue concerning those that need to be trained and those that can do the training.

A. Extended Realities in Construction Education

The use of various extended realities (XR) such as virtual reality (VR) and augmented reality (AR) in construction education has intensified [6][7]. More recently, research with a concentration on workforce development is being examined by Wu et al. [8]. Their research is aimed at a solution for workforce development by using a team’s improvement as a gauge for success when using XR. While this will be an informative study when completed, a more individual focus (a single person) may be more informative about specific student learning outcomes and achievements—especially since academic achievement is comprehensively assessed at an individual level. Bogosian et al. [9] also realizes the importance of XR in educating the entering workforce. However, they are focused on a separate predicament, where the incoming workforce may be required to work with robots—something that has not been very successful with practitioners in the past. Nonetheless, they too recognize the importance of educating the incoming workforce as a way to resolve some of the impending workforce shortage issues.

There is a noticeable connection between observing a product of the built environment (buildings) and viewing those same structures using XR. A construction management (CM) student can absorb more information about what they are viewing than when the same content is expressed to them in a lecture or through reading [10]. When used in construction education, studies have shown that VR has the potential to;
create more interest in students by engaging them in an immersive environment, assist the student in understanding more complex problems without having to visit a construction project site, eliminate language barriers for international students, and allow the instructor to provide feedback on what the student is experiencing [11]. With these advantages, it becomes clear that this modality will enhance the education of CM students. It is intended by this research to further suppose that improving the education of CM students will also enhance their productivity as they become future practitioners of the construction industry.

One of the primary roles for construction practitioners is to supervise the ways by which the elements of a construction project come together. Often, these elements must be coordinated well in advance of their need to be installed in the finalized building product. This planning requires a significant amount of spatial and abstract thinking. Practitioners in this industry envision a three-dimensional product long before it has even started [10]. Training and exercising this spatial thinking can be supported by using XR [10][12].

B. Craft Training in the Construction Education

Conventional learning/teaching techniques that include notetaking, lectures, paper handouts, presentations, and concept memorization have proven ineffective [6] yet, educators continue because these are techniques and resources that they are familiar with. As far back 1969, it was recognized that learning by doing or by seeing is much more effective [13]. In so far as craft training is concerned, the role that experiential learning (learning by doing) has is invaluable. Introducing CM students to more hands-on activities are proven to be more effective for their learning [14]. Innovative ways of using XR are proven to be effective at introducing the impression of hand-on learning [15]. Therefore, the continual development of training tools that use XR technologies will be viable solutions to the challenges of a diminishing skillset in the industry.

A subject matter that often requires a skilled practitioner to train an incoming employee is in the work task of wall framing. The practice is common across most building types (commercial to residential) and the materials that are used are standard within the US construction industry. Wall framing requires interpreting the finished product from a 2D set of paper plans. The practice often combines the integration of unwritten procedures (commonly referred to as “knowhow” in American English vernacular) with well-established building codes. Aside from this, the practitioner must operate efficiently and safely and often must meet productivity goals. The parameters set forth by this work task are the study of many research projects concerning productivity and safety and usually incorporate the use of technology [16]. Trade specific terminology and an example wall frame that was used in this study are represent in figure. 1.

Fig. 1. Example of a wall framing exercise used in construction.

C. Rationale

The industry is experiencing a reduction of its skilled workforce [17]. The ramification of this decline is an overall reduction in the overall experience of the workforce which adversely affects the productivity of the industry [3]. Technology certainly is a way of tackling the problem, however, the industry is adverse toward adopting new technologies that do not seem to provide an immediate return on investment. The effort toward creating a technological solution seems paltry and historically since 2012, according to JB Knowledge [18] have not improved. Considering this formidable challenge, this research has been established to tackle the problem as CM students transition from students to incoming practitioners within the construction industry. It is surmised that if the process of educating the CM student can be improved through immersion in their learning activities, there will be a direct benefit to the productivity that the construction industry at-large experiences.

II. METHODOLOGY

The aim for this research was to assess the effectiveness of using AR as a tool to train CM students on wall framing layout. Layout is typically the first step of framing a wall in construction and the consequences of an incorrect layout will lead to lost productivity. An emphasis on proper training of wall layout is a customary entry level topic.

This research study was established as a between-groups experiment. Both CONTROL and TEST groups were trained by an in-person instructor on the procedures of proper wall layout. The study continued by separating the two groups and allowing them to complete the wall framing layout with different modalities. Each person in both groups completed the wall layout in private and were observed by the researcher.

A. Traditional Wall Framing – CONTROL GROUP

Individuals of the CONTROL group completed the wall framing layout by using 2D paper construction plans. This method was designed to mimic the traditional manner of
building by observing what can be interpreted from 2D paper plans. In this study, students entered a room with a blank bottom plate (refer to figure 1) and were asked to interpret from a 2D paper plan where the planned vertical wood studs, jacks, kings, and cripples would be attached. The attachment point for each element is marked with specific symbols on the top side of the bottom plate. The basis for making these marks is a partial understanding of regional building codes and some basic mathematics used to determine where and how many of each of the aforementioned elements are to be placed.

B. AR Assisted Wall Framing – TEST GROUP

Individuals of the TEST group used an AR assistive training tool to complete the layout. Similarly, the students would enter a room with a blank bottom plate. The primary difference (independent variable) for the TEST group students was the use of an AR assistive tool to complete the layout markings on the bottom plate. As the students viewed the bottom plate with the AR headset, they could see the indicators for where the marking needed to be placed. This visual was accompanied by audio instruction for how each marking is established along the bottom plate (see section II. C. for specifics regarding the AR training tool).

The results from each group were analyzed and compared for accuracy. Lastly, both groups completed a NASA Task Load [19] (NASA TLX) survey that collected the participant’s perceived workload during the experiment. The NASA TLX survey is a widely used instrument designed to subjectively assess workload (perceived effort) on six sub-scales (1) mental demand, (2) physical demand, (3) temporal demand, (4) performance, (5) effort, and (6) frustration. It was developed by the National Aeronautics and Space Administration Ames Research Center and its use in this research was to assess if the modality used by the CONTROL and TEST groups interfered with the learning experience in any way. It is documented in research that if technology is employed improperly, the technology itself can be a distractor in the learning experience [20]. Therefore, the results of a NASA TLX would be informative about the results from the between-group study. The overall workflow of the experiment is illustrated in figure 2.

C. Augmented Reality Training Tool and Content

While the CONTROL group used the 2D paper construction plans (see figure 3) the TEST group used an assistive AR training tool. The Trimble XR10 with HoloLens 2 was used in this study (see figure 4).

The Trimble XR10 form factor was designed to be used in the construction industry and mimics a construction hard hat that practitioners are comfortable using. The integrated HoloLens generation 2 allows the wearer to interact with the images that are displayed in the see-through holographic lenses. The wearer uses hand gestures to interact with the content being presented. Through the built-in speaker array the wearer will receive audio instruction during the experiment.

The content being presented in the HoloLens was authored by the researchers using Enklu, Inc. software. The Enklu platform enables a “drag-and-drop” interface for creating AR content. The researchers used this platform to create an interactive instructional interface that the wearer could use to guide them through the process of wall framing. The wearer received both visual and audio instruction during the time that they used the HoloLens. A sample of the AR environment is illustrated in figures 5 and 6.
The Trimble XR10 with Hololens 2 used by the TEST group (Trimble, Inc).

The Enklu software platform for creating the AR content.

A sample image of the AR experience used by the TEST group.

**D. Data Gathering**

Both groups were assessed for accuracy in their placement of markings on the bottom plate. After each person in both the CONTROL and TEST groups completed their work, the researcher would score the results of the student’s markings on the bottom plate. A complete layout required that the students accurately mark 20 positions (steps) along the bottom plate at the correction location based on the 2D plans or the AR visualization and their interpretation of the local building code. The score for each marking was binary, either correct or incorrect.

**III. RESULTS**

The participants in this study included CM students from a post-secondary institution in a 4-year construction management program. The students in this program were requested to volunteer as a part of one of their regularly scheduled CM classes. This convenience population was selected for their limited experience with wall framing – making them ideal as candidates that would soon enter the workforce and need some additional training from more seasoned practitioners. Twenty-two students participated with the following characteristics (see Table I).

**TABLE I. PARTICIPANT DEMOGRAPHICS**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control Group n=9</th>
<th>Test Group n=13</th>
</tr>
</thead>
<tbody>
<tr>
<td>GENDER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>100%</td>
<td>76.92%</td>
</tr>
<tr>
<td>Female</td>
<td>0%</td>
<td>15.38%</td>
</tr>
<tr>
<td>No Answer</td>
<td>0%</td>
<td>7.69%</td>
</tr>
<tr>
<td>ACADEMIC YEAR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Year (Junior)</td>
<td>78%</td>
<td>61.54%</td>
</tr>
<tr>
<td>4th Year (Senior)</td>
<td>22%</td>
<td>38.46%</td>
</tr>
<tr>
<td>EXPERIENCE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall framing exp.</td>
<td>2.67</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Note: “Experience” was self-reported on a scale of 1 to 10. 10 was considered “most” experienced.

The wall framing experiment was assessed based on the accuracy of completing each of 20 steps during the wall framing exercise. In table 2, the accuracy of those steps is tabulated by each group. The percentages represent the accuracy on a scale of 0% (completely inaccurate) to 100% (perfect accuracy).

**TABLE II. EXPERIMENT ACCURACY RESULTS**

<table>
<thead>
<tr>
<th>Step No.</th>
<th>Layout Description</th>
<th>Control Group n=9</th>
<th>Test Group n=13</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stud Marking 1 (Start of Wall)</td>
<td>67%</td>
<td>69%</td>
</tr>
<tr>
<td>2.</td>
<td>Stud Marking 2 (Wall Corner)</td>
<td>44%</td>
<td>92%</td>
</tr>
<tr>
<td>3.</td>
<td>Stud Marking 3</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>4.</td>
<td>Door Opening King Stud Marking 4</td>
<td>44%</td>
<td>46%</td>
</tr>
<tr>
<td>5.</td>
<td>Door Opening Jack Stud Marking 5</td>
<td>67%</td>
<td>54%</td>
</tr>
<tr>
<td>6.</td>
<td>Cripple Marking 6</td>
<td>67%</td>
<td>100%</td>
</tr>
<tr>
<td>7.</td>
<td>Cripple Marking 7</td>
<td>67%</td>
<td>100%</td>
</tr>
<tr>
<td>8.</td>
<td>Cripple Marking 8</td>
<td>44%</td>
<td>92%</td>
</tr>
<tr>
<td>9.</td>
<td>Door Opening Jack Stud Marking 9</td>
<td>67%</td>
<td>54%</td>
</tr>
<tr>
<td>10.</td>
<td>Door Opening King Stud Marking 10</td>
<td>56%</td>
<td>54%</td>
</tr>
<tr>
<td>11.</td>
<td>Stud Marking 11</td>
<td>56%</td>
<td>100%</td>
</tr>
<tr>
<td>12.</td>
<td>Window Opening King Stud Marking 12</td>
<td>56%</td>
<td>54%</td>
</tr>
<tr>
<td>13.</td>
<td>Window Opening Jack Stud Marking 13</td>
<td>56%</td>
<td>54%</td>
</tr>
<tr>
<td>14.</td>
<td>Cripple Marking 14</td>
<td>56%</td>
<td>92%</td>
</tr>
</tbody>
</table>
Lastly, the NASA TLX data was collected from each participant in both groups and an improvement percentage was calculated between the CONTROL and the TEST group’s perceived effort during the experiment. Those results are tabulated in Table 3.

<table>
<thead>
<tr>
<th>Step No.</th>
<th>Layout Description</th>
<th>Control Group n=9</th>
<th>Test Group n=13</th>
<th>Improvement Percentage Test - Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>Cripple Marking 15</td>
<td>56%</td>
<td>92%</td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Cripple Marking 16</td>
<td>60%</td>
<td>92%</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Window Opening Jack Stud Marking 17</td>
<td>78%</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>Window Opening King Stud Marking 18</td>
<td>67%</td>
<td>46%</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Stud Marking 19</td>
<td>22%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>20.</td>
<td>Stud Marking 20 (End of Wall)</td>
<td>67%</td>
<td>92%</td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL    | 60%               | 77%               |                                       |

Note: Each subscale is measured between 0 and 10. The highest perceived effort is rated at 10.

IV. DISCUSSION

A review of the data contained in Table 2 reveals that overall, the TEST group (77% accuracy) performed better than the CONTROL group (60% accuracy). In most of the steps (steps 1, 2, 4, 6, 7, 8, 11, 14, 15, 16, 19, and 20) the TEST group outperformed the CONTROL group. However, the CONTROL group outperformed the TEST group in steps 5, 9, 12, 13, 17, and 18 and this is where this analysis will focus. The results in steps 12 and 13 are only marginal and it could be argued that in those steps the performance was inconclusive between the two groups. However, in the remaining steps (5, 9, 17, and 18), the CONTROL group was convincingly successful. The common factor with each of these steps is that they occur where an opening was being framed in the wall. Step 5 begins the opening of a door and step 9 ends the opening of that door and steps 17 and 18 frame the opening for a window. In the course of this experiment there was no additional data collected to make a determination for why this would occur. The researchers noted that the conditions for marking the door and window openings in this experiment may have been confusing since a full representation of the finished wall was not included in the AR experience for the TEST group. Conversely the CONTROL group had a fully detailed 2D paper plan that they could use to compare the required finished product. The difference between the two instructions may have led to a confusion about what to mark in the wall frame layout. Refer to figure 7 that compares the representation that each group would have observed.

In figure 7, “A” illustrates a part of the 2D paper plans that the CONTROL group would have used to layout the wall. The door and window are clearly visible in the image that the students would have used during the layout experiment. However, in “B” the holographic image that the TEST group would have seen only shows the points that need to be marked without an indication that there may be a door or window at the location of the desired mark. This may have led to a higher accuracy score for the CONTROL group.

The overall results of the experiment are further supported by the data analyzed from the NASA TLX survey at the conclusion of the experiment. As noted in Table 3 in all instances the TEST group perceived less effort during their experience with the AR training tool. The positive “Performance” metric in the NASA TLX results is to be interpreted as the TEST group perceiving a higher level of performance over the CONTROL group. These findings wholly support that the AR experience was not perceived by the students as a distraction during their work task and ultimately during their learning.

The results of this experiment should be tempered by the realization of some limitations. A chief limitation when using AR is ambient lighting. This study did not measure or control for lighting conditions. The experiments were conducted inside and therefore sunlight, that can often be detrimental to the AR experience was not a factor in this study. It should be considered in future iterations of this research because most construction work occurs in an outdoor environment. The study was conducted in a short amount of time and with a very controlled group of students. In the future, the population pool should be expanded and a more diverse set of students representing varied experiences, backgrounds and ages should be used. Furthermore, a definitive generalization based on a population of 22 students (N=22) cannot be made. Increasing the population would allow for a detailed statistical analysis that may yield different results, however, this study does serve as a good basis for continuation of a larger research effort.

V. CONCLUSION

There are many methods available for assessing the pedagogical effectiveness of using technology in the classroom. Not all technology is beneficial to the learning process and therefore examining the distracting effects of using technology should accompany studies such as the one presented in this paper. The findings in this paper, while limited in their
significance because of a small population, demonstrates how observing the perceived effort that the students experienced with the AR tool can validate the results. Previous studies [10] have also supported this notion and have been confirmed by this study. This study leads researchers in an optimistic direction regarding the use of this exciting new technology. This optimism is also well placed especially a time when AR technology is readily available to the general public. Content for the AR experience is crucial, and through software vendors such as Enklu, Inc, which was used in this study, the variety of AR applications for education is expanding.

The results from this study are promising for the use of AR in the construction management classroom and can serve as a benchmark for any discipline that chooses to introduce AR technology as a part of the student’s learning experience.

REFERENCES

Recommendation Tool for Use of Immersive Learning Environments

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Abstract—In the field of immersive learning, instructors often find it challenging to match their pedagogical approaches and content knowledge with specific technologies. Unfortunately, this usually results in either a lack of technology use or inappropriate use of some technologies. Teachers and trainers wishing to use immersive learning environments face a diversity of technological and pedagogical alternatives. To scaffold educators in their planning of immersive learning educational activities, we devised a recommendation tool, which maps educational context variables to the dimensions of immersion and uses educators’ contexts to identify the closest educational uses. Sample educational activities for those uses are then presented, for various types of educational methodologies. Educators can use these samples to plan their educational activities in line with their current resources or to innovate by pursuing entirely different approaches.

Index terms—immersive learning, immersive environments, recommendation tool

I. INTRODUCTION

Due to the recent COVID-19 pandemic situation around the world, society is more aware of the advantage of and dependence on digital technologies, experiencing a unique evolution of digital maturity, as reported in newspapers [1], and in reports of advisory bodies and think tanks [2–3]. Society has also embraced more disruptive technologies in traditional domains, such as training and education, including virtual, mixed, extended, and augmented reality (VR/MR/XR/AR) [4], commonly considered as immersive technologies that present vast potential for simulations of activities in the physical world, as they become less expensive and more diversified. These technologies can also be of paramount importance to foster higher order thinking skills such as students' autonomy, collaboration, active learning, and emancipation. It is thus essential to clarify how we can benefit from them in education, considering, as Elmqaddem argues, that “when applied properly, these technologies can create enhanced contemporary educational environments and enriched learning opportunities” [5]. A wide range of devices, including wearables, support the use of immersive environments and stimulate different senses and emotions, which may be relevant features for training and education contexts [6]. This has been changing instructional scenarios, creating unique opportunities [7]. However, a critical challenge is identifying suitable methods to deliver these courses for the educational or training purposes and objectives defined [8].

Considering the entire mixed reality spectrum, it is possible to find different approaches, each presenting its pros and cons depending on a variety of factors. In line with this, instructors often do not know how to leverage immersive technologies to implement immersive learning environments. An immersive learning environment (ILE) considers three dimensions of immersion: one is the feeling of presence within a space provided by immersive technologies, another is the psychological absorption provided by narrative aspects, and yet another the psychological absorption originating from mental engagement while exerting agency, such as completing challenges, making decision, or collaborating with others [26].

Further, ILEs need instructors to ponder other aspects, such as where or how to collect/generate educational material, or how to plan and deploy innovative training/educational courses based on immersive technologies. There is also a lack of knowledge on how to leverage existing technological capabilities with the common low technical skills possessed by most instructors. “The balance between the required efforts and expected benefits provides presumably the basis for decision-making on the implementation of simulation-based training” [9]. Selecting suitable approaches for a specific instructional context is critical to guarantee the program’s success.

In this paper, we present the prototype of a recommendation system as a decision-support tool to minimize these barriers to the adoption of immersive environments in education and training. It employs a questionnaire to capture the educational or training context in terms of its resource constraints and objectives, i.e., following Kloke & Thoben’s suggestion of balancing efforts and benefits [9]. The tool then situates this context on the conceptual space of uses of immersive environments and locates the types of educational uses closest
to that context. For those, sample educational practices are provided for four different educational approaches. These can be used by the instructor as inspiration and guidance to plan their courses leveraging ILEs.

II. BACKGROUND

A. Technology Integration into Instruction

Integrating technology into instruction is not easy for instructors. Technology integration literature contains multiple accounts of its scarcity, or obstacles to integration, or the lack of effects on student learning. Why is this so difficult? Mishra & Koehler [10] suggest that technology integration is a ‘wicked problem’. Wicked problems are unique, often containing contradictory or incomplete requirements, and situated in complex social contexts [11]. Solutions often require the use of expert knowledge to author solutions which will achieve a good outcome. Therefore the mere use of technology in the classroom most often results in no change in outcomes [12].

Instructor technology integration involves much more than software and hardware fluency - it requires a grasp of interconnections between students, technologies, and pedagogical practices. Specific technologies have affordances, or strengths, that work best in specific social contexts, with specific users, pedagogical methods, and academic content. Also in the domain of technical training, the balancing of effort and benefits is complex, depending on many diverse factors: training risks, training availability, performance transparency, training adaptability, technological limitation and financial limitations: capital costs, recurrent costs, training costs [9].

The COVID-19 pandemic has greatly increased interest in the use of technology in education. Instructors have been forced to adopt either a fully online or blended instructional approach. Fortunately, research has produced several evidence-based models for technology integration, including the Technology, Pedagogy, and Content Knowledge Model (TPACK) [13], Technology Integration Matrix (TIM) [14], Replacement, Amplification and Transformation (RAT) [15], and the Substitution, Augmentation, Modification, and Redefinition (SAMR) model [16]. However, although these models have been helpful to a minority of instructors, many do not utilize them due to a variety of reasons, including time constraints, unavailable resources, inadequate instructions, need for training and support, and fear of technology [17], [18].

The nature of technology integration as a wicked problem and the lack of use of technology integration models point to the need to scaffold teachers in their technology integration [19] through the development of a recommendation tool for technology integration into instruction.

Instructors using immersive environments face a similar version of the challenges of integrating technology into instruction. These are found in three major categories: access to immersive environments; producing immersive content; and deployment [20]. Two recent surveys provided insights on this. One was a worldwide survey of the Immersive Learning Research Network (iLRN) community that ranked as a research priority deployment (linking immersive environments with learning systems or tasks) and content production by non-technical users, [8]. Another was a survey of experts on training with virtual reality (VR) [11], which also identified deployment and end-user content production as decisive factors. This survey also identified an access factor: hardware for smaller organizations. This emphasis on deployment factors also matches the literature on the wider challenges of integrating games in education: they are hard contexts for teachers to plan time allocation and tasks, plan students’ activities, be aware and keep track of students’ activities, and orchestrate learning (e.g., by assessment and feedback) [21].

B. Immersion Dimensions and Usage Clusters of ILEs

The integration of immersive environments into instruction requires an understanding of the concept of immersion, often left undefined in technology-centric literature. The past several decades provided two main approaches to understanding immersion, either as an attribute of a technical system [22] or as a psychological state based on an individual’s perceptions [23]. Recent reviews by Agrawal et al. [24] and Nilsson et al. [25] demonstrated these two approaches lacked important dimensions of immersion from the literature in other areas, such as narrative, the ability to create “a degree of mental absorption or intense preoccupation with the story, the diegetic space, and the characters inhabiting this space” (ibid.); and the challenges one faces, leading to “absorption brought about by the experience (...) requiring mental or sensorimotor skills” (ibid.). Nilsson et al. conceived of narrative, challenges, and technology along three dimensions of a conceptual cube - the immersion cube framework.

Beck et al. [26] used this approach to immersion and situated the uses of immersive environments for learning within Nilsson et al.’s immersion cube framework. Although there are many ways to interpret and organize instructional uses of immersive environments, the authors provide an inductively derived list that can be used to better understand the intersections of the different types of immersion (e.g., technical, narrative, and challenge) and various instructional uses. They found 16 use typologies or simply “uses”, grouped under six different clusters found along the three axes. We are employing Beck et al.’s [26] sixteen uses as mapped into Nilsson et al.’s immersion cube framework in the development of this tool, as described in the next sections.

C. Pedagogical Practices

There is a wide diversity of pedagogical practices adopted by educators. Torres et al. proposed a global taxonomy of educational processes for higher education [27], providing a framework for combining pedagogical work modes, learning approaches, and assessment types. Thus, it supports pedagogical planning by enabling educators to integrate teaching, learning, and assessment, guiding reflection on educational strategies.

In this work, we selected from that framework four combinations, representing pedagogical methodologies that are commonly used in education and training (Table 1).

Learning is a complex process that can occur in different ways and according to various objectives. So, we recommend that an educational strategy be specified for each use of the immersive training platform. To do this, it is necessary to define the expected learning outcomes and objectives, target
population, material and technical conditions, and assessment procedures [28] [29].

<table>
<thead>
<tr>
<th>TABLE I. EDUCATIONAL APPROACHES USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expository method</td>
</tr>
<tr>
<td>Interrogative method</td>
</tr>
<tr>
<td>Demonstrative method</td>
</tr>
<tr>
<td>Active method</td>
</tr>
</tbody>
</table>

To facilitate this task, we create a single set of questions:

1) Define the expected learning outcomes and objectives: what to know, know-how, know-how to be, and for what purpose (knowledge, skills, attitudes)?

2) Define target population: what are the needs and expectations of individuals, the characteristics of their initial profile, previous levels of knowledge, and experience?

3) Provide for material and technical conditions: where, for how long, by what means? What VR system(s) (and AR) are expected to be used, and in what way?

4) Predict the evaluation training: how will the achievement of learning outcomes be demonstrated? (Results?) How will the training quality be evaluated? (Satisfaction?)

III. METHODS

To create a recommendation tool, we started by considering the instructional context regarding the various categories of challenges mentioned above: access, production, and deployment. This was done by developing a questionnaire on several aspects of these challenges, based on empirical and theoretical knowledge [30]. A tentative form was developed, with a set of questions matching aspects of the categories, asking instructors to respond on a Likert scale how they relate to each aspect. This questionnaire was then subjected to expert feedback [30], leading to correction and changes, over several iterations.

Given the lack of literature on a right vs. wrong approach to employ immersive learning environments (as mentioned in the background), we determined that the existence of accounts of use in the literature would provide a practitioner perspective on how to use them. First, because the existence of such a cluster of uses indicates that researchers and practitioners have considered its feasibility. And second, because those same accounts indicate that an instructor can readily locate and use them for guidance and inspiration.

Thus, the next step in developing the tool was establishing a relationship between the instructional context and the usage clusters. We followed Beck et al.’s approach of interpreting this within the immersion cube framework [25]. We conducted an inter-rater vetting process [31] to establish relationships between the questions in the previous questionnaire and the dimensions of immersion, debating divergences between raters until consensus was reached. The raters for this process were the six researchers who are authors of this manuscript, who possessed both technical and pedagogical expertise in the area of immersive learning. For instance, if a rater would find that there was not relationship between a question on available time for activity planning and the Narrative Immersion dimension, it would be established as zero (0); if that rater would find the relationship to be direct (i.e., the more time to plan, the more narrative), it would be established as one (1). And if that rater would find that relationship to be inverse (i.e., the more time to plan, the less narrative), it would be established as negative one (-1). We then multiplied these relationship factors by the Likert responses about the instructional context, added them for each immersion dimension, and then scaled this to the 0-1 range. This process enabled us to reach a set of three values situating the instructional context alongside each of the axes of the immersion cube framework. Beck et al.’s “use clusters” are also situated in this cube framework, so we can directly measure the distance between each use cluster and the instructional context as a Euclidean distance, as described in the next section. This enables ranking the use clusters per proximity to the instructional context according to the immersion cube framework.

Finally, to support teachers and trainers in deciding how to consider those uses for their pedagogical preferences, we provided a matrix of examples across four main educational method categories (Expository, Interrogative, Demonstrative, and Interactive, see section 2.3).

This tool was then tested with several different instructional scenarios: two cases within our research group (welding training and remote consultancy), three from the EIT Manufacturing pilots (Energy, Food and sustainability, and Escape Game Tank Problem), and one from a masterclass at the Future of Learning 2021 conference (onboarding process of a company). These tests consisted in asking a volunteer trainer in each case to consider an instructional scenario for which he/she required support planning how to employ immersive learning, and then employing the tool, following its various phases. We discussed with the respondents their perspective and opinions during the various phases, to collect feedback about the process and the results.

IV. RESULTS: THE RECOMMENDATION TOOL

Following the method presented in the previous section, the recommendation tool follows the workflow presented in Fig. 1. First the teaching/training context is identified via a questionnaire; then that context is situated within the immersion cube, and its distance to known uses of immersive learning is measured. The uses are then ranked by proximity, and the three closest ones highlighted. For each use, the instructor can then access a matrix of examples of their application using different pedagogical approaches. These can then be used to inspire instructor practice or educational planning.

For Phase 1 (Instructional Context Identification), we employed the questionnaire, with each question related to the immersion dimensions, as described in the previous section, as shown in Fig. 2. As an example, the fourth question in Fig. 2
focuses on the learner’s level of experience with the planned learning content. The interrater process resulted in no relation between this aspect and System immersion (uses of immersive environments where the learner feels present within an environment), meaning our raters agreed that this aspect will not impact the level of system immersion recommendation. However, the interrater process revealed a direct relationship to Challenge-based immersion. This means that the tool will recommend that if learners are more experienced with the subject matter content, then the instructional context should be closer to uses of immersion that leverage challenge aspects more, i.e., activities that require learners to interact more, to engage more, to be absorbed in tasks.

TABLE II. SAMPLE QUESTIONNAIRE RESPONSE AND MATCHING OUTCOMES FOR EACH DIMENSION

<table>
<thead>
<tr>
<th>Question aspect</th>
<th>Sample Answer</th>
<th>System</th>
<th>Narrative</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time available</td>
<td>1</td>
<td>0 x 1 = 0</td>
<td>1 x 1 = 1</td>
<td>0 x 1 = 0</td>
</tr>
<tr>
<td>Depth</td>
<td>1</td>
<td>1 x 1 = 1</td>
<td>1 x 1 = 1</td>
<td>1 x 1 = 1</td>
</tr>
<tr>
<td>Duration</td>
<td>2</td>
<td>0 x 2 = 0</td>
<td>0 x 2 = 0</td>
<td>1 x 2 = 2</td>
</tr>
<tr>
<td>Learner's experience</td>
<td>3</td>
<td>0 x 3 = 0</td>
<td>-1 x 3 = -3</td>
<td>1 x 3 = 3</td>
</tr>
<tr>
<td>TOTAL</td>
<td>—</td>
<td>0+1+0+0 =1</td>
<td>1+1+0*(-3) = -1</td>
<td>0+1+2+3 = 6</td>
</tr>
</tbody>
</table>

Conversely, the interrater process established an inverse relationship to Narrative immersion. This means that the tool will recommend that if learners are more experienced with the subject matter content, then the instructional context will be farther from uses of immersion that leverage narrative aspects less. For clarity, this could be expressed more concisely – if learners are less acquainted with the subject matter content, narrative and story would be recommended activities compared to challenge-based activities; and if learners are more familiar with the content, challenge-based tasks would be recommended over story and narrative explanations.

The responses to each item in the questionnaire, graded as a 1-5 Likert scale, are multiplied by their System, Narrative, and Challenge relationship values. For instance, if an instructor answers the four sample questions of Fig. 2 as 1, 1, 2, and 3, respectively, this is multiplied by the factors in that figure and will yield the results in Table II. In this example, the coordinates (System, Narrative, Challenge) are (1,-1.6).

The minimal results for each dimension occur if an instructor responds “5” to all questions with a “1” factor, and “1” to all questions with a “1” factor. The maximal result occurs if an instructor responds “5” to all questions with a “1” factor and “1” to all questions with a “1” factor. In the sample case of Fig. 2, this would mean the following ranges for the possible outcomes: System [1..5]; Narrative [-3..9]; Challenge [3..15]. In our tool, considering all questions and factors, actual ranges are mapped into a three-dimensional unit cube. Thus, these ranges are scaled to [0..1] in order to achieve coordinates within the immersion cube, using Equation 1. This enables the teaching/training context coordinates to be identified, using Equation 2.

Normalized immersion dimens. = \frac{\text{Questionnaire immersion dimension}}{\text{Max. dispersion of the dimension}} \quad (1)

Teaching/Training Context = (Normalized System, Normalized Narrative, Normalized Challenge) \quad (2)

Phase 2 from Fig. 1 initiates, “Ranking Uses by Proximity”. The proximity of the Teaching/Training Context to each Educational Use is then simply a matter of calculating its Euclidean distance using Equation 3: “x”, “y”, and “z” represent the Normalized System, Narrative, and Challenge dimensions. The index “rc” refers to the Teaching/Training Context coordinates from Equation 2, and the “r” index refers to each of the Beck et al.’s educational uses of immersive environments [26].

Euclidean distance = \sqrt{(x_{rc} - x_i)^2 + (y_{rc} - y_i)^2 + (z_{rc} - z_i)^2} \quad (3)

Fig. 2. Sample questionnaire items, with their relationship values to immersion dimensions.
The calculated distances are ranked, and the tool presents the ranked uses, highlighting the three closest ones to recommend as educational approaches (Fig. 3).

![Image](https://immersivetraining.eu)

**Fig. 3.** Sample tool output, highlighting the closest ILEs use themes.

This leads into Phase 3 of Fig. 1, “Check Matrix of Examples for each Pedagogical Approach”. As explained in section 2.3, while there are many educational theories and approaches, we have considered four main categories of approaches, which are commonly used in education and training contexts: Expository, Interrogative, Demonstrative, and Active.

Regarding the 16 uses of ILEs identified by Beck et al. [26], such as those visible in Fig. 4, we created a matrix that provided examples of how to apply each use within the four pedagogical methodologies. To facilitate understanding of the resultant learning activities, we used verbs distinguishing between teaching actions (plain verb) and learning actions (“quoted verb”). So, for each of the 16 uses of immersive learning environments, we created a matrix that provides an example of how to apply each use within each of these four educational approaches. We patterned this matrix after common presentations of Bloom’s revised taxonomy [32] as a matrix of two dimensions, cognitive process vs. knowledge, with the cells of the matrix containing proposed action words: verbs (process) or objects (knowledge). We used Bloom’s revised taxonomy as a template because just as with our work, it contains two dimensions with an actionable outcome. Also similarly, our matrix does not contain fully described examples but action words, as shown in Fig. 4. We used verbs, since these are meant to represent activities, but distinguished between teaching actions (plain verb) and learning actions (“quoted verb”).

The current Web platform for this tool (https://immersivetraining.eu) enables the user to navigate these options, by presenting them in a plain text context: “I use immersive environments for <immersive learning use>, within an <methodology name> methodology to, for example, <action word>”. For example, from Fig. 4, for Emphasis in an Expository methodology, this would be:

“I use immersive environments for Emphasis, within an Expository methodology to, for example, Alert”

Whereas for a Demonstrative methodology, this would yield:

“I use immersive environments for Emphasis, within an Demonstrative methodology to, for example, Highlight”

Figs. 5 and 6 present the current outlook of the Web prototype of this tool. The final phase 4 from Fig. 1 is for teachers to use the matrix to develop measurable objectives and plan their educational intervention. This would be supported by providing several specific examples in each cell, rather than just...
the action words. Teacher thus could select from that list in developing a lesson plan.

However, there are several assumptions embedded in this tool that require further research, for validation and refining. First and foremost, the testing scenarios mentioned in the methodology section are only preliminary. Thus, extended testing is required to determine the quality of the recommendation, e.g., whether the instructors find the recommendations adequate to their context of resources and goals. Another limitation lies in the action words provided as examples in the matrix: there are many forms of application of a given use within an educational approach. Suggesting that Emphasis for Demonstrative methodologies is limited to Highlighting is but a glimpse of the variety of ways in which that use could be employed, and more diversity is needed. Also, the way in which the educational context is determined and mapped needs wider validation: the coverage by the questions of the panorama of constraints and goals needs to be evaluated, and the adequacy of the questions themselves for that purpose as well. For example, we need to validate the questionnaire with instructors from a wide range of professional and educational contexts and seek feedback on additional questions to add. The relationship of the questions to the dimensions of immersion is yet another item for further validation, as is the ranking of alternatives: perhaps Euclidean distance is too plain a method to rank the uses for further consideration. In other words, we need to broaden the diversity and number of experts used in this validation process in order to increase the quality of the relationship of the questions to the dimensions of immersion.

Finally, the basis for the recommendation is currently not research results on educational outcomes of the uses, about which simply there is not enough knowledge available in the literature [26]. Rather, we are assuming a combination of two things: that existence of accounts of a given use is indication of some feasibility for it, and that it is also an indication that the instructor can expect to find examples in the literature from which to draw insights and inspiration. This shortcoming is currently insurmountable, but one should reasonably expect that the body of literature on immersive learning environments grows, reliable outcome measures become available, and should then be included in recommendation tools such as this one. The Knowledge Tree [33] initiative, authored by the Immersive Learning Research Network, is a promising example of an effort to systematize the field of immersive learning, which would combine both scholarly and practical knowledge and create an ever-growing knowledge base of research-based accounts of specific uses of immersive learning.

The Immersive Training Platform is found at https://immersivetraining.eu. It was designed as part of the RedVile activity of the Cross-KIC Human Capital project at EIT...
Manufacturing, one of the innovation communities of the European Institute of Innovation and Technology (EIT). The RedVile activity aims to support innovation in education using virtual reality, leveraging knowledge and evidence on the use of immersive technologies in education and training. This online tool aims to fulfill one of its stated goals, provide implementation and use case recommendations based on an assessment of instructional needs and context.

The tools and methods provided are a novel approach to the dilemmas of integrating technology in instruction. We leveraged the existence of a recent survey on educational uses of immersive learning environments to situate the researcher amidst a context of resources and objectives, thus recommending educational uses aligned with that context, based on actual accounts found in the literature. The resulting matrix enables instructors in any context to perform educational planning decisions more aware of their feasibility and innovative potential.

Given the multiple limitations presented in the previous section, significant research is needed to validate this tool, but it shows promise as an approach to support instructors in their educational planning. Future research should seek to test and refine the tool with large numbers of instructors, learning designers, and educational researchers, across the various limitations: the phrasing of the questions, the coverage of different constraints and goals, and the adequacy of the examples for the educational approaches, and the way that the context is matched to the known uses to provide recommendations.

Should results confirm the adequacy of this approach, the refined tool should be integrated with specific standards for primary, secondary, vocational, professional, and higher education in various content areas in different nations. Doing this would further improve its recommendation value and ensure that instructors are adequately addressing the standards for each age level and content area and would greatly support educational planning. Ultimately, the knowledge emerging from the development and application of this tool may result in the development of a technology integration model for teachers to use immersive learning environments, empowering their greater adoption and better learning.

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A Mixed Reality Teaching Course for Formal Higher Education

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Abstract—The advancements of mixed reality technologies enable a productive application of mixed reality in various fields. This increases the demand for skilled mixed reality developers. Current curricula do not offer dedicated mixed reality courses in higher education that provide the necessary competences. We demonstrate a lab course for mixed reality software engineering in a bachelor program at a technical university with its learning goals and the identified skills to support future mixed reality computer scientists. The course was conducted five times over two and a half years with a total of 38 students. In all instances, the same open-source software project was used as a boundary object to train agile software engineering, mixed reality development competences, and presentation skills. As the course teaches state-of-the-art agile workflows, its aim is to prepare students for scientific projects, a bachelor thesis and industry training scenarios in mixed reality.

Index Terms—mixed reality, augmented reality, education, curriculum, workplace training

I. INTRODUCTION

There is a rising demand for skilled mixed reality (MR) developers both in industry and research and with potential benefits for many domains. This field experienced a steep incline in job offerings which, according to the job site Hired, rose by 1,400% in 2019 [1]. As a spectrum of reality-virtuality, it incorporates augmented reality (AR) and virtual reality (VR) [2]. AR combines virtual content into the real world whereas VR immerses the user in a purely virtual environment. There is a mismatch between the job requirements and the MR content that is taught in higher education [3]. We chose to fill this gap by developing a structured MR lab which targets bachelor students of computer science-related programs.

Students who start our courses rarely show previous knowledge about MR or development tools like Unity. They often rely on video tutorials to establish it as a hobby but they cannot provide feedback about the learning success [4]. Therefore, we created a structured curriculum that first defines key learning goals and a plan how to optimally reach these goals.

The rest of the paper is structured as follows: Section II presents related approaches to MR curricula. In Section III, we identify the learning goals as key qualifications. Section IV describes the structure and how to achieve the learning goals. Section V highlights the five iterations and the student results in each instance. A juxtaposition of the course’s strengths and challenges is given in Section VI. The paper closes with a conclusion and outlook on future work in Section VII.

II. RELATED WORK

A majority of research is concerned with applying MR as a technology to improve learning activities. However, little research can be found that investigates how students can gain the necessary qualifications in order to support such MR research projects. In 2018, Klimova et al. published a report which outlined the top universities that already feature AR courses in their curriculum [5]. It became evident that there is not yet a general approach in the course design as courses varied in length and workload. Moreover, the report found that there is a focus on theories of AR. Similar results were also published in a report by the AR-for-EU consortium [3]. There are study programs in the fields of media, computer science or game design that touch the topic of MR but they only focus on the relevant aspects for the particular study field. The most demanded skills regard knowledge of AR and VR development tools like MR SDKs. Recruiters looked for experts in multi-platform development to migrate applications to different devices. Based on this report, Fominykh et al. constructed an AR curriculum plan that can serve as a blueprint, by mapping the AR qualifications to lectures and tutorials [6]. Cliburn presented the creation of a VR course where the focus is on cross-disciplinary collaboration between students [7]. This was achieved by group work where team members came from different disciplines and each participant could contribute a unique skill to the teamwork.

The courses focus either on AR or VR content but seldom, cross-platform support between AR and VR is taught. Most courses show a design-related approach where a large portion of teaching units stems from human-computer interaction. Software engineering is not as prominent in the related work. In the model AR curriculum, there is a lecture and a tutorial unit that introduces the concepts [6]. Nevertheless, many courses do not use agile methods like Scrum for group work. One publication mentions in its future work that the author is interested in introducing the Scrum process [7].
III. Learning Goals

The created practical course targets beginners who have no previous knowledge of MR concepts. The students are not familiar with the interaction methods for spatial user interface (UI) and the common development tools. Few students know how to use a consumer VR device as they previously used one privately. Hence, we identified the necessary skills for a beginner course based on Fominykh et al. [3]. The goal of this course is to provide a high-quality, practical approach to state-of-the-art MR concepts and development procedures. The elective practical course targets bachelor students in Computer Science-related fields of study at RWTH Aachen University and is recommended to be taken in the fifth semester. The course should guide students in applying the MR concepts in an implementation. We also teach about cross-platform and cross-device development using common MR SDKs. Moreover, we convey agile methodology by letting students apply Scrum and DevOps in order to prepare them for state-of-the-art teamwork practices. The course also simulates customer contact where students pitch ideas and demo software to gain feedback. After completing the course, students should be able to create immersive 3D experiences with intuitive spatial UI.

Based on the skill demand described in [3] and our goals for the course, we chose Unity as the base engine and the Mixed Reality Toolkit (MRTK) by Microsoft, as well as the Vuforia AR library. To cover the spectrum of MR, students are provided a series of AR and VR devices. On the AR side of the MR spectrum, the Microsoft HoloLens 1, Microsoft HoloLens 2, and Android smartphones are used. As VR devices, the HTC VIVE Pro and Oculus Quest are employed. The AR devices and smartphone-based solutions are already commonly available with dropping prices. Therefore, students can continue in the field with affordable own devices after completing the course. Only the Microsoft HoloLens is currently less affordable but still in high demand in industry, e.g. at NASA [8] or for on-the-job-training, for instance at the Deutsche Bahn [9]. Hence, it is important to give students the opportunity to also work with these devices. The MRTK provides the UI and base systems such as a device abstraction layer. All created applications can be ported between AR, VR and smartphone devices. Hence, students acquire the skills to create their own cross-platform MR applications and to work in teams on a larger software project in an agile manner.

IV. Course Structure

The course is separated into a scaffolding phase to get acquainted with the tools and a project phase, shown in Fig. 1.

A. Phase One: Scaffolding

The first phase consists of lecture-style meetings that are accompanied by practical exercises to deepen the understanding of the just learned concepts as shown by the first four steps in Fig. 1. Students work on the exercises in groups of up to four participants. We apply the pedagogical concept of scaffolding where exercises start as step-by-step instructions and help is reduced with each task. It decreases frustration and has been shown to be effective for programming-focused learning activities [10]. We give feedback for the submissions in the form of issues on GitHub. We contributed the content of the course material to the Open AR Teaching Book of the AR4EU consortium [11] and are actively using the book as a teaching resource in the course. The exercises are built upon each other and construct an MR game in order to address the students’ common previous experience with MR and to motivate students to test their results. As the result is a finished, self-made MR application, it can be shown to friends and family as an achievement of the first phase.

1) Unity Introduction & Setup: In the first step, students are introduced to the 3D engine Unity for their MR development activities. They get to know the UI of Unity’s editor and its component-based programming model. The first exercise handles setup tasks for Unity, Visual Studio and Git. It also starts the task series that creates a larger MR application. For instance, in the first iteration of the course, participants were asked to create a tilt maze where a marble rolls through a maze. Students set up the 3D scene, work with pre-made Unity components and create materials.

2) Agile Project Management & Mixed Reality Toolkit: The second module conveys the basics of agile project management and working in groups. Participants are introduced to the Scrum process and learn how to use Git with its branching model while avoiding common pitfalls [12]. Moreover, the students are guided on how to use the Requirements Bazaar, a social requirements engineering platform, to discuss their ideas about the project [13]. Students learn about collaboration using GitHub’s project management options where they can organize their work by creating issues and pull requests. On a technical level, the MRTK by Microsoft is presented. In the successive task, the students set up the project for MR by configuring the MRTK. A third task asks the students to implement application logic in C#. The tasks make use of the MRTK’s UI elements.

3) Spatial Computing: The third module focuses on the options for creating MR experiences and the spatial nature of MR. Participants learn about the MR hardware where we present the aforementioned devices. These options are accompanied by a short overview of available SDKs like Vuforia, ARCore and ARKit, as well as solutions like WebXR. Regarding the spatial aspect, placement solutions like the bounding box and solvers of the MRTK are highlighted. They are applied in the exercise and in the MR application by asking students to implement a movable menu and to use the surface magnetism solver. In addition to these tasks, the exercise sheet also contains a small breakout project with Vuforia and smartphones. Students design a suitable marker, import it into Unity and place an animated figurine on it.

4) Immersive Project: The fourth meeting and exercise mark the transition between the guided scaffolding exercises and the larger project. We create issues in their repositories about aspects that need to be improved and in the fourth exercise, this feedback is addressed. For the successive MR
project, the work should be based on our immersive project management framework VIAProMa [14]. Its functionality is demonstrated to the students, including its collaborative platform implementation which uses the Photon engine.

B. Phase Two: Mixed Reality Project

In the second phase, the learned content is put into practice. Depending on the winter or summer term, it spans from six to ten weeks. The structure of this second phase is based on our DevOpsUse training course that teaches students agile practices for startups [15]. We extend its structure of a group work assignment that practices agile methods and customer interactions with an MR context. Each group can choose a different topic out of a list of four to six topics. The topics are high-level descriptions of features that are required to be added to VIAProMa which acts as a persistent learning artifact. Students contribute to the same repository and build upon the results of groups from previous semesters. We create the topics based on user feedback, results of the previous course iterations and the demands of related research projects. We match them to the set of qualifications that students acquired during the scaffolding phase.

1) First Review: Presentation of the Concept: Once a group has chosen a topic, they elaborate a concept for this topic. According to the agile workflow, they will first formulate user stories for the feature. Based on these user stories, they compile a prioritized product backlog. Moreover, they should prepare their agile group work by agreeing on a Definition of Done which can, e.g., concern the amount of documentation or unit test coverage. To ensure consistent contributions to the persistent learning artifact of VIAProMa, we ask the groups to follow the C# style guide by Microsoft [2]. After agreeing on the organization parts, the teams should come up with a plan for their solution. It should highlight their proposed user interface design, e.g. using mockups and identify possible challenges. The groups present the preparation results at the first review. As course organizers, we switch between the roles of stakeholders and customers. Based on our role, we give feedback to the groups. The feedback addresses how well their plans fulfill the task description, whether the plans are achievable in the available time frame and whether the complexity of their solution is adequate.

2) Second Review: Prototype: Based on the feedback, groups adapt their plan and proceed with the implementation. They generate a sprint backlog out of the product backlog to define the tasks for the sprint. The main goal is to reach a prototype that demonstrates the core functionality of the feature. At the end of the sprint, the groups organize a retrospective meeting where they reflect on the sprint to identify their group’s strengths and areas of improvement. At the meeting of the second review, the groups present their updated product backlogs, their progress, a live demo of their prototype and insights from the retrospective meeting. In the role of stakeholders and customers, we again give feedback about the shown solution, the progress and the team’s organization.

3) Third Review: Polished End Product: For the final sprint, groups update their backlogs to extend the feature and to incorporate feedback. The sprint ends with another retrospective meeting. Finally, an overall pull request is posted. In the last meeting, the teams provide a live demo of the final MR feature and reflect on their group work.

V. Course Instances

The described course format was held a total of four times, with a fifth iteration ongoing. We scaled the course from six to twelve participants. This relatively small number of students ensures that there is sufficient access to hardware and that we are able to provide meaningful feedback.

A. Scaffolding Projects

With each execution of the course, we updated and changed the use case and topic of the scaffolding project. The taught content and qualifications stay the same but the game elements and game design are varied. In the iterations of the course, we created four introductory applications. Exemplary screenshots are provided in Fig. 2. The implementations are available as open-source projects in our GitHub organization. In the first instance, a tilt maze which is a virtual form of the wooden equilibristic game was developed for the scaffolding application. Students implemented control elements to rotate the maze and to open doors in the maze so that a marble can be rolled to a target. For the second course installment, students

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2https://docs.microsoft.com/en-us/dotnet/csharp/fundamentals/coding-style/coding-conventions
created an MR weather widget which pulls real data from the web and displays an according 3D model. Around the widget, placement options and buttons for setting the location were realized. The next scaffolding project contained a harvesting game where students added the logic for letting apples fall out of a tree. The apples interact with the real surroundings and they can be picked up to place them in a basket. In the following instance, a dart game was implemented where users can aim dart arrows at a target. It consists of snapping options to put the target onto real walls with a speech command.

1) Observed Results & Experiences: We varied the projects in order to gain insights into the types of use cases and task designs that students prefer and motivate. The results listed in this section are based on oral interviews with the students, our observation of their working behavior and the submissions. All students appreciated the tangible use cases and commented that they liked them more than artificial tasks. Moreover, we observed that the three games were better received than the weather application. Due to the detailed guidance in the tasks and immediate feedback by the course conductors, students never struggled with the tasks that build upon one another. If they made errors, they could immediately rectify them before starting with the next exercise sheet. Moreover, no group failed to deliver the results of a task. Based on posted questions, we were also able to refine and polish the exercises for the next iteration of the course. An example for such a question regards which workloads to include in the Visual Studio configuration.

The majority of students did not have knowledge about 3D content creation. In the first two iterations, we created 3D models ourselves and provided them to the students. We used online resources from Sketchfab starting with the third iteration of the course. This encouraged students to find suitable 3D assets online and it briefed them about licensing and copyright of third-party models. After the scaffolding projects, fewer questions appeared during the group projects. We deduct from this that the first phase prepared them well for the group project where they applied their learned knowledge.

B. Group Projects

In the second phase, the group projects took place. Once a topic was selected, we replaced the topic in the following semester with a new one. This way, we received a variety of results that challenged the student’s learned skills and that were integrated into VIAProMa’s feature set. Topics always contain the design of UI elements, implementation work and collaboration. Students were required to apply the Scrum methodology and should ensure the compatibility of the implementation for AR and VR devices. Hence, all students face a similar level of complexity in the given task despite the fact that they work on different topics. A selection of results is described in the next sections and their screenshots can be seen in Fig. 3. One topic added connection lines to establish associations between objects. In a successive bachelor thesis, a pathfinding and collision avoidance algorithm was inserted that allowed the connection lines to bend around obstacles. Another topic introduced gaze visualizations where users could direct the attention of peers using pointers and cursors. One group extended the collaborative space with a participants list. Another project realized a heatmap that records where users typically stand in the environment to visualize places of interest. A group created shared sticky notes which augment the project management space of VIAProMa. For project meetings, one group also implemented a polling system.

VI. DISCUSSION

We consider the MR course successful in every iteration based on the student’s performance. Due to ethical reasons, we could not directly ask students to rate the course in a survey. As this is a graded course, the relatively low numbers of students would still allow the identification of individuals in the anonymized results. Students were always able to complete the introductory exercises and group projects with little help. Moreover, the scaffolding phase showed a sufficient preparation effect as the number of questions decreased in the project phase. Whereas an average of 4.2 technical questions were posted in the support forum or sent by mail in the scaffolding phase, only 1.8 questions on average were raised during the project phase. We recorded no drop-outs after the course had started. We were able to recruit three students who are now working on research projects as student employees for more than one and a half years. Moreover, three participants of the course continued with bachelor theses in the area of MR at our chair. This suggests that the course acts as good preparation for subsequent work in mixed reality. The main challenge is to find a balance between interesting projects and a doable time frame. For the introductory project, we usually implement the entire code in advance and estimate the time for a beginner. To prepare for the group work phase, we approximate the complexity of every topic. During the COVID-19 pandemic, we were able to conduct the course in a remote form with video conferences. We developed a hygienic concept with alcohol- and bleach-free disinfectants, as well as special VR masks. Students were able to collaborate remotely.
using the given project management tools like GitHub and could also test in the editor. To experience the different hardware, it can be exchanged between the groups as the developed applications can be ported to all these devices with help of the abstraction layer of the MRTK. For VR, a virtual environment is put around the content.

VII. CONCLUSION & FUTURE WORK

The amount of job positions in research institutions and industries that require MR skills is rising. The inspected literature did not show course designs that convey knowledge about cross-platform compatibility and the combination of agile development with MR practices. Hence, we created a lab course for MR teaching in a bachelor program at a technical university. The main learning goals of the course concern the training of students in hands-on group work that is organized using the Scrum methodology. Students learn about applying MR in a cross-platform environment on different devices and with the necessary tools from the DevOps cycle. The course is divided into two phases where students work in small groups of up to four participants. At first, a scaffolding approach is chosen where students are guided through the first steps and the usage of the necessary tools. In this phase, they are also introduced to the underlying concepts. For eight weeks, they have to work on a continued exercise series to create their first MR application. The second phase contains project work. The groups can choose from a list of topics and given task descriptions. After six to ten weeks and two intermediate review presentations, they demonstrate the final result. We conducted the course a total of four times, with a fifth iteration currently running. Every group finished their projects with useful prototypes that contribute to the persistent learning object VIAProMa. Future participants of the course can build upon the achieved results in their projects. So, students train skills for their future work in research and industry.

For future iterations of the course, we would like to explore automated solutions for immediate feedback using continuous integration pipelines. We consider extending the course with a module about digital content creation for 3D modeling.

All in all, the concept and structure of the mixed reality lab course were successful in each iteration of the course. The projects yielded meaningful results and the course provided a useful preparation for future work in the field of MR.

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Work-In-Progress—Paper-Maintenance Skills Enhancement Using Smart Documents Integrated with Self-directed Learning

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Abstract—This work-in-progress paper describes Smart documents which are work instruction, standard of procedure, or manual are a part of smart factory. Smart documents are used as supporting tool to obtain high efficiency of production. Maintenance skill enhancement is another benefit of smart documents which is capable to obtained. Therefore, utilization of smart document integrated with self-directed learning to enhance maintenance skill was proposed in this research. Substitution-Augmentation-Modification-Redefinition (SAMR) model was applied to self-directed learning process to enhance maintenance skill. Based on SAMR model, self-reflection on used of smart document and on ineffective process can encourage self-improvement on critical thinking. Smart documents designing, method of smart document utilization integrated with SAMR model based on self-directed learning were explained. Utilization results and work productivity were studied.

Index Terms—self-directed learning, smart documents system, substitution-augmentation-modification-redefinition (SAMR) model, productivity

I. INTRODUCTION

Smart factory is a key focus of industrial revolution 4.0 which is required new technology such as internet of thing (IoT), artificial intelligence (AI), robotics and etc. Therefore, new technology disrupts the world of work that transforms every profession. The arrival of new technologies has created a new role or function of work. Consequently, workers were required to adapt and enhance their skills to fit with a new role or function of jobs to obtained high performance on production. Preparation of technician for the upcoming technologies is essential in the manufacture because technicians are directly involved in solving problems immediately when problems arise. Solving time is depended on abilities and experience of technician. Usually standard operating procedures (SOP) or work instructions (WI) are supporting tool for fixing the occurred problem and reducing of repairing mistake which is effects to occur of unexpectation problem in the future. However, problem solving skill, analytical thinking skill, critical thinking skill, and technical knowledge and skills, which related to machine, are required from technician in order to evaluate the occurred symptom of machine and to criticize the suitable solution. After that, SOP or WI will be used [1]-[5].

This research aims to develop the knowledge and skills of maintenance technicians. Smart documents were developed in order to transform to smart factory in the future. SAMR model was introduced self-directed learning process in order to use smart documents as maintenance technician development tool. And this is the way of high benefit obtained from developed smart documents whereas it usually plays a role on, only, supporting of machine repairing or operating. The result of technician capability enhancement is a part of development of smart employee which is increasing employee capability to handle wide variety of work or multi-tasking coming from disruptive technology.

II. THE PROPOSED CONCEPTUAL FRAMEWORK

A. Self-Directed Learning

Self-directed learning originates from the learner’s initiative. The researcher applied the Person Process Context (PPC) Model to use with a developed tool. The PPC Model is the developed version of Self-Directed Learning (SDL). Person, in this paper, is learner who has the specific characteristic, such as having creativity, critical thinking, enthusiasm, experience, life satisfaction, motive, education background, spiritual security, and self-thought. Process which is the transition of teaching and learning, and social contexts, which are learning facilitation, learning skills, management planning, competency assessment, teaching guideline, and technological skills, and Context which includes the environment, social atmosphere, finance, gender, learning atmosphere, organizational policy, politic, race, and sexual orientation. All factors should be prioritized because they affect efficient self-learning based on balanced and holistic cooperation [7].

SAMR model is the framework for technology integration for teaching learning. It was divided in to 4 steps. First is substitution (S) referred to the introduction of technology to replace the old tools that have been used. Second is augmentation (A) referred to the introduction of technology to improve the efficiency of the old work. Third is modification (M). At this step, the introduction of technology not only improves efficiency but also improves performance. It will lead to changes the design of new teaching and learning to suit the technology used. Fourth is redefinition (R). Technology is used to create new learning opportunities and new teaching methods that are different from the old ones [8].

B. Application of PPC Model and SAMR Model

SAMR model is suitable to use as process in PPC model as shown in Fig. 1. For S step, technician can fluently use the smart
documents instead of paper-based document. And they required regularly used of smart document whenever they operate or repair the machine. For A step, technician needs to learn and use addition function of smart documents such as search function and work example video. This will affect to obtain of doing faster work. After utilizing of smart documents, technician was asked for document modification such as process flow, new work example video which had more clearly detail. This step is the E step. For R step, which is the last step, meeting will organize to discuss the new standard procedure and lesson learn. Therefore, the new idea of smart document development can be proposed in this step. Based on the whole process, technician is capable to learn by themselves during do the job and smart documents is also used as learning tool. Finally, the effective smart documents will also obtain.

III. IMPLEMENTATION

A. Design of Smart Documents System

Previously, the documents/manuals of the machine were on the factory’s database and the access was likely difficult because they were stored without classifying by the work area, but at the department where the document was. Sometimes, the staff needed to use the documents/manuals to prevent the error or mistake from their performance or the skipping steps. The documents/manuals that link to the QR Code of the machine have been sorted with ISO Document system following as shown in Fig. 2.

At designing process of smart document, the developer designed the user interface (UI) together with the current QR code of the machines in the factory to facilitate the work of the maintenance staff. Workflow of the proposed smart document is shown as in Fig. 3. Smartphone and tablet can be used to accessed to the developed smart document through QR code scanning. Because the document is classified, username and password are required to do authentication process prior the smart document visualization process. Therefore, technician can easily reach to required document. Fig. 4 is shown the utilization of the proposed smart document system.

B. Design of Research Instruments

Three kinds of assessment were developed for this research consisted of satisfaction assessment, self-assessment, and smart document development assessment. Satisfaction to the developed smart document was determined which it was led to improve UI of the proposed system. Technical skill development and work performance were assessed with pre- and post-self-assessment tool. 5M module was used as the last assessment which led to smart document improvement.

C. Employee Training

Utilization of the proposed system both smart document and PPC model integrated with SAMR model was required training. The training was divided to 2 sessions. The first session was middle management team consisted of Manager of Department, Supervisor, and engineers. The second session was operating staff consisted of maintenance staff from electronic maintenance department. The training content contained the overview, developed smart document, benefit of the proposed smart document, demonstration of use, and concept of the PPC model integrated with the SAMR model. Both training sessions were online due to the COVID-19 pandemic.

IV. RESULTS AND DISCUSSION

As aforementioned, three assessments were conducted. Satisfaction assessment focused on system utilization as shown in Fig. 6. The average and standard deviation of the satisfaction was 4.46 and 0.51 respectively. It represented that both middle management team and technical staff like the proposed system at high level. They were also agreeing that they were capable to develop capability themselves with the proposed system. Self-
assessment of skill development was done 3 times which were before, after first time, and after second time use. This is led to evaluate of self-directed learning of technician. The results obtained from each person were shown in Fig.7 and shown that the proposed smart document and SDL model can be used to develop technical skill of technician themselves. The total repairing or maintenance times were corrected to follow up technical skill enhancement of technician. As shown in Fig. 8, repairing or maintenance times were reduced month by month. This show that the proposed smart document and SDL process was capable to develop technician performance well. The maintenance/repairing time was reduced after first use of the proposed system. However, it is not clear that the reduction time influential from utilization of the proposed system. On second use, the result shows the maintenance/repairing time was still reduced of almost 40% compared to result of the first use. The result of maintenance/repairing time reduction agreed with the result of technical skill capability based on self-assessment. Therefore, it can be said that this is because the use of the proposed system.

Fig. 5. Satisfaction Assessment Form on The Developed Tool.

Fig. 6. Self Satisfaction assessment result.

Fig. 7. Repairing or maintenance times after applied the proposed system.

Fig. 8. 5M Model which was the tool for the proposed smart document improvement. Maintenance staff analyzed how to improvement of the proposed smart documents system based on lesson learn. The result form an analysis was shown in Fig. 8. They agree that the next development should be insertion of clip VDO related to machine operation. This is led to elevate to A and R step which are the higher level of SMAR model

V. CONCLUSION

PPC Model or the Person Process Context is one of the self-directed learning models which SAMR Model was used along with the developed Smart Documents system. It was found that the maintenance staff had a better evaluation result and were able to resolve the problem accurately followed the steps. Furthermore, the time spent for solving problem decreased gradually. They analyzed and extended the developed tool to become more efficient for the benefits of the current and new maintenance staff.

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Work-in-Progress—Stress and Flow Assessment during a Virtual Reality Fire Extinguishing Training

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Abstract—Firefighters must be trained to deal with stress during firefighting and applying procedures. Aiming to alleviate the limitations in practice opportunities, a virtual reality (VR) application for training on fire extinguishing was developed, allowing for practice in a safe learning environment, while remaining aligned with the real-life training and the corresponding procedures. This work-in-progress paper investigates whether recruits experience stress and flow during the training by means of self-reported and physiological data. The physiological data measured (heart and respiration rate) significantly increased during the VR training, thus confirming arousal. The participants reported experiencing flow but not stress during the training.

Index Terms—virtual reality, training, stress, physiological data, fire training, flow

I. INTRODUCTION

Firefighting causes a lot of stress. It is physically demanding, since firefighters have to wear heavy gear and must drag and control a heavy fire hose while crouching. It is also mentally demanding as firefighters must apply several safety procedures, assess the danger, be considerate of their colleagues and casualties, etc. Consequently, firefighters not only need to master practical and safety procedures, but they should also be able to deal with stress under difficult circumstances to ensure that they apply all procedures cautiously and correctly. Complex real-life exercises are organized at various practice centers; however, they are expensive, dangerous, and require lots of organization, which limits the training possibilities. Therefore, there is a need for a more accessible and flexible training setup where recruits can practice skills in a safe and recurrent manner. Virtual reality (VR) technology can play an important role in achieving this goal. VR offers a cost-effective opportunity for training in otherwise difficult or impossible situations. As such, it provides endless practice opportunities in a safe environment. As a result, a VR fire training was developed to train recruits. In order to investigate whether the VR training aligns with the real-life training, this study measures stress during the VR training by means of both self-reported and physiological data.

II. THEORETICAL FRAMEWORK

A. Physiological Data for Stress Measurement

Stress is defined as a physiological response to a threatening situation and is considered a survival mechanism. Given the close relationship between stress and neural systems, human neurophysiological signals can be used to assess stress [1]. Physiological metrics which have been proven to be reliable for stress assessment are respiration rate (RR), heart rate (HR), and galvanic skin response (GSR) [2]-[4]. HR can be measured by a non-invasive electrocardiographic (ECG) method. HR averages the number of beats per minute. Respiration is also known to be related to stress, such that an increase in respiratory frequency occurs when the stress level is higher [5]. GSR, also known as skin conductance or electrodermal activity (EDA) refers to the variation of the electrical properties of the skin in response to sweat secretion [6]. The time series of skin conductance can be characterized by a slowly varying tonic activity (i.e., skin conductance level, SCL) and a fast-varying phasic activity (i.e., skin conductance response (SCR) [2].

B. VR for Training

VR offers great opportunities for creating authentic learning environments. Brown et al. (1989) argued that meaningful learning takes place and knowledge transfer is promoted when it is embedded in the social and physical context within which it will be used [7]. This also aligns with the idea of situated learning, which emphasizes the idea that the majority of what is learned is context-specific and should not be taught in a typical school situation [8]. Conventional school-based learning methods are known for an objectives-based approach that breaks down authentic learning tasks into their constituent parts [9]. Subsequently, instructors apply an instructional method for each of those separate parts and their corresponding objectives. As a result of this approach, students do not learn how to coordinate these parts into a coherent whole which leads to fragmentation of the learning material and counteracts the transfer of learning content in a real-life context. In contrast, by creating an authentic learning environment, VR allows for whole-task training. By providing a series of problems that are causally connected based on learners’ actions, training in VR allows learners to train specific professional skills [10].
As a result, VR is a powerful tool for context-specific training of complex professional skills since repeated practice is possible while providing a safe space to make mistakes. Nevertheless, the sense of reality of VR training is questioned. Especially in the case of fire training, it is important that learners are sufficiently prepared to deal with stress [11]. Therefore, this exploratory study investigates whether stress is experienced during VR fire training. More specifically, the study investigates whether the tasks performed during fire extinguishing that provoke stress in reality, also cause stress during the VR fire training.

III. Method

A. The VR Fire Extinguishing Training

The VR fire training tested was developed by OneBonsai (www.onebonsai.com) and it simulates extinguishing of fire on a ship. It requires two HTC Vive Pro headsets, connected to their corresponding custom Pelicase PC with a VIVE Wireless Adapter, and a commercial laptop for the instructor.

As in real life, during the task, the firefighter and the leader need to cooperate. The firefighter is responsible for extinguishing the fire while the leader directs the firefighter and ensures his safety. In the training, both members can practice the procedures (e.g. hot door detection, ensuring safety, extinguishing, and monitoring the fire, checking the compartments).

B. Participants and Study Design

The study took place at the Damage Control Center (DCC) of the Belgian Navy, where 8 recruits with minor experience went through the VR Fire training as firefighters. The average age was 24 (1 female, 7 male). Participation in the study was on a voluntary base and all participants signed informed consent.

Each participant went through a baseline measurement and had to go through two phases. During the baseline measurement participants had to stand still with their eyes closed before entering the VR learning environment. In order to look for the relationship between stress and specific events, the training was divided into two phases. The first phase started with seeing smoke development and ended when the fire was extinguished. In the second phase, the fire was extinguished, and the participants had to check the remaining compartments on the ship. The average time of the training was 9.63 min.

At the end of the session, stress was surveyed by means of the NASA Task Load Index (NASA TLX) [12]. Moreover, we measured flow, which is used to describe a state of mind experienced by people who are engaged during the activity, which can promote learning [13]. The concept of flow is investigated as a motivational state in the context of information systems. Both workload and flow were assessed on a 7-point Likert Scale.

C. Physiological Recordings and Analysis

For the recording of HR and HRV, Biopac ECG electrodes were connected via surface electrodes on the chest. For the recording of respiration data, a Biopac belly band tightened around the abdomen. For the recording of GSR, GSR electrodes were connected via surface electrodes at the participants’ fingertips. Data were recorded at a sample rate of 2000 samples/s. The raw physiological data, i.e., respiration [Volts], ECG [mV], GSR [microsiemens], were processed using BioSPPy and Neurokit2 in Python resulting in five features: respiration amplitude, RR, HR, tonic and phasic skin conductance. A repeated measure ANOVA was conducted to measure a within-subjects effect of the different interventions, controlled for VR experience. As multiple comparisons were conducted, the Holm-Bonferroni correction was applied [14].

IV. Results

A. Physiological Data

In this study we investigated whether stress was present during two specific phases in the VR training i.e. Phase 1: observing smoke development and extinguishing the fire and Phase 2: inspection of the remaining compartments on the ship after extinguishing the fire, compared to Baseline: the moment before entering the VR training environment.

Fig. 1. Screenshot of the VR Fire Training

Fig. 2. Boxplot of HR: Baseline (green), Phase 1 (yellow), and Phase 2 (red).

Fig. 3. Boxplot of RR: Baseline (green), Phase 1 (yellow) and Phase 2 (red).
The results revealed that the mean HR (Fig. 2) was significantly lower during the baseline measurement when compared to Phase 1 (MD_ph1-base = 14.71, \( p < 0.001 \)) and Phase 2 (MD_ph2-base = 16.68, \( p < 0.001 \)). No significant differences were found between Phases 1 and 2 (MD_ph2-ph1 = 1.96, \( p > 0.05 \)).

In terms of respiration data (Fig. 3), results reveal that RR was significantly lower during the baseline measurement when compared to Phase 2 (MD_ph2-base = 3.92, \( p < 0.001 \)). No significant differences were found between Baseline and Phase 1 (MD_ph1-base = 1.65, \( p > 0.05 \)) and between Phase 1 and Phase 2 (MD_ph2-ph1 = 2.28, \( p > 0.05 \)). No significant differences were found for features of GSR.

**B. Subjective Evaluation Through Questionnaires**

The findings of the NASA TLX questionnaire on a 7-point Likert Scale ranging from “Totally not agree” to “Totally agree”, revealed that recruits did not experience the VR training as complex (\( \mu = 2.12 \)), exhausting (\( \mu = 2.75 \)), and frustrating (\( \mu = 1.86 \)). However, they indicated that they experienced flow during the training (\( \mu = 5.53 \)).

**V. CONCLUSIONS AND DISCUSSION**

**A. Stress or Engagement?**

The subjective evaluation of the recruits through questionnaires showed that they do not experience stress during the VR training. However, the recruits indicated that they experienced flow during the training.

Additionally, we have proven that the HR and RR increased while the recruits followed the VR training. Contrary to what we expected the physiological responses were not stronger during Phase 1 (extinguishing the fire). This might indicate that these responses are less linked to stressful situations and refer more to overall engagement i.e., attention, mental and physical effort. During the whole training, the recruits had to remember and apply safety procedures while crawling, which required both mental and physical effort (especially during Phase 2).

**B. Limitations**

The design of this study has some important limitations related to practical issues. First of all, the data was collected in an authentic learning context which caused the study to proceed in a less controlled manner. For example, participants with low prior knowledge received a lot of guidance (external to the VR environment) from their trainers. The amount of guidance might also have negatively influenced the sense of flow. Additionally, since the training required collaboration, the training can be perceived differently by the firefighters. For example, a confident leader may cause the firefighter to experience less stress since they guide the firefighter correctly and firmly. Moreover, due to the many events in the VR training, it is not possible to link the data to specific events. For instance, stress can be caused by extinguishing the fire, not mastering the procedures, poor collaboration between the leader and the firefighter, and more. A final limitation is related to the physiological data collection. Distorted GSR data was recorded as participants pressed the surface electrodes when using the VR controllers. As a result, GSR data was not used for further data analyses.

**C. Follow-up Studies**

The exploratory study shows that VR has great potential for teaching procedures in a realistic context. Follow-up studies should focus on VR training as a means for elevated engagement and as such, its potential for meaningful learning. To refine the study a more controlled environment should be enforced. This implies that the recruits should have more or less the same basic knowledge of the procedures. Moreover, future studies should entail a larger sample size in order to conduct more complex analyses, using multimodal data, to detect stress or arousal.

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**REFERENCES**


Abstract—Server maintenance operations require vast knowledge about the functionalities of various devices and their troubleshooting procedures. Workers often have to deal with complex paper manuals. This work-in-progress paper evaluates the effectiveness of a system to bring the onsite human supervisor experience, using an AR-based avatar with pointing gestures and voice instructions to guide the technician. 11 participants were asked to perform the set of instructions both in manual and avatar-based guided settings. A statistical analysis of raw NASA-TLX supports that the avatar-based guided maintenance system reduces the mental workload when compared to the manual-based maintenance procedures.

Index terms—maintenance, avatar support, augmented reality

I. INTRODUCTION

In any kind of repair and maintenance operations, hard paper manuals or 2D display-based tablet instruction are very common, but following them requires the engagement of workers, which cost their time and is inefficient. The workers need to switch back and forth between manual and the actual working equipment, which can be troublesome for most of the workers, as we found out first-hand from our clients. To solve this problem and make the process more efficient, some researchers have suggested the use of augmented reality (AR) devices, overlaying the appropriate information by identifying the objects in the real world. In this direction, Malta et al. [1] have proposed a model to provide real-time assistance to the maintenance worker in the automotive field by recognizing certain parts of an automobile using YOLOv5 and then overlaying the appropriate AR instructions such as “open here.” The integration of image processing algorithms with overlaying instructions in the real world using augmented reality devices such as HoloLens is becoming popular in recent years. However, it is important to assess the way information is being presented to the maintenance worker, as an improper display of AR content could be misleading, resulting in the lower adaptability of the overall system. In this direction, Wang et. al. [2] have presented the comparison of three different avatar designs (“full-body”, “hand + arm”, “hand only”) in an augmented reality (AR)-based remote work application, which enables workers to receive instructions from an avatar. In the same direction, a study by Keighley et al. [3] was conducted to understand the perceived quality of experience (QoE) for three different multimedia platforms (interactive augmented reality, virtual reality, and tablet-based application). The authors have not only focused on the explicit methods (post-test questionnaire) but also the implicit (heart rate and electrodermal activity) methods. In this study, we consider the server repair and maintenance operations, and propose the use of an expert avatar to guide the workers during repair and maintenance operations. The technician not only receives the guidance as and when needed but also has a perception of the onsite human supervisor which is a common practice if the technician is a novice.

To summarize, the main contributions of the paper are as follows: (i) Design and implementation of an avatar-based support system where a full-body avatar greets and introduces himself as the instructor expert. The avatar uses spatially accurate hand pointing gestures to signal the next target object, while voice messages that explain the repair and maintenance activity corresponding to the maintenance task provide a subjective feeling of togetherness. (ii) To evaluate the effectiveness of avatar guided instructions over paper manual-based maintenance operations, we have presented a statistical analysis of the raw NASA-Task Load Index (RTLX) questionnaire, filled by the 11 participants, after experimenting with each of the two settings.

II. METHOD

A. Experiment Setup

A typical server rack consists of a patch panel, hub, switch, and hard disk drives. It is important to understand that the
recognition of every component with their model numbers and the Ethernet cables, which establish a connection among different network devices and hard drives is something crucial, and requires higher attention during maintenance operations.

In a routine server maintenance task, the first step is to identify the server rack in which maintenance is required. Then the devices in a server rack (switch, hub, patch panel, and their model number) should be identified, followed by the replacement of the old device with a new one, or changing the existing configuration to match the network topology. The plug-in or plug-out operation of the Ethernet cables is crucial and takes enough amount of time and attention of the technician. Hence, a higher mental workload and early fatigue become present. With the advancement in computer vision and augmented reality devices, it is now possible to precisely identify the objects [1], such as server rack, switch, hub, or similar devices, and then the position of ports can be estimated according to the model number.

It was difficult and insecure to do any experiment with real servers. Hence, for ease of convenience, we have imitated the server rack with some dummy devices. In this experiment, we have used the following server rack as can be observed in Figure 1. It consists of two patch panels, two switches, and one hub. In this pilot study, we propose the use of an avatar for guiding the technician in removing the optical cables by pointing to the exact ports, from where a cable needs to be plugged out with real-time feedback using voice messages. HoloLens 2 is used to realize the avatar-based guided operations. It should be noted that pointing to a small object such as switch ports requires high precision control of the avatar. We intentionally chose such task in this study to show that it would be easily extendable to situations where it is required to point to a specific server rack and parts (switch, hub) if required. In this study, the focus has been given to evaluating the user experience when the avatar assists workers in server maintenance tasks rather than developing the actual computer vision algorithm which detects and locate the ports and device in the server. Therefore, we have used fixed positions predefined and the avatar was made to point to those ports with the click of a button from the web interface which sends the command signal over the local network to the application. The participant was observed by the web interface operator so that he can control the avatar actions (i.e., voice and finger pointing) based on the participant actions.

| Table 1. List of Instructions Given to the Participants in the Manual-Based Setting |
|-----------------|-----------------|
| Number | Instruction |
| 1. | Plug out the cable from patch panel 1 at port number 4. |
| 2. | Plug out the cable from switch 1 at port number 17. |
| 3. | Plug out the cable from switch 2 at port number 6. |
| 4. | Plug out the cable from switch 2 at port number 18. |
| 5. | Plug out the cable from switch 2 at port number 16. |
| 6. | Plug out the cable from the patch panel 1 at port number 12. |
| 7. | Plug out the cable from switch 1 at port number 11. |
| 8. | Plug out the cable from the patch panel 1 at port 13. |
| 9. | Plug out the cable from the switch 1 at port number 18. |
| 10. | Plug out the cable from the switch 1 at port number 16. |

B. Hypothesis and Method

Our hypothesis is as follows: The avatar-based guided server maintenance operations reduces the mental workload when compare to paper manual-based maintenance procedures.

C. Procedure

We have randomly selected 10 ports distributed among different devices (switch, patch panel, and hub) from which participants have to plug out the cables. The experiment has been conducted in two settings, in the first condition, the participant has been provided with the following instruction set as shown in the Table I. Then he was asked to follow the instructions in a sequence, one at a time, identify the port and then plug out the cable, followed by writing a checkmark in the instruction manual to maintain the task integrity and coherence. While in the second condition, the application starts with a display of a human avatar that greets the participants and introduces himself as today’s instructor with a voice message. Then the avatar guides the participant using voice messages and a finger-pointing action to plug out the cable from the appropriate port as shown in Fig. 2. Because the same participants have experimented with both settings, to avoid the task memorization between conditions, two different sequences of ports have been utilized in each setting, with half the participants first asked to experiment with a manual-based setting, while the other half were first asked to experiment with the avatar-based settings to mitigate the novelty effect.

After experimenting with each setting, the participant was asked to fill raw NASA Task Load Index (RTLX) [4], [5], [6] questionnaire to analyze the perceived mental workload under both conditions.

D. Participants

11 participants (9 males and 2 females) were recruited for the experiment within our company. All the participants had zero experience in the field of server repair and maintenance. 40% of the total participants were familiar with the HoloLens 2.
and often use it, while the other 60% used the HoloLens 2 for the first or second time only.

III. RESULTS AND DISCUSSION

We statistically analyzed the perceived cognitive workload utilizing the raw NASA Task Load Index (RTLX) and applied post-test to both conditions. We chose the raw version of the questionnaire since it has proven to be highly correlated to the weighted version while being more practical to apply [4], [5], [6]. Descriptive statistics show the avatar-based worker support system led to the lowest RTLX score during the task (M=20.22, SD=12.19), compared to the manual-based work task (M=38.56, SD=20.22). To determine if there is a significant difference between the two conditions within-subjects, we applied a paired sample t-test. Visual inspection of the histogram and Kolmogorov–Smirnov statistic test (D = 0.206, p-value = 0.66296) indicates a normal distribution, so we proceed with assumed normality of the dependent variables, finding a highly statistically significant difference (t(10) = 3.23, p = 0.009) at 95% confidence as shown in Figure 3. These exploratory results indicate a positive effect on the perceived mental workload from our avatar-based expert support system when compared to the traditional manual-based approach. This implies a possible reduction of the negative effects derived from work-related stressors and subsequent increment in the Quality of Work (QoW) of trainees with the implementation of our proposal.

IV. CONCLUSIONS AND FUTURE WORK

In this initial exploratory work, we have introduced avatar-based guided instructions for the server maintenance and repair field. Our results of the statistical analysis of raw NASA-TLX scores strongly support the hypothesis that the avatar-based guided maintenance operations have a positive impact and will help reduce the mental workload of server technicians. We are aware of the limitations of the current work, such as the simplicity of the task, low number of subjects, and limited comparison material (i.e., manual quality may affect the outcome). We will address these in future studies. These initial findings will serve as a base for advancing the further exploration of avatar-based guided operations for bringing the human supervisor-like experience in various domains of the maintenance and repair industries.

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Work-in-Progress—Blower VR: A Virtual Reality Experience To Support the Training of Forest Firefighters

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Abstract—First responders require adequate training to operate safely in dangerous situations. However, low-fidelity exercises used in courses are an approximation of real scenarios. This is particularly true for firefighters since practice sessions often do not include real fire. A way to overcome these limitations consists in using Virtual Reality (VR) to create experiences where trainees can face detailed simulations of actual risks. The system presented in this work-in-progress paper aims to support practice training on the use of the blower as a firefighting tool and offers two training modes to assist trainees in learning the procedure and assessing their knowledge.

Index Terms—virtual reality, training system, workforce development, evaluation, assessment

I. INTRODUCTION

First Responders (FRs) are operators that are called to act in the presence of dangerous situations, like floods and fires. Being the first to enter in action, FRs usually operate in unknown conditions and are exposed to life-threatening risks. It is therefore clear that they must be well-trained and prepared to act in order to ensure their and other people’s safety.

When it comes to training, prospective FRs must attend structured courses that teach not only the procedural details, but also all the safety measures that have to be mandatory followed in the presence of risks. Certain procedures and measures can be easily taught in video-based courses, but in many cases it is necessary for the trainees to put into practice the acquired knowledge and to undergo accurate exercises that properly simulate real scenarios. However, this consideration leads to a problem: the complexity of real scenarios cannot be easily reproduced in real practice sessions.

This is particularly true for firefighting operations, especially those that take place near the fire fronts and encompass the use of firefighting tools. Since new trainees lack the experience and the certifications required to safely operate in the presence of fire, most of the courses only offer low-fidelity simulations without real fires or, occasionally, exercises on controlled fires; in both cases, the simulations fail to reproduce the behavior and the spreading of real fires, e.g., for safety reasons. Thus, the trainees may exit the course without receiving a proper feedback [1].

To cope with these limitations, it is necessary to explore alternative ways to organize practice sessions and put the trainees in the condition of making realistic experiences in safe environments. A possible solution consists in using Virtual Reality (VR) to create immersive simulations. In fact, VR Training Systems (VRTSs) are nowadays widely-used tools that can be integrated in standard courses and offer a series of advantages with respect to their real counterparts: in particular, they offer realistic, highly detailed experiences with reduced costs, which can be easily distributed to the trainees and can provide automatic guidance and evaluation functionalities.

II. RELATED WORKS

The use of VR technology for training FRs has been widely described in the recent literature [2]. Previous works considered, e.g., hydro-geological risks management [3], CBRN (Chemical, Biological, Radiological and Nuclear) defense procedures [4], and crisis management in rescue missions [5]. A particular attention has been devoted to firefighting operations [6]–[8], which are specifically addressed by the present paper. As said, this domain has been considered as particularly relevant from the perspective of VRTSs, mainly due to the need to train operators in an effective way without exposing them to unnecessary risks. For instance, Querrec et al. [9] described a training scenario to manage firefighting teams, leveraging VR to create realistic situations that cannot be easily and safely replicated in real exercises. Cha et al. [10] described a VR-able to offer a realistic representation of fire and smoke, using data coming from a fire dynamics simulation in real time. In this case, the simulation was characterized by large processing times, therefore fire-extinguishing operations were not considered. This limitation was partially addressed by Calandra et al. [11], who presented a multi-role, multi-user VR-based training simulator for tunnel fires management.

Overall, VR technology is able to increase the safety of high-risk, firefighting training and the trainees’ engagement, is characterized by high ecological validity and cost effectiveness, and also enables interesting features such as data
recording as well as automatic guidance and evaluation mechanisms, together with the possibility to create complex and high-fidelity scenarios. These benefits are specifically analyzed for the domain of interest for this paper in the work by Engelbrecht et al. [12], which also points out some weaknesses, such as the still limited maturity of the technology, and the fact that, often, the developed VRTSs are not validated by actual firefighting operators or integrated in structured, standard firefighting courses.

III. Case Study

In this work, the focus is on the use of the blower in forest firefighting operations. This tool produces an air flow that can be exploited by operators for extinguishing small flames or removing fuel (e.g., foliage) to stop the progression of a fire front. The blower can be used in three different modes.

- **Direct attack**, in which the operators use the blower directly on the front to remove oxygen and extinguish the fire; this mode is possible only in the presence of slow-burning fires with low flames.
- **Indirect attack**, in which the operators use the blower to remove the fuel and stop the fire front propagation, creating a safety line.
- **Mop up**, in which the operators use the blower to isolate the embers, once the fire has been extinguished.

The use of the blower exposes the operators to fires and high temperatures, thus it is necessary to wear adequate personal protective equipment (e.g., firefighting gloves and helmet with visor or goggles) and follow mandatory guidelines to ensure the safety of those involved (for instance, in the direct attack, the blower must form a 30° angle with the ground to properly extinguish the flames and avoid feeding neighboring fires). These guidelines are usually taught in official, e.g., video-based, courses for firefighting operators. For safety reasons, these courses may also offer practice sessions that, often, can only be an approximation of real situations.

IV. Design and Implementation

The VRTS presented in this study was designed with the help of trainers from the Italian forest firefighting unit of the Piedmont Region, Italy, and consists of an immersive experience where operators can train in the use of the blower in a virtual environment. Only the direct and indirect attacks (described in Section III) have been considered so far; the mop up procedure will be included in future developments. The design and development of the application were inspired by the methodology followed by previous studies [4], [11].

The VR application can be used with Head-Mounted Displays (HMDs) like the HTC Vive Pro, and was implemented using the Unity game engine together with the SteamVR framework. To reproduce the weight of a blower and enhance the realism of the experience, a real tool was modified to be used as an interface to the application: in particular, the original handle was replaced with a Vive Pro controller (Fig. 1a), whereas a Vive Tracker was attached to the body of the blower (Fig. 1b). The tracker, combined with the HMD, allowed the system to track the position and rotation of the trainee’s head independently of the body pose.

To further enhance the realism of the experience, the application offers a believable (though not physically accurate) simulation of the blower behavior and the fire front. In particular, the blower affects the fuel and the fires present in the 3D scene. Its power can be modulated by pressing the Trigger button on the controller attached to the real tool. If the blower is used on the foliage, the affected leaves are scattered in the scene, whereas if it is used directly on the fire, the flames react depending on the blower orientation: if the angle is approximately 30°, then the flames progressively lose intensity, whereas if the angle is different, the flames intensity and height increase. Moreover, when not affected by the blower, the flames spread in the scene, moving from the existing fires to the areas covered by foliage.

The application offers two different training modes: the **Guided mode (GM)** and the **Evaluated mode (EM)**.

In the GM, a Non-Player Character (NPC) illustrates all the necessary information required to properly use the blower as a firefighting tool. The explanation is divided in steps, in which the NPC presents an action and the trainee is asked to correctly reproduce it. If the trainee acts correctly, the explanation moves to the next step; in case of errors, the NPC signals them to the trainee. In addition to the NPC’s voice, further visual elements (like markers and icons) are used to guide the trainee throughout the experience. The steps considered in this training mode are reported below.

- **Set up**, where the trainee is first invited to grab and turn on the blower. Then, he is asked to move in the 3D environment while keeping a correct posture (evaluated by the system by leveraging the position and rotation of the HMD and the Tracker on the real blower).
- **Indirect attack**, where the trainee has to remove the foliage from a given area to create a safety line. The trainee is instructed to blow the foliage away from the fire to correctly stop the fire front.
- **Direct attack**, where the trainee has to extinguish a fire front. In this step, the trainee is asked to correctly use the blower (by swinging it from left to right) and to point...
keeping a 30° angle with the ground (Fig. 2).

In the EM, the trainee is asked to use the blower to extinguish a fire front without the support of the NPC or additional visual hints. Errors are not signaled at run-time, and the trainee can get a feedback about the correctness of his or her actions only by observing the fire front and the changes in the scenario. At the end of this mode, a report is produced by the VRTS describing the overall performance of the trainee. The report is split in sections, and also includes an overall score on a 0-to-100 scale. The evaluation considers the trainee’s posture, the orientation and the use of the blower, and the evolution of the fire front during the experience.

V. CONCLUSION AND FUTURE WORKS

This paper presented a VRTS that was developed in collaboration with forest firefighters to train FRs in the use of the blower as a firefighting tool. The devised VR application aims to represent a complementary training material that can be integrated in standard courses to fill the intrinsic gap of firefighting education, i.e., the fact that trainees need to be prepared to face the risks of real scenarios, but cannot be exposed to these risks during courses because of their lack of experience. This paper reports on a work that is still in progress. In fact, a previous version of the VRTS was developed to support the training in the use of other firefighting tools (like the shovel, the rake and the beater), and was already used in the context of courses held by the school. This new application has not yet integrated in the said courses due to limitations imposed by COVID-19 restrictions. At present, only qualitative feedback has been collected from the trainers that were involved in the development. Overall the evaluation was positive, and the application was deemed to have the potential of the previous one.

Considering envisaged developments for the current work, the first step shall consist in the validation of the system. To that aim, the plan is to conduct a user study involving trainees from a standard, video-based firefighting course. Two possible protocols could be used.

- A three-group study, where one group of trainees attends the standard course, a second group experiences the training in the VRTS in addition to the standard course, and a third group goes through the standard course in addition to a real, low-fidelity practice session using a real blower. Quantitative and qualitative feedback is collected to compare the three training experiences.

- A two-group study, where two groups of trainees attending the standard course are asked to use the VRTS at different times: the first time before the course, the second time after the course. By collecting quantitative and qualitative feedback after each experience (namely, after the VRTS and after the standard video-based course) it would be possible to isolate the contribution of the VRTS and evaluate its efficacy.

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Abstract—Virtual Reality as a learning technology has been indicated numerous times to be an evident improvement over conventional learning methods. This work-in-progress paper describes and analyses the didactic and design factors for an effective use of virtual reality for basic vocational training. Guided by pedagogical principles for effective teaching and learning, a prototype of a virtual learning unit for apprentices in the field of electrical installation was developed. The impact of this learning unit on learning success is to be evaluated in an ongoing field study in Switzerland.

Index Terms—virtual reality, basic vocational training, immersive learning

I. INTRODUCTION

There is widespread consensus that virtual reality (VR) as a learning technology can methodically enrich learning and can add value compared to conventional learning media [1], [2]. This is also the case in the context of vocational education and training.

In basic vocational education, apprentices are trained to professionally perform the essential activities of their occupation. These activities require vocational action-oriented competencies, which are understood as a holistic repertoire of actions and a person’s ability to act in a self-organized manner in a variety of settings [3], [4]. These professional competencies are assessed at the end of the apprenticeship in the practical part of the qualification procedure.

Our project focuses on a use case for apprentices who are preparing for their exams as assembly electricians in Switzerland. The use case comprises the correct safety check of an electrical installation as specified by the Swiss standardization organization Electrosuisse: Before being put into operation by the user, every electrical system in Switzerland must be tested during construction or completion in order to prove that it meets the safety requirements [5]. This so-called “initial test” of an electrical installation must be carried out using predefined check lists, on the basis of which potential faults of an electrical installation can be located or excluded. An immersive VR learning environment is used to simulate the initial test of an electrical installation, consequently removing the potential risks of human harm and helping the apprentices to prepare for their exams in a realistic yet easily available environment.

The aim of the project is to examine the necessary didactic and design factors for an effective use of VR for basic vocational education in Switzerland and in a developing country (Tanzania). Furthermore, a business and operating model for the production and distribution of VR learning units is designed together with a software company.

II. USE CASE

Learners can test a basic electrical installation of a lamp and a fuse box in an immersive VR representation of a car garage and adjoining basement to demonstrate that it meets the safety requirements, as defined by the Swiss regulations. In doing so, they must be able to correctly perform the specified action elements and respond to any faults in the system. Our working hypothesis is that immersion is an enabler for an additional sustainable learning effect. The criterion for choosing this use case was the feedback of exam experts that many apprentices perform poorly in the practical part of the exam, which is concerned with measuring and testing an installation. Our working hypothesis is that immersion is an enabler for an additional sustainable learning effect. The criterion for choosing this use case was the feedback of exam experts that many apprentices perform poorly in the practical part of the exam, which is concerned with measuring and testing an installation. The prototype implementing the use case is built in Unity for Oculus Quest 2 using the VR Interaction Framework.

A. Scope: Available Test Options

The current available measurements, which can be performed by apprentices (see Fig. 1) are as following: visual inspection, insulation measurement, residual-current device measurement, short-circuit current measurement, and polarity check.
B. Didactic Concept: Scaffolding Principle

Scaffolding is an approach used in the context of constructivist learning theories. The term goes back to the learning psychologists Wood, Brunner, and Ross and refers to the support of learning processes through the selective provision of a “learning scaffold” consisting of instructions, food for thought, and other types of assistance [6]. This scaffolding is provided only to the extent that learners are challenged but not overwhelmed and that they can move within their individual “zone of proximal development” [7]. As soon as the learner can work independently on a particular subtask, this scaffolding is gradually removed again, thus help is offered “drop by drop”.

The approach is put into effect via granular help messages and a sequence of subtasks visualizing the milestones of a measurement. In case the learner is at a loss, they can get assistance from the help screen via task-specific hints or by looking at the work order (see the left side of Fig. 2 as an example). The individual steps are gray and not labeled initially, and turn green upon completion. An audible signal is played as a secondary feedback modality. In order for the principle to be understood, the apprentice completes the first milestone directly on the help screen (e.g., the battery test during the insulation measurement).

The help system emulates a chat that allows the apprentice to get further instructions from a virtual tutor. In case the button “I need help” is pressed, a chat message appears explaining the next step. The list of chat messages is scrollable. The messages are enhanced with a text-to-speech feature, implemented with Microsoft Azure Cognitive Speech, to minimize the reading effort for the learner.

C. Theory Inputs

The learning content of vocational schools is ideal for the application of VR learning environments, as VR can support situated learning at vocational schools [4], [8]. In the vocational school context, learning can be facilitated by a professional trained in vocational didactics and can occur in a setting that is learning-oriented rather than production-oriented. However, there is a lack of opportunities to perform professional actions and thus to intertwine theory with practical action.

D. Gamification

“Gamification is using game-based mechanics, aesthetics, and game-thinking to engage people, motivate action, promote learning and solve problems” [9]. By applying game design elements (milestones, visible status, leaderboard), usage motivation can be increased [10]. Learners should be motivated to complete a measurement fully and correctly, and to repeat measurements even if they have already completed them. This is put into effect through a system of awards (e.g. stars) based on certain success criteria such as completed measurements and successful repetitions of a measurement.

Learners should be able to track their performance across sessions and thus retain their progress regarding measurements. The progress is translated into score points and is updated during the session and will be saved persistently across session for each user, as seen in Fig. 3. The score is calculated on the basis of the complexity of a measurement and the number of help calls. Each user appears on a leaderboard, which is a list of usernames and scores presented in decreasing order of scores. The usernames do not contain personal data from apprentices in order to protect their identity.

E. Evaluation

The effect of the learning unit on learning success and user acceptance is currently being evaluated in a comprehensive field study in the cantons of Zurich and Berne with 75 apprentices split in a VR intervention group and a control group. The quantitative field study is accompanied by qualitative
user experience studies involving additional users at vocational schools.

III. DISCUSSION

The feedback during the agile development phase including apprentices as well as instructors is encouraging but also reveals initial assessments concerning the added value. Learners and trainers from the field do not regard the VR application as a substitute for practical real-life training. However, they clearly see the value of VR as an additional tool that accelerates learning, reinforces routines, and most importantly is equally accessible to all learners. From a technical point of view the haptics are a weak point, as the standard peripheral hardware haptic feedback is limited to a vibration of the controllers. This limits the immersive experience but cannot be solved at the moment.

A most relevant impact on the immersive perception is the interaction concept. The design is a trade-off between simplicity, realistic functionality and pragmatism. For instance, any simplified interaction can be perceived as not sufficiently realistic if it differs considerably from the real-world situation. However, a detailed modeled and designed interaction with, for example, the measurement device consisting of various dials, knobs and displays would require a great deal of time to program without a significant benefit to the learning process. Hence, pragmatism has played an important role during modeling and design.

Regarding future development, the extension of certain features is taken into consideration, namely the possibility to perform additional measurements (e.g. protective conductor check) and that the user can resume sessions after exiting the application. Beyond the scope of the research project, the potential to commercialize the VR learning unit is evaluated by a VR agency.

Finally, the application will undergo modifications to be used in the vocational training of electricians in Tanzania for the Swiss NGO Helvetas. Since real equipment is expensive and training facilities are scarce, not many opportunities exist for apprentices in developing countries to apply the learned knowledge in practice. Evaluating the transferability of a scaled-down version of the prototype to this context is therefore a socially relevant next step in the ongoing project.

ACKNOWLEDGEMENTS

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Abstract—Virtual reality (VR) not only expands the learning field and enriches the learning experience, but also provides an effective presentation for scarce educational resources. However, because VR mainly depends on image processing technology, its application in the field of education mostly stays at the level of knowledge observation, and many challenges are gradually exposed, such as untimely interaction and weak sense of existence. In recent years, haptics has gradually become the development frontier of human-computer interaction, breaking through the limitation of single visual stimulation of VR to a great extent. Some researchers began to explore the teaching mode of VR with haptics, in order to mobilize learners' multi-sensory stimulus responses such as hearing, touch, force and movement, and enhance learners' on-the-spot experience and flow experience. In order to deeply explore the effectiveness of VR with haptics in teaching and explore the regulatory variables affecting this teaching method, 1646 academic papers published from 2010 to 2020 were screened based on WOS and Scopus databases. After meta-analysis of 50 selected research data, it is found that: (1) from the perspective of overall effect, VR with haptics can significantly improve learners’ learning performance and efficiency; (2) Through the analysis of the effects of three regulatory variables, it is found that VR with touch has a positive impact on learning performance; VR with haptics has a positive impact on learning efficiency, especially for learners who have no previous learning experience and take practical skills as their learning goal for a long time. This discovery provides an important data reference for building an effective "virtual reality with haptics” teaching scene.

Index terms—VR, Haptics, learning performance, learning efficiency

I. INTRODUCTION

Revolutionary technological development has changed the means and mode of education. For example, haptic activation devices and VR supported platforms have greatly changed the educational environment of most stakeholders in the education sector [1]. Potential and realized implications suggest that these technological advances give learners the opportunity to learn in a richer media environment, which can be both immersive and interactive to some extent [2]. In addition to the bright prospects of these technological advances, there are still some controversial areas, in which the effectiveness of these advances remains the main concern of researchers, educators and policy makers [3]. For example, VR with haptic are suitable for what kind of teaching environment and what kind of people. Therefore, the conflicting views that support or oppose the effective use of immersive media in education still have the significance of re-examination [4].

Aiming to fill the above-discussed research gaps, we provide a more systematic and detailed account of using VR with haptics in educational settings through employing meta-analytic techniques. Specifically, we attempt to address the research question: (1) What is the overall effect of using VR with haptics on educational outcomes? (2) How do various moderating variables influence the effects of the utilization of VR with haptics? In the following sections, we first provided a brief review of existing educational literature regarding the application of VR and haptics, which will lead to the methodological aspects before illustrating the results. Finally, a detailed discussion based on the meta-analytical findings will be
discussed with the potential theoretical and practical implications in context of haptics and VR.

II. LITERATURE REVIEW

A. Definition of virtual reality and haptics

It is widely acknowledged that VR refers to an immersive environment where the enriched technological flavor is involved [5]. Researchers suggest that learners using VR is one of the modern source to achieve better immersive experience [6]. Distinguished from traditional medium, a prominent structure of VR can be characterized as three-dimensional (3D) [7].

Researchers suggest that haptic feedback is an integration of haptics through sensory skin receptors and kind aesthetic feedback which involves muscle, tendon, and joint sensory receptors [8]. Haptics is defined as a certain process where learners can touch the objects by developing their recognition about the objects through touch [9]. Since it delivers a two-way information flow, it becomes more essential in the areas of distance learning, interactive telemedicine, and computer simulation [10].

B. Application of VR with Haptics in Education

Practitioners and researchers in educational have acknowledged that the utilization of smart tech-devices (which includes VR and haptic devices) can influence learners’ achievements, learnability and smart communication [11]. Prior research indicates that learners have a high level of satisfaction while using VR simulators with haptics [12]. However, the literature holds no noticeable trace till now where the meta-analytical review addressing the effectiveness of haptics incorporation into VR settings in education. For example, in David’s investigation on whether VR with haptic can accelerate motor learning efficiency, concluded that it can improve learners’ learning efficiency. [13]. However, in Mustafa et al.’s findings which involved 16 urologists concluded that the students’ performance worse in VR with haptics [14].

III. METHOD

A. Data source and selection criteria

The current meta-analytical study takes data from the most well recognized data repositories ‘Web of Science’ and ‘Scopus’. All the studies relevant to the VR and Haptics published from 2010 to 2020 were included for further analyses. Four sets of keywords were adopted during the paper searching process: (1) VR related keywords; (2) Haptics related keywords; (3) learning achievement-related and learning motivation-related keyword; and (4) training related keywords.

B. Repositories crawling, extraction and assessment

In the meta-analysis of this study, detailed inclusion and exclusion criteria were made for the selected studies according to the PRISMA literature screening criteria(as shown in Fig.1)[15]. Based on the screening criteria, 1646 academic papers met the keyword retrieval criteria. After reading the abstract, this study made a judgment on whether these articles should be included in the meta-analysis of this paper. Due to a number of studies on some articles, a total of 50 cases were finally included in the meta-analysis.

C. Descriptive and the Selection of regulating variables

According to the basic elements in the design process of general teaching system, the meta-analysis code of this study includes descriptive variables and regulatory variables [16]. Descriptive variables include title, author information, sample size, year of publication and teaching model; Regulating variables include teaching objectives, sample levels and evaluation methods. After classifying the literature reading included in the analysis, the teaching mode is divided into three categories: physical, traditional VR and VR with haptics; The teaching objectives are divided into knowledge transfer and skill training; The sample level is divided into two categories: whether the learners have previous learning experience in the experimental course or not; The evaluation method analyzes short-term effectiveness and long-term effectiveness through immediate test and delay test. The code of adjustment variables is shown in Table I. In addition, the Cohen kappa consistency test was used to evaluate the reliability of the coding process of the paper, three VR education experts evaluated the coding. The kappa reliability was 0.84, reflecting the high coding reliability.

![Systematic process of article selection](image)

**Fig. 1. Systematic process of article selection.**

**TABLE 1. META-ANALYSIS ADJUSTMENT VARIABLE CODING**

<table>
<thead>
<tr>
<th>Adjustment variable</th>
<th>Coding object</th>
<th>Coding types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching objectives</td>
<td>Learning results</td>
<td>(1) Knowledge transfer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2) Skill training</td>
</tr>
</tbody>
</table>
IV. RESULTS

A. Heterogeneity and bias test

In this study, I² statistics are used to define heterogeneity, if the heterogeneity is low (I² < 50%), select the fixed effect model; Conversely, the random effect model (I² > 50%) was selected [17]. The learning performance and efficiency data is expressed by the standardized mean difference (SMD) of the time required for learners to complete the same task with the same accuracy, and is associated with 95% confidence interval (CI). As shown in Table II. (a), in the meta-analysis table on learning performance, Q = 167.771, P = 0.000 < 0.10, I² = 85.695; As shown in Table II. (b), in the table on learning efficiency, Q = 64.900, P = 0.000 < 0.10, I² = 883.051. This data shows that there is great heterogeneity among samples, so the random effect model is selected.

Publication bias is easy to have a great impact on the results of meta-analysis and will lead to the conclusion of bias in meta-analysis. In this study, the funnel diagram and Begg’s rank correlation method are used to test the publication bias [18]. The funnel diagram is obtained by meta-analysis software comprehensive meta-analysis (CMA). The data in the funnel chart show a uniform distribution of the axis of symmetry, indicating that the publication bias used in this meta-analysis is acceptable (See Fig. 2a and Fig. 2b).

![Fig. 2a. Funnel plot analysis for learning performance.](image)

![Fig. 2b. Funnel plot analysis for learning efficiency.](image)

B. The overall effect of VR with haptics on improving learners

The first purpose of this study is to explore whether VR with haptics can improve learning performance and efficiency. From the random effect models in Table II. (a) and Table II. (b), it can be seen that the combined effective values of meta-analysis are 0.261 (P = 0.002 < 0.01) and -0.384 (P = 0.009 < 0.01) respectively, reaching a statistically significant level. Follow the effect value standard defined by Cohen: if the effect value is less than 0.2, it is a small effect; If the effect value is between 0.2 and 0.8, it is a medium effect; If the value of the effect value is greater than 0.8, it is a large effect [19]. Therefore, in terms of overall effect, VR with haptics plays a medium role in promoting learning achievement and efficiency. According to the meta-analysis results in Table III. (a), in terms of improving learning performance, compared with the traditional VR learning environment without haptics, the comprehensive effect value of VR with haptics is 0.465, which is significant at the level of 0.01 (P = 0.009 < 0.01). Compared with physics classroom, the comprehensive effective value was 0.073, which did not reach the statistical significance level (P = 0.782 > 0.05).

According to the meta-analysis results in Table III. (b), in terms of improving learning efficiency, compared with the traditional VR classroom without haptics, the comprehensive effect value of VR with haptics is -0.053, which is significant at the level of 0.01 (P = 0.007 < 0.01). Compared with physics classroom was 0.932, which was significant at the level of 0.001 (P = 0.000 < 0.001). The results of meta-analysis show that VR with haptics has a slight effect on learning efficiency compared with the traditional VR classroom; Compared with physics classroom, VR with haptics not only does not promote, but also inhibits learning efficiency.

C. Analysis of adjustment variable

The second purpose of this study is to explore which regulatory variables will affect the learning efficiency of VR with haptics, so as to seek the effective application situation of this tool in educational application and optimize its technical efficiency. As shown in Table IV. (a) and Table IV. (a), this study makes a meta-analysis on three aspects: teaching objectives, sample level and teaching evaluation. The meta-analysis results in Table IV. (A) show that in terms of academic performance, VR with haptics has a moderate positive impact on the two coding objects of skill learning content (z = 0.234, P = 0.008) and delay test (z = 0.831, P = 0.007). The meta-analysis results in Table IV. (B) show that in terms of learning efficiency, VR with haptics has a great positive impact on three coding objects: skill based learning content (z = -2.192, P = 0.008), previous experience (z = -1.742, P = 0.008) and delay test (z = -3.372, P = 0.001).

V. DISCUSSION

The current study underlined several theoretical and practical implications as discussed in the following subsection. First, by conducting meta-analyses, authors observed that while comparing the physical learning environment or virtual environment without haptics, and learners in virtual learning environment with haptics achieved better learning effect, including learning performance and efficiency. This can lead to
theoretical explanation with the arguments that VR with haptics enables users to gain a highly immersive haptic experience as it provides haptic collocation of physical objects with their corresponding virtual objects, which helps to connect immersive and real world. In addition, VR with haptics helps to enable 3D environment where the user was completely occluded from reality, users’ multi-sensory participation could be significantly stimulated to obtain a sense of presence and media rich experience of flow that they are in a virtual environment [20].

<table>
<thead>
<tr>
<th>Model</th>
<th>Effect value</th>
<th>95% confidence interval</th>
<th>Asymptotic</th>
<th>Heterogeneity test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower limit</td>
<td>Upper limit</td>
<td>Z</td>
</tr>
<tr>
<td>Fixed</td>
<td>0.140</td>
<td>-0.309</td>
<td>0.589</td>
<td>0.612</td>
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<tr>
<td>Random</td>
<td>0.261</td>
<td>0.097</td>
<td>0.425</td>
<td>1.782</td>
</tr>
</tbody>
</table>

TABLE II (B). OVERALL EFFECT OF LEARNING EFFICIENCY

<table>
<thead>
<tr>
<th>Model</th>
<th>Effect value</th>
<th>95% confidence interval</th>
<th>Asymptotic</th>
<th>Heterogeneity test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lower limit</td>
<td>Upper limit</td>
<td>Z</td>
</tr>
<tr>
<td>Fixed</td>
<td>0.053</td>
<td>-0.223</td>
<td>0.330</td>
<td>0.379</td>
</tr>
<tr>
<td>Random</td>
<td>-0.384</td>
<td>-1.096</td>
<td>0.329</td>
<td>-1.056</td>
</tr>
</tbody>
</table>

TABLE III (A). THE INFLUENCE OF VR WITH HAPTICS ON DIFFERENT TEACHING SCENARIOS (LEARNING PERFORMANCE)

<table>
<thead>
<tr>
<th>Elements of instructional design</th>
<th>Coding object</th>
<th>type</th>
<th>N</th>
<th>Effect value</th>
<th>95% confidence interval</th>
<th>Asymptotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacing place</td>
<td>Learning environment</td>
<td>VR</td>
<td>5</td>
<td>0.465</td>
<td>-0.034</td>
<td>0.964</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physics</td>
<td>20</td>
<td>0.073</td>
<td>-0.445</td>
<td>0.592</td>
</tr>
</tbody>
</table>

TABLE III(B). THE INFLUENCE OF VR WITH HAPTICS ON DIFFERENT TEACHING SCENARIOS (LEARNING EFFICIENCY)

<table>
<thead>
<tr>
<th>Elements of instructional design</th>
<th>Coding object</th>
<th>type</th>
<th>N</th>
<th>Effect value</th>
<th>95% confidence interval</th>
<th>Asymptotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacing place</td>
<td>Learning environment</td>
<td>VR</td>
<td>6</td>
<td>-0.053</td>
<td>-0.257</td>
<td>0.408</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physics</td>
<td>19</td>
<td>0.932</td>
<td>0.654</td>
<td>1.210</td>
</tr>
</tbody>
</table>

TABLE IV(A). INFLUENCE OF VR WITH HAPTICS ON LEARNING EFFECTS OF DIFFERENT MODERATOR ESTIMATION (LEARNING PERFORMANCE)

<table>
<thead>
<tr>
<th>Instructional design elements</th>
<th>Coding object</th>
<th>N</th>
<th>Effect value</th>
<th>95% confidence interval</th>
<th>Asymptotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching objectives</td>
<td>skill training</td>
<td>12</td>
<td>0.234</td>
<td>-0.707</td>
<td>1.175</td>
</tr>
<tr>
<td>Knowledge transfer</td>
<td>13</td>
<td>0.110</td>
<td>-0.315</td>
<td>0.534</td>
<td>0.505</td>
</tr>
<tr>
<td>Sample level</td>
<td>Previous experience</td>
<td>14</td>
<td>0.268</td>
<td>-0.529</td>
<td>1.065</td>
</tr>
<tr>
<td></td>
<td>No previous experience</td>
<td>11</td>
<td>0.038</td>
<td>-0.448</td>
<td>0.524</td>
</tr>
<tr>
<td>Teaching evaluation</td>
<td>Test immediately</td>
<td>8</td>
<td>0.192</td>
<td>-0.335</td>
<td>0.720</td>
</tr>
<tr>
<td></td>
<td>Delay test</td>
<td>17</td>
<td>0.431</td>
<td>-0.542</td>
<td>1.404</td>
</tr>
</tbody>
</table>
Second, when the learning goal is skill training, VR with haptics plays a positive role in both learning performance and efficiency. This is mainly because VR with haptics can fully mobilize the collaborative perception of vision and touch, expand learners’ perception form and perception range of practical content, and fill the shortage of single channel visual perception of traditional VR [21]. At the same time, the performance of skill training mainly depends on repeated practice, traditional physical training is often difficult to carry out repeated training due to the lack of training materials or the limitations of conditions [22]. Learners are more likely to express tension and other emotions in the face of scarce experimental materials [23]. VR with haptics overcomes the above difficulties and psychologically allows learners not to worry about the limitations of experimental materials and environment, so it gives learners a relaxed training environment to a great extent [24].

Third, with regard to the learners’ performance, there was no significant difference in whether learners have experience or not. However, with regard to the completion time, there was a significant difference between experienced learners in the two learning environments. Specifically, for inexperienced learners, VR with haptics not only does not promote learning efficiency, but also has an obvious inhibitory effect. But in case of the experienced learners, it took less time to complete the task under the virtual reality condition with haptic feedback. This could be theoretically explained with the arguments that the existing virtual reality technology and haptic feedback technology is in line with the real environment to the certain limit [25]. Specifically, it can be captioned as an easier for experienced learners to use virtual reality with haptic feedback towards completing the learning task quickly because of their previous knowledge accumulation [26]. Yet for the inexperienced learners, due to the fact that they were completely unfamiliar with knowledge and the virtual environment, they needed to explore step by step; thus, their lack of efficacy to handle VR equipment can be noted as a hurdle in acquire knowledge better [27].

Fourth, VR with haptics can promote learners’ achievement and efficiency to a great extent only when delayed testing is adopted. A potential explain for these findings is that learners are not familiar with virtual learning environment at the beginning, they thus will spend more time exploring the interactive features and scope of learning-norms. However, after receiving some trainings, their learning related hurdles been eliminated, and the completion time of learners’ time noticeably reduced. Precisely, it’s been recorded that when the goal of learners is to use virtual reality with haptic feedback for training, the time spent would be shorter than that of the control group, and the effect would be significant [28]. In other words, lack of VR self-efficacy can produce weak positive or negative effect on VR and haptic based learning. However, in case of high VR self-efficacy, VR and haptic support produce significantly constructive results [29].

### VI. VR WITH HAPTICS APPLIED IN EDUCATIONAL SCENARIOS

Educational technology and the needs of educational applications are mutually supportive, thus constantly contributing to the iterative development of both sides. On the one hand, the realities and needs in education guide the integration and innovation of technology. While virtual reality image simulation enriches the form of knowledge representation, learners often lack the experience of learning by doing, and the incorporation of haptic feedback can effectively activate multi-sensory stimulation for learners, enhancing the sense of experience and engagement of students in existing VR teaching. On the other hand, the integration of information technology is also progressing, not only solving current educational problems, but even creating new educational needs. VR with haptics is opening up many new application scenarios and forms of service in terms of knowledge understanding, physiological feedback and remote collaboration.

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**TABLE IV(B). INFLUENCE OF VR WITH HAPTICS ON LEARNING EFFECTS OF DIFFERENT MODERATOR ESTIMATION (LEARNING EFFICIENCY)**

<table>
<thead>
<tr>
<th>Instructional design elements</th>
<th>Coding object</th>
<th>N</th>
<th>Effect value</th>
<th>95% confidence interval</th>
<th>asymptotic</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower limit</td>
<td>Upper limit</td>
</tr>
<tr>
<td>Teaching objectives</td>
<td>skill training</td>
<td>11</td>
<td>-1.289</td>
<td>-2.441</td>
<td>-0.136</td>
</tr>
<tr>
<td></td>
<td>Knowledge transfer</td>
<td>14</td>
<td>0.192</td>
<td>-0.655</td>
<td>1.038</td>
</tr>
<tr>
<td>Sample level</td>
<td>Previous experience</td>
<td>12</td>
<td>-0.973</td>
<td>-2.068</td>
<td>0.122</td>
</tr>
<tr>
<td></td>
<td>No previous experience</td>
<td>13</td>
<td>0.025</td>
<td>-0.881</td>
<td>0.931</td>
</tr>
<tr>
<td>Teaching evaluation</td>
<td>Test immediately</td>
<td>7</td>
<td>0.840</td>
<td>0.170</td>
<td>1.509</td>
</tr>
<tr>
<td></td>
<td>Delay test</td>
<td>18</td>
<td>-1.969</td>
<td>-3.113</td>
<td>-0.824</td>
</tr>
</tbody>
</table>
A. VR+Haptic applied in knowledge understanding

Feedback is an important way to help learners build knowledge and cognition, to stimulate learning through improvement and to enhance the mind-flow experience. In recent years, VR has made efforts to try to implement interactive feedback through gesture recognition based on image positioning. However, as it is still based on visual senses overall, its feedback effect is not ideal. The dual channel of 'visual-touch' feedback, which incorporates haptic perception, has many applications for learners in terms of associative thinking and knowledge transfer understanding.

B. VR+Haptics applied in physiological feedback

From a neuroscientific perspective, tactile feedback effectively stimulates brain neurons in perception perception and plays an important role in the learner's adaptation to the external environment. In a large number of skill-based professions in practical training, two issues need to be addressed: firstly, the problem of limited space and secondly, the problem of enhancing the degree of response to the external environment. The former has been addressed through VR and zero-friction gimbal walkers, for example, while the latter needs to be stimulated by the incorporation of tactile sensors and positioning technologies for different senses.

C. VR+Haptics for remote collaborative teaching or research

Remote collaboration will be widely used in education and research in the future, and it is becoming an important trend to solve complex problems in an integrated manner across regions and platforms. With the increasing popularity of 5G networks on campuses and the enhancement of sensor and simulation technologies, the combination of VR, AR (Augmented Reality) and Haptics is bound to become an effective way of remote collaboration in the future. As force feedback devices mainly include robotic arms and wearable devices, VR+Haptics remote collaboration can take the form of remote co-manipulation and remote correction. Remote collaboration is the collaborative manipulation of a robotic arm by multiple people in different locations, using VR to simulate images of the experimental material. In many complex teaching and research scenarios, multiple people are often required to work together on a task. Tele-recognition is the remote control of the wearable exoskeleton by the controller to perform corrective activities. Tele-education is used extensively in medicine, mainly to assist in the rehabilitation of movement by controlling the wearable exoskeleton of a distant patient.

VII. CONCLUSIONS AND FUTURE STUDIES

According to Mayer’s multimedia cognitive learning theory, the usage of multimedia can provide various information through different sensory channels to learners [30]. However, the utilization of multimedia is not equal to the innovation of teaching methods, it fails to promote students’ learning, as the essence of enjoyment supposed to be smarty managed while communicating and encountering VR environment for learning intentions [31]. In the practical context, VR with haptics requires more efforts to combine with the actual situation and consider various regulatory variables towards maximizing its role and effect. In the current meta-analytical paper, we found that the VR-based instruction with haptics feedback is a useful and efficient means to improve diverse learning outcomes. In addition, the author highly encourages VR with haptics learning environment to be more suitable for experienced learners, more suitable as a practice tool rather than a means of acquiring knowledge, and more suitable for delayed testing rather than immediate testing.

We need to point out the limitations of this study and potential future studies. First the number of included studies are limited because the topic only addressed the VR with haptics in recent decade. A larger number of studies, therefore, are highly encouraged to include towards verifying result analysis as well as to continue future research. The second limitation regards to the educational fields. Most studies used samples from doctors and students pursuing their medical degree, limited studies on pharmacists, dentists. Thus, the research findings may not be generalized to the most extend. Finally, given the fact that the advent of highly immersive VR with haptics rely on the advancement of specific technologies, existing studies thus far mainly involved limited samples. Moreover, since the commercially obtainable haptic devices are diverse, the validity of the different assessments used in the included studies can potentially hold the skewness in the results of each study.

REFERENCES


A Survey of Educational Augmented Reality in Academia and Practice: Effects on Cognition, Motivation, Collaboration, Pedagogy and Applications

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Abstract— Augmented Reality (AR) technology is gaining popularity and adoption by educational pioneers. While there is great excitement about this technology, there is also a lack of systematic understanding of what makes this technology effective or ineffective for education, and the practical and systemic challenges of implementing it at scale in classroom settings. In this research we provide a synthesis of empirical scientific findings about the factual benefits and detriments of this technology (from a dataset of 2023 academic papers, of which 39 were analyzed in depth), and of public opinions about augmented reality in education practice (gathered from a dataset of 86 websites and blog posts, of which 53 were analyzed in depth). We contribute a list of specific cognitive, motivational and social processes that are enhanced by AR technology. We also identify popular curriculum topics and popular AR applications, as well as summarize several factors that are important for educators to consider for integrating AR into classrooms.

Index terms—augmented reality, education, affordances, pedagogy, curriculum, learning gains

I. INTRODUCTION AND RELATED WORK

Augmented Reality (AR) technology and its cousin technology of Virtual Reality (VR), are gaining popularity and adoption by educational pioneers. AR technology combines real-world environments with interactive 3D graphics, such as the ability to see electromagnetic fields around physical objects [16], mathematical formulas in 3D [40], historical depictions of a real neighborhood [51], etc. There is currently great excitement about the potential of AR for educational settings among educators. As seen in a wide variety of blog posts and websites, educators share excitement and futuristic visions, arguing for the potential of AR technology to accelerate student learning, and to transform pedagogical practices. However due to the novelty of this technology, while there is great excitement there is also a lack of systematic understanding of what makes this technology effective or ineffective for education, and the practical and systemic challenges of implementing it at scale in classroom settings. Some empirical data exists in the academic sphere, as researchers have systematically studied the effects of this technology on students in specific contexts, and currently there are many research papers that explore how AR technology interacts with learning processes.

In this research we aim to provide a synthesis of public opinions about augmented reality in education (gathered through websites and blogs), as well as the empirical scientific findings about the factual benefits and detriments of this technology (from academic literature). This synthesis can help teachers, designers, and learning science researchers understand why AR is effective for learning, as well as to have a set of considerations that teachers and designers can use to create and curate AR-enabled learning environments. In this systematic review we answer the following research questions:

RQ1: What are the specific cognitive, motivational, and social processes that are impacted by augmented reality technologies in educational settings?

RQ2: For what curriculum topics could AR provide a benefit, and what are popular AR educational apps that have been used by teachers?

RQ3: What factors should teachers and students consider when designing or implementing novel AR learning activities & environments?

Previous research that synthesized augmented reality literature has focused on factors such as the advantages and challenges of AR in education [41], [42] identified trends and tendencies [41], [43]-[45] and examined different tools and evaluation methods for AR-based educational technology [49]. Although these literature reviews have provided overviews of the uses and benefits of augmented reality, the review literature is lacking an in-depth analysis of statistically significant findings. Most surveys did not explicitly limit themselves to papers which have a hypothesis-driven experimental methodology - thus, the findings are gathered from various
research methods which may not be statistically generalizable beyond specific case studies or informal observations. In contrast, our review investigates specifically only studies that have performed statistical analysis comparing AR to non-AR systems, allowing us to make claims about which specific processes are actually enhanced by educational AR. Additionally, recent reviews focused on a specific use case such as using AR for STEM learning [48], or a specific age group such as primary and secondary school education subjects [46], or a specific learning context such as formal education [45]. Such studies are valuable for understanding the needs of a specific target group but the results are not generalizable to many learning scenarios. Instead, in this survey, we are interested in understanding the effects of AR in general, thus we did not restrict to specific age groups or learning activities. Furthermore, it is important to note that in the literature, there is no consensus on the definition of augmented reality. We have encountered many studies that refer to VR or other tangible and projection technologies as “augmented reality”. For this reason, we differ from existing surveys by limiting the term “augmented reality” to specifically match Azuma’s [52] criteria that AR applications must (1) combine real and virtual content, (2) interactively respond to user input, and (3) respond to object manipulation in 3D space. Finally, to our knowledge, there is no other literature review that includes websites and blog posts in their review. By doing so, we have gained an insight into the practical perceptions and considerations from public understanding of educational AR, and we reflect on how these compare to findings of actual empirical studies.

II. METHODS

For this review our dataset includes academic papers and website posts. Four researchers were part of this process, first gathering all publications, then filtering for inclusion/exclusion criteria, then manually coding them in a spreadsheet, followed by thematic analysis presented in the results.

<table>
<thead>
<tr>
<th>Step</th>
<th>Papers Excluded</th>
<th>Papers Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Data Collection</td>
<td>--</td>
<td>2023 (Initial)</td>
</tr>
<tr>
<td>Semi-Automatic Filtering (Titles)</td>
<td>1532</td>
<td>489</td>
</tr>
<tr>
<td>Manual Filtering (Abstracts)</td>
<td>420</td>
<td>69</td>
</tr>
<tr>
<td>Full Coding</td>
<td>30</td>
<td>39 (Final)</td>
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</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Websites Excluded</th>
<th>Websites Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Data Collection</td>
<td>--</td>
<td>86 (Initial)</td>
</tr>
<tr>
<td>Full Coding</td>
<td>33</td>
<td>53 (Final)</td>
</tr>
</tbody>
</table>

A. Papers Dataset

To be considered for this review, papers had to meet all the following criteria:

- Published between 2010 - 2021
- Published as peer reviewed conference and journal proceedings papers (i.e. no workshop papers)
- Described an AR system designed for educational purposes
- Presented results of an experimental study involving statistical analysis (i.e. we did not include literature reviews, surveys, or purely qualitative case studies)
- Studied augmented reality (ex: we excluded papers that only studied virtual reality or other technologies), matching Azuma’s [52] criteria: (1) combine real and virtual content, (2) interactively respond to user input, and (3) respond to object manipulation in 3D space (i.e. we excluded papers where virtual AR content is simply projected or not tracked in 3D)

Papers were analyzed through a three-phase filtering process (Table I). During initial data collection, 2023 papers were first gathered from proceedings of conferences and journals focused on augmented reality (ex: IEEE International Symposium on Mixed and Augmented Reality; ACM Conference on Human Factors in Computing Systems; IEEE Conference on Virtual Reality; Journal of Computers and Education; etc). We selected publication venues typically associated with ACM or IEEE, and searched material through digital libraries accessible to the researchers’ institution, ensuring they meet the inclusion and exclusion criteria below. In the following semi-automatic step, duplicates were removed and titles searched to remove papers not matching our inclusion criteria. In the following manual phase, researchers manually read paper abstracts to further ensure inclusion/exclusion criteria. The full text of the remaining papers was read and coded by separate researchers. The results from the final 39 papers were thematically analyzed.

At the beginning of the manual coding process, researchers commonly coded 15% of papers and discussed any inconsistencies, repeating until inconsistencies were resolved. The final coding scheme included information about the general research design (such as research questions, participant demographics, curriculum and user study tasks and conditions, research metrics), research results (including the type of metrics tested, and which results were statistically significant).

B. Websites Dataset

To be considered for review, websites had to meet all of the following criteria:

- Published between 2019 - 2021, to reflect current applications and trends
- Can be a blog or standalone website
- Described the use of augmented reality for educational purposes
- If discuss AR applications, must focus on more than one AR application and must not be sponsored by a single company (lack of sponsorship was assumed when a website discussed applications from multiple sources, was not hosted on a software development company’s website; AND did not specify the page was sponsored).

In this paper we refer to blog posts and standalone websites under the generic term “website posts”, or simply “websites”. Websites for review were collected through searching publicly available sources. Researchers conducted Google searches for the following terms: (“augmented reality”) AND (“teachers” OR “education” OR “classroom” OR “students” OR...
“learning”). Initially 83 total website posts were reviewed; 33 of these websites were excluded because they did not meet the criteria, resulting in 53 websites for final analysis (Table II). A coding scheme was created to collect information about curriculum topics, names of AR applications, benefits of challenges of using AR in educational settings, what factors teachers should consider when using AR, as well as tips for implementing in learning environments.

III. RESULTS AND DISCUSSION

A. RQ1: What are the Specific Cognitive, Motivational, and Social Processes that are Impacted by Augmented Reality Technologies in Educational Settings?

In this section we organize our findings in the categories of cognitive processes, motivational processes, and social processes that are impacted by augmented reality technology. We begin each section with a discussion of findings from website posts, where authors typically report firsthand impressions and practical applications from AR applications used in educational contexts. We follow with a detailed discussion of statistically significant empirical results from the academic research literature which have studied specific components and processes and empirically shown whether AR is better or worse than non-AR alternatives. The results of academic studies are summarized in Table III.

1) Cognitive Processes

When a learner is engaging with educational content, various cognitive processes can become engaged to ensure effective learning. For example, learner attention may need to be maintained on activities relevant to the learning content; long term memory may be needed to bring background knowledge to conscious awareness, or short-term memory needs to track previous activities; and cognitive load will be influenced by the design of the learning activity. The design of the learning experience, as well as the medium of the experience (including whether AR technology is present or not) will influence the impact on the learner.

| Constructs evaluated by academic studies | Which medium (AR or Non-AR) was generally better?
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>COGNITIVE PROCESSES</td>
<td>Content Learning: AR</td>
</tr>
<tr>
<td></td>
<td>Memory: Unclear</td>
</tr>
<tr>
<td></td>
<td>Cognitive Load / Task Load: Unclear</td>
</tr>
<tr>
<td></td>
<td>Attention and Flow: AR</td>
</tr>
<tr>
<td>SOCIAL PROCESSES</td>
<td>Communication &amp; Group Dominance: AR</td>
</tr>
<tr>
<td></td>
<td>Guided Exploration: Unclear</td>
</tr>
<tr>
<td>MOTIVATION AND USABILITY</td>
<td>Ease of Use &amp; Overall Usability: AR</td>
</tr>
<tr>
<td></td>
<td>Interest &amp; Motivation: AR</td>
</tr>
<tr>
<td></td>
<td>Usefulness &amp; Relevance: AR</td>
</tr>
<tr>
<td></td>
<td>Confidence &amp; Perception of Self Efficacy: Unclear</td>
</tr>
</tbody>
</table>

TABLE III. CONSTRUCTS EVALUATED BY ACADEMIC STUDIES WHEN COMPARING AR TO NON-AR, AND OVERALL RESULTS

a) Results from Websites

The websites dataset provides information about the current public expectations and beliefs about augmented reality. It suggests that AR could have substantial capacity to enhance cognitive processes. Websites mentioned that AR technology’s ability for visualizations can enable students to learn faster (mentioned in 44% of website posts), interactivity of AR and the ability for students to “learn by doing” can increase memory retention (mentioned in 22% of websites), and AR can help make abstract topics more concrete (20% of websites). AR can be well suited for project-based learning and simulated learning activities (10% of websites) and recreating past experiences (4% of websites). AR can also benefit through being multisensory (8% of websites), and can lead to improved physical task performance (6% of websites).

b) Results from Academic Papers

The academic research papers dataset provided nuanced empirical findings about the various processes enhanced by AR technology, with results grouped in the following categories:

1. Content Learning: In the research papers literature, we surveyed experimental studies using quantitative measures to compare educational augmented reality with other traditional methods. It has been found that students who used AR showed better learning performance than the ones who learned through traditional methods such as text [9], [24], [28], [33], [38], verbal instruction [6], [8], [28], mobile application [5], or web-based learning [4], [7]. Better learning outcomes due to AR have been observed, for example, in math [7], physics [4], [8], [23], [36] and other science topics [5], [9], [33] (also see research question 2 below). However, some studies reported did not find significant differences between AR vs non-AR groups in geometric analysis [33], theoretical physics questions [4], reading and spelling [35], or learning language [15]. This indicates that for some topics AR technology is not better than more traditional approaches. Furthermore, some studies found that using AR can result in worse learning performance in specific areas, for instance, understanding the relationship between physics concepts involving kinesthetic forces [23, 36].

2. Memory: Memory performance measures can give us insight into what has been learned in an activity and what has been retained in the long term. Since AR learning experiences have shown to be more motivating and engaging [2], [5]-[7], [17], [22], one would expect the experience and the content to be more memorable. However, studies measuring memory performance have failed to find a significant difference between AR and non-AR groups, for example, in measuring the number of words [15] or paintings recalled [31]. On the other hand, [24] found that a 3D tangible interface was more effective for memorization than using 2D paper representations. Based on these results, we can infer that simply visualizing things in AR might not be enough to increase memory performance.

3. Cognitive Load / Task Load: When introducing new technologies into a classroom setting, it is important to ensure that the students’ working memory resources are not used up by the complexity of the application. Using AR has been shown to reduce the physical and cognitive demand of a learning task [10], [20] by freeing the learner’s hands and removing the need to switch back and forth between the physical objects and the
learning content, which is overlaid on top of the physical world in AR. On the other hand, the physical demand of using an AR headset was shown to be higher compared to using a desktop PC [16] possibly because of carrying the weight of a headset and lack of familiarity with the interface, which increased the task load. However, these results vary among the nature of the task, as research in [1], [5] showed that using an AR HMD may not provide extra advantage in reducing the cognitive load, and found no significant difference between AR and non-AR groups.

**Attention and Flow:** Psychological flow is a state of being present, attentive and engaged with the learning content, and such a state leads learners to feel pleasure, dedication and perseverance in the learning activity [53]. AR learning content has been shown to be more effective than non-AR alternatives when measuring student attention, involvement and focus [7], [5], [37], [23] and when measuring flow [4]. However, the impact of AR on attention was not significant in one study [37] comparing AR to video recordings, indicating that the effect depends on the type of user experience.

2) **Social Processes**

Learning in group settings can be effective because collaborative learners are able to solve more complex problems than they would individually, they can persevere for longer periods of time, and can engage in peer teaching activities that allow them to reinforce and check their own understanding. In this section we present results about AR technology’s impact on social processes.

a) **Results from Websites**

From the websites dataset, the benefits of AR is believed to be potential for increased collaboration and communication skills (mentioned in 16% of websites), improved safety and security in learning experiences (14% of websites), and the ability to connect students at long distances (14% of websites). Additionally, AR may enhance learning accessibility (10% of websites) since it does not depend on books or supplies, and in many cases is cost effective in comparison to VR (10% of websites). However, hardware is believed to be expensive to make available to all students (18% of websites), and AR can be difficult to implement without outside assistance or training (20% of websites).

b) **Results from Academic Papers**

The academic papers provided empirical perspectives on AR’s ability to support group collaboration, in the following categories:

**Communication and Group Dominance:** Research papers indicate that augmented reality can be useful to help collaborators externalize their thoughts by creating annotations into the real world, or by having external representations to ground their communication. AR was found to benefit communication processes. For example, in [36] it was reported that groups who used AR typically communicated by referring to the external representations provided through augmented reality, rather than creating new ones through drawings. AR groups also spent more time teaching each other than non-AR groups. Similarly, in [17] AR reduced the dominance exhibited by strong leaders and caused more balanced group dynamics. However, in [29] there were no significant differences found between AR vs non-AR groups, when studying the number of help requests initiated by participants, indicating that for some contexts AR does not make a strong difference to communication.

**Guided Exploration:** When groups have access to more information about a problem (through augmented reality displays or any other technologies), this availability of information may encourage groups to ask more questions because more aspects of a problem become more salient. For example, in [36] and [23], it was found that augmented reality was better than non-AR technology in improving task time, whereby AR groups completed the task faster. However, in [23] it was also found that AR groups ignored parts of the learning content, and also didn’t use as much of the physical tools available compared to the non-AR groups. This hints at the possibility that AR visualizations focus the learner’s attention on information that is displayed, but may detrimentally cause learners to not use all of the tools available at their disposal.

3) **Motivation and Usability**

When users feel motivated to engage with a learning activity, and when the interface is learnable and easy to use, they are likely to persist in being present with the learning content even when faced with challenges. On the other hand, when the user experience is lacking and users are not motivated to engage, then users may not engage with the full content and the possible learning benefits may be lost.

a) **Results from Websites**

Examination of the website dataset revealed consistent beliefs that AR may be effective in increasing student motivation. 54% of websites mentioned that AR has the capacity to make learning more interesting, fun, and engaging. Specifically, students may be able to take on a more active role in their own learning with AR, and learning may become more personalized through the adoption of AR. The potential for gamification in AR and the ability to introduce interactive puzzles/quizzes can enhance homework assignments and make tests more engaging by presenting students with 3D models.

b) **Results from Academic Papers**

Academic literature provided more nuances on the dimensions of motivation and usability in the following categories:

**Ease of Use and Overall Usability:** From the academic papers, research that has shown that when users are asked their subjective perception about AR experiences in contrast to non-AR alternatives, the AR experiences were typically experienced to be overall better [3], [9], [8], [20], and specifically more easy to use [38], [3], [39], more learnable [10], [37], more responsive [3], or comfortable [10]. The reason for these results may be that AR is intuitive to use: a user simply moves their body or the augmented objects and observes the effects from three dimensions; in contrast, learning through desktop PCs requires understanding of mouse and keyboard interactions, and paper/video instructional media is not responsive to user actions. It is worth noting that in some cases AR was not statistically different from non-AR alternatives when comparing on factors such as overall usability [15], ease of use [3], [16], or responsiveness [3].
**Interest and Motivation:** Augmented reality experiences can be highly motivational and engaging, in part due to the novel experience of observing 3D content mixed with real objects, and due to the interactivity and personalized learning that is permitted by digital experiences. Interest and motivation has been measured through a variety of metrics, such as in studies that show AR users, when compared to non-AR users, feel the experience is more fun and motivating [2], [5]-[7], [17], generates higher satisfaction [7], [38], [5], [30], [37], more curiosity and interest to engage for longer [17], [22], feels more aesthetically and visually pleasing [3], [23], and creates more endurance [17]. In a few studies, no significant results were found when AR to non-AR desktop interfaces in terms of challenge [4], [16] or frustration [16].

**Usefulness and Relevance:** Beyond the short term motivational effects, being able to see the usefulness and relevance of a learning experience can make students have a more meaningful experience that personally engages them and even encourages transfer to other contexts in their lives. Learners feel that an AR experience is more relevant than non-AR approaches [7], [5], more useful [38], [30], and generally more preferred [10], [39].

**Confidence and Perception of Self Efficacy:** When students gain confidence and feel their skills are high enough to be effective at doing a task, then they will want to engage and persevere with a learning experience. Such confidence and self-efficacy do not merely influence the short term engagement with an experience, but also have potential to change student career paths. Compared to non-AR approaches, AR has led learners to feel higher confidence [5], [37] and higher self-efficacy [23], [36]. However, some studies did not find significant effects in some metrics of confidence or curiosity [7], [23], and in one study it was found that perceived performance in AR was lower than in a desktop-based alternative [16], indicating that differences in design and usability can hinder student self perceptions.

**B. RQ2: For What Curriculum Topics Could AR Provide a Benefit, and What are Popular AR Educational Apps that Have Been used by Teachers?**

In this section we present the wide variety of curriculum topics and popular AR applications that have most frequently appeared in our dataset. Table IV shows the most popular curriculum topics applied to AR according to websites (Table IV left) and research papers (Table IV right). When counting the number of websites mentioning a specific curriculum topic, we found that some websites referred to a specific science field (ex: “physics”), while others mentioned “science” in general; for this reason, when reporting the popularity of curriculum topics in Table IV, the sub-fields of science do not add up to the total percentage of websites mentioning science. One common theme between academic papers and websites is that Science ranks the highest among all the curriculum topics AR is being used for, and Medicine/Biology topics are highly popular in common, while Language and Literacy appears relatively popular in both datasets. Interestingly, Physics was popular for research papers but not highly cited in websites; while Anatomy and Space were popular in websites but not in research literature. Furthermore, using AR as an Authoring Tool was highly cited in websites indicating a strong need for authoring tools by students and teachers but was not popular in AR research. Other topics differed in popularity, for instance websites Math, History and Art while papers do not cover these deeply. One possible explanation is that most applications in websites are mature applications for students, while academic research tries to explore experimental possibilities that might be difficult to implement in classroom settings.

<table>
<thead>
<tr>
<th>Curriculum / Content</th>
<th>% Sites</th>
<th>Curriculum / Content</th>
<th>% Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science</td>
<td>52%</td>
<td>Science</td>
<td>36%</td>
</tr>
<tr>
<td>Anatomy</td>
<td>16%</td>
<td>Physics</td>
<td>14%</td>
</tr>
<tr>
<td>Space</td>
<td>10%</td>
<td>Biology</td>
<td>10%</td>
</tr>
<tr>
<td>Medicine</td>
<td>10%</td>
<td>Anatomy</td>
<td>3%</td>
</tr>
<tr>
<td>Chemistry</td>
<td>8%</td>
<td>Astronomy</td>
<td>3%</td>
</tr>
<tr>
<td>Biology</td>
<td>6%</td>
<td>Aerospace</td>
<td>2%</td>
</tr>
<tr>
<td>Astronomy</td>
<td>4%</td>
<td>Environment</td>
<td>2%</td>
</tr>
<tr>
<td>Geology</td>
<td>2%</td>
<td>Language and literacy</td>
<td>7%</td>
</tr>
<tr>
<td>Physics</td>
<td>2%</td>
<td>Coding</td>
<td>2%</td>
</tr>
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<td>Botany</td>
<td>2%</td>
<td>Science museum</td>
<td>2%</td>
</tr>
<tr>
<td>Authoring Tool</td>
<td>26%</td>
<td>Graphic design</td>
<td>2%</td>
</tr>
<tr>
<td>Math</td>
<td>22%</td>
<td>Library</td>
<td>2%</td>
</tr>
<tr>
<td>History</td>
<td>18%</td>
<td>Geometry</td>
<td>2%</td>
</tr>
<tr>
<td>Art</td>
<td>16%</td>
<td>Warehouse operation</td>
<td>2%</td>
</tr>
<tr>
<td>Foreign Languages</td>
<td>12%</td>
<td>Archaeology</td>
<td>2%</td>
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<tr>
<td>Virtual Field Trips</td>
<td>10%</td>
<td>Artifacts</td>
<td>2%</td>
</tr>
<tr>
<td>Physical Training</td>
<td>8%</td>
<td>Social emotional</td>
<td>2%</td>
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<tr>
<td>Reading</td>
<td>6%</td>
<td>Learning</td>
<td>2%</td>
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<tr>
<td>Computer Science</td>
<td>4%</td>
<td>Makerspace</td>
<td>2%</td>
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<tr>
<td>Writing</td>
<td>2%</td>
<td>Logistics</td>
<td>2%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>2%</td>
<td>Art museum</td>
<td>2%</td>
</tr>
<tr>
<td>Geography</td>
<td>2%</td>
<td>Factory machine tasks</td>
<td>2%</td>
</tr>
<tr>
<td>Logic</td>
<td>2%</td>
<td>Factory machine tasks</td>
<td>2%</td>
</tr>
<tr>
<td>Journalism</td>
<td>2%</td>
<td>Factory machine tasks</td>
<td>2%</td>
</tr>
</tbody>
</table>

**Table V. Popular AR Applications Appearing in Websites**

<table>
<thead>
<tr>
<th>AR App</th>
<th>Curriculum / Content</th>
<th>% of Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoSpaces Edu</td>
<td>Authoring</td>
<td>16%</td>
</tr>
<tr>
<td>Merge Cube</td>
<td>Authoring &amp; Simulations</td>
<td>10%</td>
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<tr>
<td>Metaverse</td>
<td>Authoring</td>
<td>10%</td>
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<tr>
<td>Moatboat</td>
<td>Authoring</td>
<td>10%</td>
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<tr>
<td>Catchy Words AR</td>
<td>Word Learning</td>
<td>10%</td>
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<tr>
<td>Curiscope</td>
<td>STEM</td>
<td>10%</td>
</tr>
<tr>
<td>3D Bear</td>
<td>Authoring</td>
<td>8%</td>
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<tr>
<td>World Brush</td>
<td>Art</td>
<td>8%</td>
</tr>
<tr>
<td>Anatomy 4D</td>
<td>Anatomy</td>
<td>6%</td>
</tr>
<tr>
<td>Elements 4D</td>
<td>Chemistry</td>
<td>6%</td>
</tr>
<tr>
<td>Experience Real History</td>
<td>History</td>
<td>6%</td>
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</tbody>
</table>
Table V presents the most frequently mentioned AR apps from the websites. The most commonly referenced apps are authoring tools such as CoSpaces Edu (16% of websites) which is a platform utilizing AR to support 3D creation and coding skills for children and teachers; Merge Cube (10% of websites) which is a platform and kit for accessing educational AR simulations; Metaverse (10% of websites) allows teachers and students to gamify learning through the creation of interactive content in AR; and Moatboat (10% of websites), a speech-based creation engine. Other top popular apps include Catchy Words AR (10% of websites) which presents a word game used to enhance vocabulary learning in early childhood; and Curiscope (10% of websites) which enables students to learn about the human body and other STEM topics by utilizing AR visualizations on t-shirts and classroom posters. Notably, all these applications are able to be used on mobile or tablet devices, which may make it easier for teachers to use in a classroom setting, as no other bulky or expensive equipment is required.

C. RQ3: What Factors Should Teachers and Students Consider when Designing or Implementing Novel AR Learning Activities and Environments?

Educational applications contain specific design features, and they typically exist within a larger context. Thus, multiple factors may contribute to their success. Our analysis of websites revealed the following topics for considering in designing AR for educational settings:

Accessibility: The most discussed barrier to consider is whether AR experiences require expensive hardware or complicated software, this issue being mentioned in 18% of websites. While there are a lot of AR applications that can be run just with an internet-enabled smartphone or tablet and no other hardware, some apps are only available in certain operating systems or have certain technical requirements such as camera quality or OS versions. The availability of devices that match with software could be expensive for enabling a whole classroom. Additionally, some AR applications require purchase of physical objects - for example, Merge Cube provides a low-cost solution using a physical cube, but to gain a better experience, students can purchase an AR headset holder. Providing such standardized hardware for whole classrooms can be challenging.

Technology evolution: Some augmented reality apps are still in the development stages and are still working out bugs. Wherever possible, teachers should aim to test out the app themselves first to make sure they feel comfortable using the system and that interface problems will not interfere with students’ learning experience. Additionally, we found that research papers covered a variety of AR technologies; among the most popular are mobile devices (38%), head mounted AR displays (36%), desktop computers (18%). On the other hand, the scope of AR technology in the websites is very narrow, whereby 96% of the websites talked about AR applications with smartphone and tablet devices. This indicates there is a gap between what is being researched vs. what is actually used in the classroom. More efforts and investment are needed in order to convert experimental AR research technologies into practical applications for classrooms, and as technologies evolve (ex: smartphones with 3D cameras) we will see more complex applications in classrooms.

Space requirements: Some of the websites discussed the physical space needed for the experience. Many AR apps require open spaces where digital images can be projected into the real world, and where students can move around to see the content from different angles. Some applications even require walking around in a large space, or being outside where GPS signals can be used. These requirements limit the contexts where AR applications can be used.

Teacher support: Not every teacher or student is technology savvy. 6% of the websites pointed out that teachers should consider the level of difficulties to implement or to integrate the AR experience into the classroom environment and into the curriculum. For example, one teacher said despite the extensive support from her school’s administration and IT department, there were technical issues with the school firewall blocking the applications. Beyond software reliability, some websites discussed how teacher and student training is vitally important, and others mentioned the need of an ecosystem and support from others to develop good ways to teach with this new technology.

Suitability to audience and goals: Teachers should choose the apps that are suitable to students needs, curriculum and teaching goals. Individual learners may respond very differently to using AR, and some students may get distracted from the learning content by the AR experience itself. Teachers should continuously monitor students’ experiences when using AR and provide additional supports where necessary. Depending on the age and general purpose, the functions of the apps can differ widely; for example, 3D Bear claims they are for ages 3-17, while Merge Cube is more appropriate for age 10+. Some websites also mentioned it is important to help students differentiate reality from virtual content, especially for younger students who may not understand that they are seeing a simulation.

Pedagogical approaches: Some of the websites mentioned using AR for remote learning, whereby students can use the applications at home on their own devices. Also, in many instances AR may prove more useful as a supplemental instructional tool rather than as a primary means of instruction. Teachers should consider how to pair AR experiences with other instructional practices, and how AR may transform practices. For example some websites mentioned that the teacher will become more of a “guide on the side” rather than the traditional “sage on the stage”. Finally, some websites proposed the possibility to combining AR and VR applications, as they can be used for different purposes (AR to extend current physical objects and places, and VR to transport students to different places).

Contextualizing the content: When choosing which application to use, teachers need to think about what goal they are trying to reach with this technology, and how the technology can support this goal. It is important to be aware that AR (and VR) content can be overwhelming for students to process, and that each student may take a personal path through the learning content. Therefore it is important to support students in setting expectations and contextualizing engagement beforehand; and,
after the experience, to reflect as a whole class on what students experienced and how it ties to the curriculum.

IV. CONCLUSION AND LIMITATIONS

This research provided a synthesis of public opinions about augmented reality in education (gathered from a dataset of 86 websites and blogs, of which 53 were analyzed in depth), as well as the empirical scientific findings about the factual benefits and detriments of this technology (from a dataset of 2023 academic papers, of which 39 were analyzed in depth). We identified specific cognitive, motivational, and social processes that are enhanced by AR technology. We also identified popular curriculum topics and popular AR applications, and we have summarized several factors that are important for educators to consider for integrating AR into the classroom.

We acknowledge two limitations about the generalizability of these findings. First, a part of the dataset is generated from websites that contain popular opinions and expectations; these are not scientifically measured findings, and should be followed by rigorous studies. Additionally, the review findings are highly contextual: first, the academic research is typically done in controlled settings: where the results may generalize only to similar contexts that contain similarly-controlled variables; and second, the current popular subjects and applications of AR are generated from applications that have specific designs, thus it is possible that other applications in the same domains may yield different results. While these results indicate general directions where AR may be beneficial or detrimental, these results may change as different applications are developed and evaluated under varied conditions.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES


WebVR in the Facilitation of Model United Nations Simulations

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Abstract—A pilot study that explores the design, implementation, and affordances of using a virtual learning environment (VLE) in the form of highly customized WebVR in Model United Nations (MUN) simulations. A digital twin of the UN Security Council Chamber in New York was created for the simulations. A small group of students (n=7) take part in a series of simulations in virtual reality to simulate a session for the UN Security Council in virtual reality. A series of sessions with different objectives that seek to explore the affordances of WebVR as an online collaborative tool. The study documents the complete journey of the design of this intervention from training and onboarding participants, to customizing simulation parameters, and observing/polling participation for acceptance/reactions. The design and analysis come from both the perspectives of a veteran MUN facilitator seeking best practices and an educational technologist looking for design principles. The study analyzes the perspectives from the participants and facilitators to find hints at best practices and design principles for MUN simulations in VR. The findings show the need for iteration or re-design of activities from those of more traditional MUN facilitation such as face-to-face or teleconference to align with what VLEs can offer.

Index terms—Model United Nations, cooperative online international learning, virtual learning environments, webVR

I. INTRODUCTION

Model United Nations (MUN), with a history of over 70 years, is an established learning activity conducted around the world as a means of simulating international diplomacy, deepening students’ understanding of the role of the United Nations and increasing awareness of global issues. These learning simulations have been employed in various international relation education and intercultural events around the world [1]. MUN requires students to role-play, research and establish positions that may be very different from their own personally, which has shown to be an effective learning strategy [2], [3]. Every student represents a country that is not their own and this ensures that they examine different viewpoints, are exposed to different perspectives and further develop their own opinions. MUNs use a set of rules and procedures that simulate real meetings of The United Nations and delegates are expected to conduct themselves as diplomats of their assigned countries, working with each other to write resolutions on agenda items before the UN, while practicing negotiation strategies and techniques.

Model United Nations was introduced to Japan in 1983 and has continued to grow and develop in Japan amongst Japanese universities as well as at international and domestic secondary schools [4]. The Japan University English Model United Nations (JUEMUN), which began in 2010, is organized over 3 days with over 150 Japanese university students participating in this English only event. Previous studies on such simulations showed promise for language learning in practical and vocational contexts [5]. In 2020 and 2021 JUEMUN was conducted solely online due to the ongoing COVID-19 pandemic. After the JUEMUN online conference was successfully concluded in summer of 2021, the idea of combining VR and MUN simulations was considered in order to allow student delegates the chance to participate with avatars in a VR environment while conducting an MUN meeting. Faculty were interested in observing the effects of how simulations in this virtual environment could be utilized to further develop students’ negotiation strategies for use in face-to-face MUN events.

II. RESEARCH METHODOLOGIES

A. Research Design and Questions

As much of the staff and student body had no experience in the use of WebVR for MUN or even online simulations, an iterative approach was sought to allow for new information and observations to inform revisions throughout the design and implementation. A design-based research approach was adopted to fit this iterative style in order to give some flexibility to the design of the simulation and to also allow for improvements as the study progressed. Design-based research is a growing tradition in educational research as it fits into the cyclical patterns of both academic calendars and technology development [6], [7]. The goals of the study are to find practical affordances of WebVR in MUN simulations and to begin to form a framework for best practices into its implementations. As will be later discussed, the iterative process was included in several stages of both the study and the intervention itself. This allowed for additions and changes into aspects of the simulation such as moderation, virtual environment design, and activity facilitation.

TABLE I. RESEARCH QUESTIONS

<table>
<thead>
<tr>
<th>#</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1</td>
<td>What affordances come from using WebVR for MUN simulations?</td>
</tr>
<tr>
<td>RQ2</td>
<td>What are barriers to stakeholder acceptance of using WebVR in MUN simulations?</td>
</tr>
</tbody>
</table>
B. Research Instruments

As the approach to this study was based in the iterative process and using design-based research methodologies. Simple instruments were used and repeated between each cycle of implementation.

Observations were made and reflected on after each session to make appropriate changes to the virtual environment and activity design. A short survey was given to participants after every session to gather impressions and measure satisfaction. As this was voluntary the survey was not mandatory to complete. The questions were designed less to get comparisons between modes of MUN simulations but more to get a measure of how changes were enabling participant satisfaction as the sessions progressed.

The number of participants and responses for the Likert questions will not produce any significant conclusions in analysis, but as the approach of the study is design-based, we show our work here to have the ability to replicate the process in later iterations and studies.

Most of the insight and analysis from this study will concentrate on facilitator observations and open-ended question responses from the survey.

C. Intervention Design

The first stages of design were built upon previous studies on virtual simulations in other contexts. We took references from interventions in medical, aerospace, and technician-training to gain a wide perspective of design approaches. These approaches were varied and also gave further evidence to support prior studies done with board games and augmented reality in other learning contexts [8], [9]. The main themes were to find and isolate the main affordances of VR such as agency, immersion, novelty, motivation, identity, and others that best gave value to MUN simulation facilitation and design to best harness those affordances. While also looking to minimize some possible downsides of using VR such as technology literacy, bandwidth and processing disparities, accessibility, and platform agnosticism [10], [11].

D. VLE Design

Most MUN simulations are made to resemble what happens in the General Assembly of the United Nations, bringing together large numbers of students, sometimes in the hundreds, to discuss issues and draft resolutions on a host of world issues. Recently, these large-scale simulations have also been conducted virtually using teleconferencing software like Zoom or Google Meet. WebVR environments, although very accessible due to it being available on most Internet capable devices through a web browser, can also have limitations of needing much higher processing capabilities and data bandwidths than Zoom. This meant that the number of participants for the study was to be limited. This suggested a different simulation to be used and as the United Nations Security Council (UNSC) had limited members it was decided to use it as a basis from which to start designing an environment and scenario. Using Blender and other 3D rendering tools, a digital twin was constructed of the UNSC chambers from photos and 360 virtual tours available online. The physical location was altered to help facilitate the movement and interaction of the virtual participants as well, such as widening the spaces between chairs to move between and adding meeting spaces.

The survey was made to allow for answers about other online MUN participation and VR participation as well, in the hopes of seeing how perceptions changed after each session. Using the first set of responses as a control it was hoped to confirm if successive iterations were made in improving in the experience and acceptance of the use of VR in the simulations.

The survey questions from the survey.

<table>
<thead>
<tr>
<th>#</th>
<th align="left">Survey Questions</th>
<th>Question Type</th>
<th>Question</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td align="left">I enjoyed my experience at <strong>face-to-face</strong> MUN simulations. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>I enjoyed my experience at <strong>face-to-face</strong> MUN simulations. (7 meaning highly agree)</td>
</tr>
<tr>
<td>2</td>
<td align="left">My <strong>face-to-face</strong> MUN experience felt like I was in a <strong>REAL UN</strong> situation. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>My <strong>face-to-face</strong> MUN experience felt like I was in a <strong>REAL UN</strong> situation. (7 meaning highly agree)</td>
</tr>
<tr>
<td>3</td>
<td align="left">My <strong>face-to-face</strong> MUN experience motivated me to learn more about the UN and related things. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>My <strong>face-to-face</strong> MUN experience motivated me to learn more about the UN and related things. (7 meaning highly agree)</td>
</tr>
<tr>
<td>4</td>
<td align="left">I want to do a <strong>face-to-face</strong> MUN again. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>I want to do a <strong>face-to-face</strong> MUN again. (7 meaning highly agree)</td>
</tr>
<tr>
<td>5</td>
<td align="left">Please take a moment and tell us what was different about your experiences in different MUN simulations. Does something about them stick out? Was something about them better or worse than the others? Was something about them more or less enjoyable? More or less convenient? More or less immersive?</td>
<td>Open Ended</td>
<td>Please take a moment and tell us what was different about your experiences in different MUN simulations. Does something about them stick out? Was something about them better or worse than the others? Was something about them more or less enjoyable? More or less convenient? More or less immersive?</td>
</tr>
<tr>
<td>6</td>
<td align="left">I enjoyed my experience at <strong>online</strong> MUN simulations. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>I enjoyed my experience at <strong>online</strong> MUN simulations. (7 meaning highly agree)</td>
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<tr>
<td>7</td>
<td align="left">My <strong>online</strong> MUN experience felt like I was in a <strong>REAL UN</strong> situation. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>My <strong>online</strong> MUN experience felt like I was in a <strong>REAL UN</strong> situation. (7 meaning highly agree)</td>
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<td>8</td>
<td align="left">My <strong>online</strong> MUN experience motivated me to learn more about the UN and related things. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>My <strong>online</strong> MUN experience motivated me to learn more about the UN and related things. (7 meaning highly agree)</td>
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<tr>
<td>9</td>
<td align="left">I want to do an <strong>online</strong> MUN again. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>I want to do an <strong>online</strong> MUN again. (7 meaning highly agree)</td>
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<tr>
<td>10</td>
<td align="left">I enjoyed my experience at <strong>VR</strong> MUN simulations. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>I enjoyed my experience at <strong>VR</strong> MUN simulations. (7 meaning highly agree)</td>
</tr>
<tr>
<td>11</td>
<td align="left">My <strong>VR</strong> MUN experience felt like I was in a <strong>REAL UN</strong> situation. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>My <strong>VR</strong> MUN experience felt like I was in a <strong>REAL UN</strong> situation. (7 meaning highly agree)</td>
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<tr>
<td>12</td>
<td align="left">My <strong>VR</strong> MUN experience motivated me to learn more about the UN and related things. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>My <strong>VR</strong> MUN experience motivated me to learn more about the UN and related things. (7 meaning highly agree)</td>
</tr>
<tr>
<td>13</td>
<td align="left">I want to do a MUN in <strong>VR</strong> again. (7 meaning highly agree)</td>
<td>Likert (7 point)</td>
<td>I want to do a MUN in <strong>VR</strong> again. (7 meaning highly agree)</td>
</tr>
<tr>
<td>14</td>
<td align="left">Please take a moment and tell us what was different about your experiences in different MUN simulations. Does something about them stick out? Was something about them better or worse than the others? Was something about them more or less enjoyable? More or less convenient? More or less immersive?</td>
<td>Open Ended</td>
<td>Please take a moment and tell us what was different about your experiences in different MUN simulations. Does something about them stick out? Was something about them better or worse than the others? Was something about them more or less enjoyable? More or less convenient? More or less immersive?</td>
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</table>
rooms for private deliberations. The design of the environment was altered and improved after each of the stages of intervention in an attempt to better facilitate the simulation.

III. IMPLEMENTATION STRATEGIES

Negotiations are central to all Model United Nations conferences as the process of moving forward towards mutually beneficial outcomes is what delegates are engaged in during these simulations. As delegates strive to achieve their own objectives, which are based on national interests, they often find themselves in possible areas of conflict with other delegates representing opposing viewpoints and national interests. Yet, establishing agreements with other delegates is vital to the process of negotiating draft statements and resolutions that can potentially be agreed upon by consensus. United Nations diplomats negotiate global issues by meeting the interests and needs of each nation using collaboration and cooperation methods. Most discussions are interest-based negotiations, which practice joint problem solving and win-win strategies, rather than bargaining, which is a form of competitive and positional negotiation [12].

While it is imperative to include negotiation strategies and practice sessions in preparing students to participate in MUN conferences, most delegates devote their time to researching the agenda, their country’s national interest, writing speeches, and setting goals, and little time is spent on the actual practicing of negotiations, especially interest-based negotiations. Michiko Kuroda, Mercy College professor of International Relations and Diplomacy, MUN adviser and former United Nations staff member notes that interest-based negotiations should be a part of the basic requirements and communication tools for MUN delegates. Based on her own MUN faculty adviser experience she has observed that many MUN delegates tend to use bargaining rather than interest-based negotiations [12]. With this in mind the authors have designed the MUN practice sessions for this project to encourage students to practice interest-based negotiation strategies in a VR environment.

A. Session Organization

Seven students from Kyoto University of Foreign Studies’ Global Studies department were chosen based on their prior MUN experience and their expressed interest in exploring English negotiation strategies for use in future MUN conferences. These students included both Japanese and international students and for all participating students English was considered to be their foreign language. Sessions were organized around simulating the United Nations Security Council (UNSC) with three 90-minute sessions being conducted over 3 weeks. During the simulation students convened to discuss and create a UNSC presidential statement on behalf of the international community regarding the recent withdrawal of the United States from Afghanistan, which concluded on August 30th, 2021. A VR replica of the actual UNSC chambers was designed using the FrameVR platform and students were provided with the following documents:

- Country background guide – a faculty-prepared document outlining their assigned country’s official position on the recent situation in Afghanistan.
- Afghanistan background guide – a faculty-prepared document outlining the current crisis unfolding in Afghanistan.
- Emergency Session Objectives – a faculty-prepared document with national objectives for the delegates to follow when negotiating the official UNSC statement.

The schedule for the UNSC VR simulation was as follows:

- September 20th – Documents distributed - Students received their set of documents listed above and a schedule.
- September 30th – Orientation Session - students and faculty joined an online VR orientation, conducted in the actual VR replica of the UNSC meeting rooms, to familiarize themselves with the VR environment and learn more about the UNSC VR simulation.
- October 7th – Simulation Session 1 - students and faculty joined the online VR session to participate in the first of two UNSC VR meetings.
- October 14th – Simulation Session 2 - students and faculty joined the online VR session to participate in the second and final UNSC VR meeting.

The eight roles for the UNSC VR simulation were:

- 5 permanent members of the UNSC (China, France, the Russian Federation, the United Kingdom, and the United States.
- 2 stakeholders representing: 1) United Nations Aid Mission to Afghanistan; and 2) Former Afghanistan government’s UN Ambassador.
- 1 UNSC President - (faculty member).

IV. INTERVENTION OBJECTIVES

B. Orientation and Onboarding

A 60-minute orientation session conducted online in the UNSC VR environment was held for all student participants. Faculty explained the schedule, objectives, and introduced the VR replica of the UNSC chambers. From early on in the session the 7 student delegates quickly became comfortable accessing the VR environment, controlling their self-designed avatars, and maneuvering around the VR UNSC chambers to explore the main meeting room and 4 adjacent small- meeting rooms which could be used for private consultations.

C. Simulation Session 1

All participants joined a 90-minute session that began with Formal Consultations, with each of the 7 student delegates delivering their 90-second opening remarks from their assigned seats at the large round table, similar to the actual UNSC table found in the main UNSC meeting chamber. Speeches included their countries or organization’s understanding of the situation and their objectives for drafting the official presidential statement on the issue of the chaos that was being created during and after the United States recent withdrawal from Afghanistan in the summer of 2021. Upon the conclusion of the 7 speeches, the floor was opened for questions regarding the content of the speeches. As this is similar to an actual face-to-face MUN meeting, the delegates were very adept and efficient at moving through this part of the simulation.
After Formal Consultations, the president moved the meeting into Informal Consultations in which delegates were able to move around the chambers to have either public or private negotiations with each other regarding draft clauses they wished to see added to the draft statement, which was due at the end of session one. Faculty moved their own avatars around the environment observing several private discussions and noticed that delegates were doing the following:

- Students were staying in their assigned character roles.
- Students were using diplomatic language that they had been taught.
- Students were working diligently on trying to negotiate the presidential statement clauses, while protecting their own national interests.

By the end of the UNSC Session 1 the student delegates had submitted over 20 draft clauses to a Google document, which would be considered for the presidential statement. Clauses were concerned with the following topics.

- The care for refugees.
- The establishment of a safe zone in Kabul for UN aid organizations.
- The mobilization of UN support for bilateral or multilateral negotiations with the current Taliban government of Afghanistan.
- The freezing of international assets of the Afghanistan government.
- The condemnation of superpowers hastily abandoning their regional responsibilities.

D. Simulation Session 2

Session 2 opened again with Formal Consultations for opening remarks, and then the president quickly moved the session into Informal Consultations for students to continue negotiating and amending the draft clauses for the presidential statement. Negotiations mainly centered on the following:

- Could the UNSC agree to support bilateral negotiations over multilateral negotiations?
- Could the Taliban agree to the establishment of a safe zone in Kabul?
- Could the UNSC support the freezing of Afghanistan’s international assets?

Faculty observed that delegates stayed in character, following their objectives, as they negotiated the contents of draft clauses, and wrote amendments that would move the members closer towards consensus. Student delegates utilized the 4 meeting rooms in the VR environment, often moving from room to room to discuss with fellow delegates. By the end of the simulation, student delegates had submitted and amended 20 clauses to be included in the UNSC presidential statement and reached consensus on the document.

I. RESULTS

A. Observations

Constructivism is often cited as one theoretical framework that supports the implementation of learning in virtual environments. Constructivism suggests that students learn by constructing knowledge and incorporating it into their existing knowledge structure. Thus, constructivist learning environments can increase active learning, motivation, interactivity, and personalized learning. VR simulations can be conducive to higher student motivation and presence, two channels through which VR training simulations can influence student learning. As a result, VR simulations have been regarded as a pedagogical method with the potential to increase student learning [13].

Donna Hurst Tatsuki and Lori Zenuk-Nishide, Kobe City University of Foreign Studies professors and MUN advisers and researchers noted, “There is no doubt that both teaching and learning are taking place throughout and beyond the MUN experience. However, observations, analysis, and testimonials from faculty mentors – the people facilitating the events – may provide not only insights into learning but also guidance for future mentors” [14]. Observations made by the authors on the effective use of VR technology to simulate UN meetings further reinforced the theoretical idea of the use of constructivism in VR environments to motivate students to continue and enhance their learning of international diplomacy. Student delegates seemed to show more willingness to stay in character in the VR game-like environment than what has been observed of these same students participating in face-to-face and online MUN simulations. As one Japanese student representing the United Kingdom said, “I definitely felt less intimidated to disagree. I almost felt like I had more power to say what I wanted to say.” One Swiss exchange student and participant of numerous Japanese MUN conferences observed as a representative of the Russian Federation, “The Japanese students did much better at negotiating than in past MUNs. It was also easier for me to be a tough negotiator.”

Model United Nations as an educational activity in Japan continues to develop with more and more conferences organized domestically. For most of these MUN events English is the official language, but most participants are Japanese students who are learning English as a Foreign Language, thus many of these students are bringing to these conferences a common cultural and social background and understanding. Conversely, as more Japanese students join international MUN events abroad, they often find themselves overwhelmed when negotiating with higher level English speakers. Satisfied with their ability to deliver an agenda speech, or join in discussions, they are often at a loss on how to stay in character and negotiate with other delegates while protecting their national interests. Bargaining, rather than interest-based negotiations, has become the norm [12].

MUN simulations conducted in an VR environment provide an opportunity for students to practice skill-specific tasks in a less-intimidating and game-like setting. The use of avatars to role play UN diplomats provided students a safe way to explore strategies for difficult negotiations, while not having to worry about offending someone who they were interested in exploring a real-life relationship with. The confidence to take risks and
utilize newly learned techniques was reinforced by one Japanese delegate representing China, “In normal MUN conferences, I’m also really interested in the social fun of the event. It’s difficult for me to separate making friends and then playing my role. However, in VR I was able to do a better job of staying in my role and trying to represent China’s interests.”

B. Participants
The participants in the study were seven university students with previous MUN experience, in both in-person and online events. Participants were both interested and motivated to learn more about MUN and came to the study well-prepared in standard MUN rules and procedures. Four participants were international students studying in a Japanese university and three were Japanese students. Of the seven students, only five fully completed the optional survey responses, thus only five responses were included in the Post-session Survey Responses. The respondents were between the ages of 18 and 21. Two were female and three were male.

C. Survey Results
As the approach to this study was based in the iterative process and using design-based research methodologies. Simple instruments were used and repeated between each cycle of implementation.

Observations were made and reflected on after each session to make appropriate changes to the virtual environment and activity design. A short survey was given.

<table>
<thead>
<tr>
<th>#</th>
<th>Survey Responses</th>
<th>Mean (0 -7)</th>
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<tbody>
<tr>
<td>1</td>
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<td>7</td>
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<tr>
<td>2</td>
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<td>3</td>
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<td>6.25</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

The Survey was made to allow for answers about other online MUN participation and VR participation as well, in the hopes of seeing how perceptions changed after each session. Using the first set of responses as a control it was hoped to see if successive iterations were improving in experience and acceptance.

<table>
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<th>Mean (0 -7)</th>
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</thead>
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<td>6.6</td>
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<td>3</td>
<td></td>
<td>5.8</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>5.8</td>
</tr>
</tbody>
</table>

There is no statistically significant information to pull from comparing these data-sets other than an overall consensus on the acceptance and perceived usefulness of participating in MUN simulations of all kinds (face-to-face, online, and VR).

Open-ended responses yielded mixed and informative information about the perceived affordances VR brought to the MUN simulation experience.

<table>
<thead>
<tr>
<th>#</th>
<th>Survey Responses</th>
<th>Please take a moment and tell us what was different about your experiences in different MUN simulations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Online MUN simulation feels more comfortable to participate in. This is a new experience and very challenging but to gain the real experience about MUN face-to-face can offer the experience more than MUN online simulations.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Sometimes the website is not working well during the internet connection. It was fun and it was all new to me. The progress and the environment was great. To make it more immersive the content and the slide in blackboard (in VR) should be more easy to watch.</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>I would prefer to have Zoom ver. of mig rather than VR space. Of course, the communication done on the real table in the vr was great but the communication seems to be the same with Zoom ver. Also, the reason why I prefer Zoom is that Zoom is less likely to stop the screen or icon pics. However, if we use VR with our REAL face, then it would be more attractive for me. my point is that I can recognize participants' faces.</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>I felt more tension between delegates during discussion in VR simulation, which I did not experience in the online MUN.</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>As far as feeling like being at a real conference, nothing compares to face-to-face MUNs. Nevertheless, I felt that the VR simulation was more immersive than a typical online conference. However, certain aspects were worse. For example, not being able to see the faces of the people you are talking to felt a bit strange. Still, being seated at a virtual table resembling the real room felt very immersive. Obviously, the type of VR simulation we had is really only suited for small conferences. I believe that it would get too chaotic with more than 10-15 people. Furthermore, technical difficulties present a real obstacle. From my experience hosting several MUNs, you really want to minimize the possibility of technical issues. Unfortunately, with the VR MUN it seemed like there were just a bit too many issues. Having said that, these problems could be overcome with more preparation time given to the participants. I also felt like the controls felt a bit chunky but it was easy to get used to. If let's say all the participants had VR headsets, the immersion might get very close to face-to-face simulations. Referring to personal documents/notes etc, would in that case be a problem though. I think that the VR simulation is great for small MUNs, just the way we did it. It could certainly be a bit more extensive in terms of content and duration. Overall, I do think there is a place for such an MUN.</td>
</tr>
</tbody>
</table>

Many of these responses align with the perceptions of the facilitators around how the experience was received. Some
main themes found are motivation and enjoyment from the novelty of the new mode of interaction, the psychology related to the game-like environment, and technical issues both in how to use and instability of the environment.

VI. DISCUSSION

As faculty had hoped, student delegates quickly joined the VR simulation of the UNSC and achieved the goal of drafting a presidential statement on behalf of the international community that found consensus amongst the 7 participants. Student delegates did so while staying in character, using diplomatic language, and following their assigned country objectives, which were designed to create disagreements amongst the delegates. In a post-simulation survey, 6 of the 7 delegates found the VR simulation to be fun and challenging and similar to an online gaming experience. Student comments included:

“The students did much better at negotiating than in past MUNs. It was also easier for me to be a tough negotiator.” (Delegate representing the Russian Federation)

“I wanted it to last longer. It felt like a game.” (Delegate representing the former Afghanistan government)

“I definitely felt less intimidated to disagree. I almost felt like I had more power to say what I wanted to say.” (Delegate representing the United Kingdom)

“We can do this with other schools before we meet for a real MUN?” (Delegate representing China).

VII. CONCLUSION

VR learning opportunities can accelerate students’ learning curve in a simulated environment, reproducing real-life conditions and situations without time or space limitations and much fewer risks than real environments [13]. The United Nations Security Council simulations conducted in a VR replica of the UNSC chambers provided a stimulating environment for students and faculty to utilize in developing certain skills that can be continuously practiced before participation in a real-life MUN event. The authors have observed that a VR simulation of a MUN style meeting can be a constructive environment for practicing skill-specific techniques, such as interest-based negotiation, in providing students and faculty another educational tool to continue developing in order to practice the process of preparing for Model United Nation events [12]. Furthermore, the online game-like environment provided a fun activity for students to engage in, while also learning about international diplomacy and practicing basic interest-based negotiation strategies. However, some of the activities that are often associated with more traditionally facilitated MUN simulations, such as note taking and document drafting, were difficult in this environment and needed to be supplemented with other tools. If further iterations are to be done on this pilot study a re-thinking of these core activities of MUN may need to be re-examined, or more craftily paired with face-to-face or teleconference portions of the simulation.

REFERENCES


Exploring Constraints on Dialogic Interaction in Immersive Environments Arising from COVID-19 Protocols

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Abstract—This paper describes an independent research study undertaken by a high school student under the mentorship of a Research Scientist at the National Institute of Education, Singapore. It explores how dialogic interactions on a given Mathematical topic, decimals, can be constrained in the remote learning platform Zoom. This research utilises Laurillard's Conversational Framework for a small-scale intervention of two virtual learning sessions in Minecraft Education Edition, focusing on the decimal learning for primary school students. The study found that the overlapping of the immersive learning environment and remote learning platform engenders misconceptions, disorientation, and cognitive dissonance amongst both the teacher and the student, prolonging the discursive and adaptive phases in the dialogic interactions.

Index terms—Minecraft, remote learning, immersive learning, Mathematics learning, COVID-19

I. INTRODUCTION

The decimal numeral system has been a central topic in the curricula of almost all primary schools in Singapore and globally. As a foundational Mathematical topic, it has a myriad of real-life applications, such as percentages, length, and money [1]. Understanding decimals is also essential for further Mathematics Education in later stages of one’s life. [2]

However, despite the prevalence of Mathematics Education on decimals, current literature demonstrates that the decimal numeral system proves to be one of the most challenging domains of Mathematical Education for primary school students [3], [4]. The cognitive conflicts between the pre-existing knowledge of the computational rules for whole numbers and an unfamiliar decimal system necessitate re-structuring mathematical thinking, failure of which would result in various misconceptions [2], [5].

Reference [6] identified two main misconceptions surrounding learning decimals: “whole number rules” and “fraction rule”. Under “whole number rule”, when comparing different decimals, students will regard the biggest number as the one with the biggest number after the decimal point, i.e. they regard the fractional part of the decimal as a whole number. In this sense, 6.129 would be greater than 6.9 because “129 is greater than 9” [6], [7]. In contrast, under “fraction rule”, when comparing numbers, some students will regard the biggest number as the one with the smallest number on the right of the decimal point, due to the erroneous presumption they have regarded mistaken the decimals as numerators. For example, students might mistake 2.6 to be bigger than 2.77 because they confound .6 with /6 and .77 with /77. The reasoning goes: since /6 is bigger than /77, 2.6 is bigger than 2.77 [6, 8].

In the light of multitude of challenges of learning decimals [7], one of the innovative ways of teaching decimals is through capitalising on Embodied Cognition, which is the view that knowledge can be effectively attained through one’s bodily and physical actions [9], [10] as the learner actively interacts with the external environment, either naturally occurring or artificially constructed [11]. In the application of Embodied Cognition, abstract mathematical ideas such as mathematical notations, arithmetic, and functions, are connected to familiar everyday activities through “grounding metaphors” [10], [12].

There has also been mounting evidence that embodied cognition-based learning is achieved and operated through immersive learning platforms. In particular, [13] found that increased language learning outcomes are attributed to embodied cognition-based learning in immersive learning environments, after other co-variables such as motivation, presence, and cognitive load, are controlled for. This suggests that immersive learning environments do effectively enable embodied cognition.

Immersive learning environments have been designed for contexts in which the interactants are both co-located as well as physically remote and separated. For example, Minecraft Education Edition (henceforth, MEE) accompanies its lesson modules with a handbook for teachers to reference, on how to guide their students in a physical setting [14]. Such face-to-face interaction and guidance complement the affordance for embodied cognition from the digital environment, ensuring that help is immediately rendered once students meet difficulty in the virtual environment [15].

However, the onset of Covid-19 means that the entire educational landscape, especially those fields already dependent on technological platforms, is disrupted, with over 80 percent of students around the world affected. Due to Covid-19 protocols such as lockdowns and social distancing, students are obliged to stay in their homes for their lessons [16]. In the light of the Covid-19 protocols, teachers and educational institutions have resorted to remote learning, or distance learning, through
communications platforms such as Zoom and Google Meet, meaning that – unlike before – the participants in immersive learning environments are exclusively non-co-located. This, in turn, adds an additional layer to the mix of existing communication media, which teachers need to take into account the new and unfamiliar affordances and disaffordances thereof, in addition to those of the immersive learning platform itself.

This study introduces a small-scale intervention of two primary school students, where the researcher conducts decimal workshops via a self-constructed immersive learning environment on MEE using the remote-learning platform Zoom. The main aim is to provide a microscopic view of students’ learning experience when there is a superposition of immersive learning and distance learning. While each student is synchronously co-present with the teacher through their avatars in the immersive environment, the two are not physically co-located.

The remainder of this paper consists of the Theoretical Framework and accompanying Literature Review, examining the current literature on the topic of immersive learning, dialogic interactions in Mathematics Education, as well as the potential disruption of the Covid-19 protocols. This will be followed by an introduction of research framework, which is Laurillard’s Conversational Framework for digital interactions and the rationale for using it. Following which, the author will introduce the research question, and the methodology to solve the research question. This will be followed by the presentation of the results and analysis. The paper ends with discussion and potential future work.

II. THEORETICAL FRAMEWORK

This paper adopts the Conversational Framework developed by [17] as its theoretical framework. This framework posits that in an effective learning process, the dialogic interactions between the teachers and the students consist of four essential phases: the discursive phase, the adaptive phase, the interactive phase, as well as the reflective phase. As can be seen in Fig. 1 below, these four phases do not occur strictly sequentially in the dialogic interactions of the learning session, but oscillates back and forth in an iterative and circular manner.

![Fig. 1. Laurillard’s Conversational Framework.](image)

In order to apply the Conversational Framework to any learning situation, the learning process must be an iterative dialogue that operates at the level of descriptions of the topic and actions within the related tasks [17]. Our learning activities meet these criteria, since they are about a specific Mathematical topic (decimals) and provide a platform for students to solve certain tasks related to the particular topic. Further, our approach adopts the form of one-to-one tutorial, which, according to Laurillard, is the ideal situation for the Conversational Framework to occur. Additionally, Laurillard’s framework regards the technological media as the centre of focus and essential transmitters of the dialogic interactions [18], which apply to our intervention, which is mediated by both the virtual learning platform MEE and video conferencing platform Zoom.

Specifically, according to Laurillard’s framework, the four phases requisite for the dialogic interactions of a learning session are:

- **Discursive**: The teacher introduces the target goal and topic to the student, and the student generates feedback based on what they have learnt.

- **Adaptive**: The teacher perceives the learning difficulties experienced by the student and therefore adapts his way of explanation; the teacher uses the relationship between his own and the student’s conceptions to set up and adapt a task environment.

- **Interactive**: The student can interact with the task environment to achieve the task goal and receive meaningful feedback from the teacher based on his interaction with the environment.

- **Reflective**: The student has generally grasped the concept and the teacher seeks to revise the concepts with the student.

III. REVIEW OF LITERATURE

A. Zone of Proximal Development

The Zone of Proximal Development (ZPD), an educational concept originally developed by [19], is broadly defined as the cognitive space between where the learner is currently able to do on himself and what he is able to do with the help of an expert. This concept is widely used in educational studies to evaluate the effectiveness of a given educational programme. For example, [20] investigated the development of a ZPD between a primary school teacher and a fourth-grade student working on an algebra problem, and concludes with the symmetrical view of ZPD, that both participants of the ZPD learn in a teaching-learning way and that ZPD is a symmetrical space. Likewise, [21] adopted such a symmetrical view of ZPD and applied it to Mathematics teaching in a Norwegian kindergarten. Reference [21] concluded that within a ZPD, both the teacher and the student expand on each other’s action possibilities.

However, the aforementioned research studies on ZPD focus mainly on scenarios where the students and teachers are co-located and directly communicating with teach other. In Brieve’s study, for example, the teacher researcher could directly observe the physical movements and gestures of the students and use those co-temporal semiotic means to aid their understanding. Our research seeks to fill the research gap by investigating whether such seamless communication and mutual understanding in a ZPD will be retained in a remote learning setting where the teachers and students are not co-located.


B. Embodied Cognition

Embodied cognition is a concept within the field of cognitive psychology, which holds that mathematical knowledge can only be attained through our bodily and physical actions [11] as the learner actively interacts with the external environment, either naturally occurring or artificially constructed [13]. There is a consensus among scholars that embodied cognition forms a central part of and greatly facilitates Mathematical learning. Reference [10] has posited that the cognitive science of Mathematics is fundamentally based on embodied cognition, and that grounding metaphors (relating Mathematical concepts to everyday actions and bodily movements) are critical for the emergence of Mathematical ideas.

It is also worth noting that there is a distinction between macro-embodied experiences (such as moving the avatar around, placing an object, or choosing a particular path in the physical world) and micro-embodied experiences (such as expressions and gestural and visual cues). While there have been studies that investigate how macro-embodied cognition is enabled within virtual learning environments and effectively aids students’ mathematical learning [13], little research is conducted on the role of micro-embodied experiences in learning and how it is manifested in immersive learning activities. Therefore, in addition to investigating macro-embodied experiences in the virtual learning experience, this study also seeks to investigate how micro-embodied experiences, in particular gestures, are integrated in the virtual learning platform and potentially restrained by the distance learning platforms.

C. Role of Dialogic Interaction

There is a consensus among scholars that dialogic interaction in learning Mathematics aids the Mathematics learning process. Reference [22] demonstrated that dialogic interactions in effectively encourages student-initiated reasoning and turns the students’ focus on the substantive content of the lesson. Reference [23], similarly, found that through actively using dialogues and explicit reasoning in the process of problem solving, the expert-student Mathematics discourse led to improved Mathematical learning.

Reference [24] extended this discussion to online Mathematics learning. They devised and conducted small-group synchronous discourse sessions in two virtual elementary schools. Their findings confirmed that participation in Mathematics discourse and collaborative reasoning in an online environment is positively correlated with students’ self-efficacy towards, as well as performance in, Mathematics, after controlling for multiple covariables such as prior levels of mathematical achievement and degree of self-efficacy towards Math.

However, the focus of current studies on the role of dialogic interactions in Mathematical learning is more on generic collaborative Mathematics problem-solving with the teacher screen-sharing exam-styled questions, with no reference to immersive learning environments or embodied cognition [24]. This research thus seeks to fill the gap in literature by investigating the role of dialogic interactions in the MEE environment and how it is constrained in the remote learning context.

IV. RESEARCH QUESTION

In the light of gap of current literature, the research question of this research paper is proposed as such: how is dialogic interaction in immersive environments constrained in contexts where the participants are not co-located?

V. METHODOLOGY

A. Profile of Students and Logistics

The researcher conducted the virtual learning activities with two Singaporean students, Student A and Student B, who are studying currently in Grade 4 in primary school. For each student, two 1-hour sessions are held, with the first one being an introductory course for students to familiarise themselves with the MEE environment, and the second one for the actual virtual learning activities to take place.

According to the supervisor of the community tuition centre where the students attend regular tuitions, the students’ Mathematical foundation in decimals is fairly weak. This allows for room for the ZPD to occur, since their participation in the virtual learning environment can be considered a stretch of their current abilities.

B. Design of Virtual Learning Activities

In the creation of the activities, the researcher consciously chose to design activities that require spatial-temporal sense-making, for example the moving of objects. The design of the virtual learning activities was adapted from an environment known as the Decimal Forest.

In the first virtual learning activity, students get to place and move the decimal points and learn that by moving the decimal point to the right, they can increase the number by ten times. The student can place a button in the whole between columns of blocks as if placing decimal points between digits. This activity is designed in the light of the commonly reported learning difficulty with regards to understanding the position of the decimal numbers [25]. A sample design (Fig. 2) of the activity is appended below.

![Fig. 2. Design of the first virtual learning activity.](image)

In the second learning activity, the students can compare the two numbers by looking at them from the front. This is in
response to the common misconceptions of ‘whole number rules’ and ‘fraction rules’. In this activity, the task of comparing two decimals is reduced to simply aligning the decimal point and compare the height of the columns starting from the left. A sample design (Fig. 3) of the activity is appended below.

![Figure 3: Design of the second virtual learning activity.](image)

Excerpts of the transcript of the learning sessions are shared in the results and analysis section. Beside the utterances, the researcher’s and learner’s visual and gestural cues have also been incorporated to allow for a more vivid and evocative thick description of the learning sessions. Full transcripts and full videos are provided upon request.

C. Collaborative Mathematical Problem Solving

During the learning sessions, the researcher entered the Minecraft world himself and shared his screen with the two students. This echoes the Collaborative Observation (CO) approach as examined by [26], in which the students took part in virtual learning through observing a teacher-controlled avatar that carries out tasks in the virtual world. Significantly, it was found that students engaged by the CO approach benefitted from more effective knowledge gains than students engaged by the Collaborative Problem Solving (CPS) approach, where the students collectively tackle problems and resolve tasks in a small group setting, each navigating the virtual world with his own avatar [26]. The advantage of CO is due to a few contributory factors: the teacher can make sure they are not distracted by the novel environment [26] and high degree of freedom [27] and enable students to learn in authentic settings without facing an extraneous cognitive load of having to control the avatar [28].

D. Method: Autoethnography

This research employs autoethnography, a novel qualitative research method that centres on the personal experience of the researcher to derive in-depth understanding of a cultural experience [29] – in this case, the students’ mathematical learning process through virtual and immersive learning platforms. This research method applies to this intervention, since it primarily utilises deliberate self-reflection, or reflexivity, to assess the interaction and communication between the self and the surroundings [30] and examine the researcher’s own teaching practices and pedagogical philosophy [31]. This research focuses on the interaction between the researcher and two of his students over two Zoom sessions.

The primary objective of adopting this research methodology, therefore, is to investigate how both the researcher and the students are affected in the immersive learning environments with the communication mediated by Zoom; in this sense, the binary oppositions between the researcher and the researched are eliminated, incorporating the mental state and motivations of the researcher into the study as well [32]. This methodology is also preferred over quantitative research in this case, since the small scale and scope, as well as specificity, of the intervention lends it more to in-depth analytical reflection and defies generic statistical analysis.

Autoethnography, in particular, entails the extensive use of thick description [33]. A research methodology popularised by [34], thick descriptions portray the events in a visual-interactive and evocative way. According to [34], such vivid and evocative thick descriptions of the events to be studied would lead to a deeper understanding of the underlying thoughts and motivations of the events. In this study, the events to be studied are the episodes of communication between the researcher and the students. The interactions are depicted in a vivid and evocative way by integrating the gestures, expressions of the participants along with their utterances.

Since autoethnography entails prolonged, in-depth descriptive research that involves thick description, we only have the time, energy, and space to conduct a 60-minute session with each of the two students. Key parts of the dialogic interactions during these two sessions are examined in detail.

VI. RESULTS AND ANALYSIS

This section examines how the superposition of the remote learning platform Zoom with the immersive environment of Minecraft lead to various kinds of misunderstandings and thereby disrupted the nature of transactions that might otherwise have been expected from Laurillard’s framework. In the following excerpts, ‘T’ refers to the teacher-facilitator, and ‘A’ and ‘B’ refer to Student A and to Student B respectively.

A. Poor Connections and the Need to Clarify Concepts

There are some instances, like the example in Table I, where the students uttered confusion such as “what” or “sorry” because they could not hear the teacher very clearly. However, the teacher cannot know for sure whether such confusion derives from conceptual difficulties in understanding the theory at hand or simply connection issues; it was tedious to ask them “whether you can hear me” every time they expressed confusion.

<table>
<thead>
<tr>
<th>TABLE I. EXCERPT 1 BETWEEN TEACHER AND STUDENT A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utterance</strong></td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>


A (thinking for a while) the one block? Student confused

In this instance, it is notable that the student begins to doubt herself after the teacher explains to her again, mistaking that she has gotten the answer wrong. However, the teacher merely wants to clarify again because he thinks that she cannot hear him as well. In this sense, the poor connections caused the dialogic interaction to stagnate regress to the adaptive phase, even though the student has understood the concept correctly.

B. Disorientation in the Minecraft Environment on the Zoom Platform

Apart from miscommunication due to poor connections, the dialogic interactions and effective embodied cognition are also constrained by disorientation in the MEE environment, as seen in Tables II and III.

TABLE II. EXCERPT I BETWEEN TEACHER AND STUDENT B

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>T Just now we made the number bigger by moving the decimal point to the right by one digit (trying to gesture to the right, not realising that it actually appears as gesturing the left in the Zoom screen). Correct? So, from 2.31, we got 23.1. And now, from 23.1, we want to make it bigger (gesture hand moving up), again. Teacher explaining</td>
<td></td>
</tr>
<tr>
<td>B Bigger (putting up her legs, looking bored).</td>
<td></td>
</tr>
<tr>
<td>T Do we also just make the decimal point to the right by one digit? Is that correct? Teacher giving suggestions</td>
<td></td>
</tr>
<tr>
<td>B Yeah?</td>
<td></td>
</tr>
<tr>
<td>T Ok. So, if now, the decimal point is after 3, and if I make it to the right by one digit. To the right, to the right, to the right (trying to gesture to the right, not realising that it actually appears as gesturing the left in the Zoom screen). Where is the decimal point now? Teacher explaining Teacher asking</td>
<td></td>
</tr>
<tr>
<td>B At the back?</td>
<td></td>
</tr>
</tbody>
</table>

Technically speaking, by saying “at the back”, the student had answered correctly: if the decimal point is moved one digit to the right, then it would justifiably be “at the back” of all the digits. However, due to the nature of the Zoom platform, the student cannot explicitly pinpoint the direction of the decimal point, and the ambiguity of the word “back” still left room for interpretation: all the way behind? All the way in front? Or on the other side of the wall? Eager to clarify her direction, the teacher sought to clarify with the student to make sure that no conceptual errors are made.

TABLE III. EXCERPT 2 BETWEEN TEACHER AND STUDENT B

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>T At the back? Okay so what number is it after? Is it after 2? Is it after 3? Is it after 1? Which hole is it, if I want to get 10 times bigger than 23.1 (zooming out to have a bird eye’s view so the avatar could view all the numbers). Just now the digit was here (trying to point out the hole in MEE). Teacher repeating the concept</td>
<td></td>
</tr>
<tr>
<td>B After 2! Student getting wrong answer</td>
<td></td>
</tr>
<tr>
<td>T But…just now it was here right (pointing out the hole after 3)? So if I need to make it to the right… Teacher explaining</td>
<td></td>
</tr>
<tr>
<td>B (looking aside, thinking) Eh no no no Student realising she was wrong</td>
<td></td>
</tr>
<tr>
<td>T So what number?</td>
<td></td>
</tr>
<tr>
<td>B After 1. Student getting correct answer</td>
<td></td>
</tr>
</tbody>
</table>

It is interesting to note that Student B mistook the teacher’s further questioning as an indication that her answer was wrong: therefore, she switched her answer from “at the back” to “at the 2”. If these interactions had occurred in a physical, face-to-face environment, the student and the teacher could directly pinpoint the location of the objects they were referring to, and they could have moved past the adaptive phase to the interactive phase or the reflective phase. However, the difficulty of navigation and disorientation caused by the distance learning mode cause the dialogic interaction to remain at the adaptive phase.

A potential solution is that the teacher could use the Zoom annotation function to draw out the leftward and rightward direction. However, it is important to note that when the teacher or student enters a virtual world, it is impossible to click on annotation at the same time. Therefore, it is extremely difficult to use another visual aid to orient oneself in the MEE environment through the distance learning mode; using dialogues seems to be the only way to orient the participants in the virtual environment, yet it only results in much confusion, especially when the Zoom connection issues disrupt the communications.

Similarly, the disorientation of directions in the MEE environment occurred to Student A, as seen in Table IV.

TABLE IV. EXCERPT 2 BETWEEN TEACHER AND STUDENT A

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A If you want to divide it, you need to move to the back. Student explaining</td>
<td></td>
</tr>
<tr>
<td>T Yes, very very good! So if I want to make a number ten times smaller, … (expecting the student to complete the sentence using either) Teacher checking student’s understanding</td>
<td></td>
</tr>
</tbody>
</table>
It is evident that after the student has uttered “to the back”, the teacher intuitively sensed that she was meaning “to the left”, since the teachers was facing the right side in the MEE environment. However, due to the vague nature of her utterance “to the back”, the teacher wanted to double check on whether she meant “to the left” or “to the right”. Therefore, even though the dialogic interaction is supposed to bypass the adaptive phase (since the student has got it correct all along), the uncertainty stemming from the ambivalence of directional words led me into the adaptive phase, which significantly prolonged the explanatory and learning process. If the immersive learning had taken place in real life, the student and the teacher could have pointed to each other in real life, which would have spared much of this confusion.

In the light of such confusion, the teacher sought to standardise the directional words with Student A, as seen in Table V.

<table>
<thead>
<tr>
<th>Utterance</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Oh you place it behind the two?</td>
<td>Student trying</td>
</tr>
<tr>
<td>T Oh…can you don’t say “behind”? Because it makes me quite…</td>
<td>Teacher regulating</td>
</tr>
<tr>
<td>A Right.</td>
<td></td>
</tr>
<tr>
<td>T Yes, say “left” and “right”, okay?</td>
<td>Teacher regulating</td>
</tr>
<tr>
<td>A Okay. Place it the number right.</td>
<td></td>
</tr>
<tr>
<td>T Number? The what?</td>
<td>Teacher confused</td>
</tr>
<tr>
<td>A I mean the number…is it at the back of the two block?</td>
<td>Student trying</td>
</tr>
<tr>
<td>T At the what?</td>
<td>Teacher confused</td>
</tr>
<tr>
<td>A I mean place it on your right hand side?</td>
<td>Student trying</td>
</tr>
<tr>
<td>T This one? I’m standing here now. So right hand side is this one (pointing at the hole further to the right, which is wrong)?</td>
<td>Teacher confused</td>
</tr>
<tr>
<td>A Oh, left.</td>
<td></td>
</tr>
<tr>
<td>T Left. This one (pointing to the hole on the left)?</td>
<td>Teacher asking</td>
</tr>
<tr>
<td>A Yes this one.</td>
<td></td>
</tr>
<tr>
<td>T Okay. Next time when you want to describe this, can you say this as “at the right of the number 2”, or “left of number 1”, either way works. Is this okay?</td>
<td>Teacher regulating</td>
</tr>
<tr>
<td>A Okay.</td>
<td></td>
</tr>
</tbody>
</table>

It is ironic that after the teacher had tried to standardise the directional word in the dialogic construction, there were more instances of confusion and misunderstandings. To be fair, the confusion was definitely caused in part by the muffled voices communicated through the Zoom platform (which has been discussed in a preceding section). However, even after the communication issues are accounted for, it is still evident that the student was struggling to construct full sentences with the appropriate use of the directional terms “left” and “right”, despite her attempts to involve these two words in her dialogues. The vagueness of her dialogues seems to have aggravated, causing a higher frequency of code “Teacher confused” in this part of the dialogue, which further probed another instance of “Teacher regulating”, repeating the same instruction again. The high frequency of code “Teacher confused” suggests that the dialogic conversation has failed even at the adaptive phase, where the teacher and student are having difficulty understanding each other.

It can be seen that this dialogic conversation had passed the discursive phase, i.e. the teacher had successfully conveyed the idea, or instruction, to the student, and the student had been actively attempting to express the idea. However, the yet nascent nature of verbal and spatial skills amongst primary school students makes it difficult for them to accurately describe the locations and directions in a way that both participants can understand.

VII. DISCUSSION

Our research suggests that the Collaboration Observation technique, which had worked for [26], might not be applicable to virtual learning activities enabled by distance learning platforms. Such a discrepancy can be attributed to two reasons.

First, for the conventional CO approach, the interactants are physically co-located and able to capture each other’s full-expressions, body gestures, and movements in entirety [26], as illustrated in Fig. 4.

![Fig. 4. Collaborative Observation in a face-to-face setting.](image)

In this sense, neither misunderstandings due to connection issues nor disorientation will occur, since real-life, face-to-face interactions are straightforward and less prone to transmission issues. Our research, on the other hand, suggests that verbal cues and physical gestures transmitted via Zoom video conferencing are likely to engender cognitive dissonance due to connection issues and inversion of images, thereby causing the dialogic interaction to stagnate at the adaptive or even discursive phases, where the dialogic interaction is primarily led by the expert.
Second, in the face-to-face CO approach, real-life bodily movements are effectively separated from the movements of the avatar in the immersive learning environment, which means that the students can distinctly distinguish the real and virtual world and do not mix up the two. Fig. 5 provides an example.

![Students’ and teacher’s embodied actions complement each other in a face-to-face setting.](image)

However, Zoom-based immersive learning activities are characterised by an amalgamation of incomplete real-life physical movements and virtual avatar movements (Fig. 6). In this sense, the incomplete, error-prone physical movements of talking heads in the Zoom video frames might interfere with the egocentric view of a single avatar, thereby disrupting the optimal experience of the CO approach.

![Zoom-based collaborative observation with Minecraft.](image)

Technically speaking, the cognitive dissonance and prolongation of the discursive and adaptive phases are not entirely attributable to use of the CO approach in the virtual learning environment constructed in MEE, since it has been empirically proven that it facilitates effective Mathematical learning and understanding [26]. They are also not attributable to the use of Zoom-based video conferencing, which in itself has been proven to be an effective technology for enabling synchronous distance learning, memory retention, and teacher-student interaction [35], especially during the Covid-19 pandemic [36]. However, as our research has demonstrated, the superposition of these two media platforms engenders communication difficulties, cognitive dissonance, and disorientation. As demonstrated, these learning obstacles cause the dialogic interactions to linger at the the discurse and adaptive phases and requires both the students and teachers to repeat their ideas, when the conversation could have bypassed these phases and reach the reflective phase.

![Zoom-based collaborative observation with Minecraft.](image)

VIII. **Concluding Remarks**

This research seeks to fill the gap in the current literature by investigating the intersection between different forms of educational media, namely virtual learning environments through MEE and distance learning platform Zoom. However, there are several areas for improvements.

Firstly, the duration and frequency of learning sessions with the primary school students is generally limited. As illustrated by [24], students’ Mathematical competence is directly correlated with the duration and frequency of Mathematics discourse sessions. Future research needs to address whether the miscommunications, disorientations, and cognitive dissonances during the two learning sessions will be retained as more Zoom-based virtual learning sessions are conducted, or whether the interactants of the virtual learning sessions will learn from their experiences and become enculturated into this novel teaching and learning paradigm.

Secondly, with regards to the application of the theoretical framework – Laurillard’s Conversational Framework – it is notable that the teaching and learning activities designed in this study does not incorporate the interactive phase. The short timeframe of the learning sessions renders the learning activities primarily teacher-guided, and the student has little room to interact with the environment on their own. Future research can arrange for longer learning sessions where the students are allowed to explore the affordances in the virtual environment, and analyse the teacher-student discourse to examine whether more freedom will have a positive impact on the students’ Mathematical learning process.

Thirdly, with regards to the analysis of the results and the coding of the utterances in Section VI, the researcher analysing the dialogic interaction is the same participant engaging in the dialogic interactions. While the researcher sought to adopt an objective, meta-cognitive perspective, a certain level of biases is inevitable. While the researcher is able to probe into the inner mental state of the teacher i.e. himself, he can only predict the mental state of the student by observation. This may thus lead to inaccuracies in the thick description of the learning sessions, and therefore inaccuracies in the patterns. Future research can allow the utterances to be coded by at least two researchers to establish inter-coder reliability [37].

Nonetheless, this research hopes to catalyse scholarly discussion on the overlapping of remote learning platforms and virtual learning environments, investigating how teaching and learning paradigms might be affected by the user experience and interface. The potential problems encountered in the interface, as outlined in this research, serve to guide future research into educational technology and devise better pedagogy and best practices for virtual environment-based classroom strategies through remote learning platforms.

**REFERENCES**


VR-Based Context Priming to Increase Student Engagement and Academic Performance

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Abstract—Research suggests that virtual environments can be designed to increase engagement and performance on many cognitive tasks. This paper compares the effect of specifically designed 3D environments intended to Prime these effects within Virtual Reality (VR). A 27-minute seminar “The Creative Process of Making an Animated Movie” was presented to 51 participants within three VR learning spaces: two Prime and one No Prime. The Prime conditions included two situated learning environments; an animation studio and a theatre with animation artifacts vs. the No Prime: theatre without artifacts. A 20-question multiple-choice content test, User Experience (UX), and affective (anxiety and positive affect) surveys were completed prior to and immediately after the learning session. Increased academic performance was observed in both Prime conditions compared to the control. UX and affective surveys related to the immersive VR experience were positive, but there were no significant differences observed between the Prime and No Prime conditions in either case.

Index terms—Context, priming, immersive, supraliminal, positive affect, anxiety, academic performance, situated learning, experiential, virtual reality, applied computing, education, computer-assisted instruction, human-centered computing, human computer interaction, interaction paradigms, virtual reality

I. INTRODUCTION

Winston Churchill famously said, “We shape our buildings and afterwards our buildings shape us” [10]. We know instinctively that where we live, work, and learn can affect how we feel and perform. Nature, open spaces, and locations with gorgeous aesthetics are highly coveted and can often improve performance [8][6] yet are inaccessible for most people.

Virtual Reality (VR) affords the opportunity to create and design these highly coveted spaces to Prime (act as stimuli that improves subsequent cognition) engagement and academic performance. While there is research demonstrating that the context of our experiences can affect cognition and behaviour [4][5], there is little research validating the transferability of these effects to leading-edge educational technology like VR or research that informs the design choices to improve cognition within these environments. Given the potential for VR priming to greatly impact the learning process we investigate environment context priming; the impact of VR environments on learning which we achieve by varying the context of the learning spaces.

Following a review of related work and description of our study, we discuss the academic performance, UX, and affective results that will help inform the design of future VR experiences. Our results clearly demonstrate the positive effects of both Prime scenarios to improve academic performance compared to the No Prime condition. We conclude with future research considerations and propose further VR priming studies focused on motivational, reflective, and aggregate priming methods within the experiential learning cycle [22].

II. RELATED WORK

A. The Nature of Context

Marshall McLuhan posited that “the medium is the message” [26]. He theorized that the medium is any innovation or enhancement that extends human capability. The lightbulb brings light to an environment providing new visual insights and allowing many new activities during periods of darkness. Similarly, VR affords many new possibilities including the design of high-fidelity learning spaces and custom designed scenarios to realistically simulate specifically desired contexts. While these extensions of our visual/spatial capability provide a tangible, observable result, McLuhan’s theory suggests that the message is the overall impact of the medium. For example, providing customized VR learning environments may function quite effectively, creating feelings of presence and authenticity [26], [12] but may also induce positive affect and subsequently improve creativity [3].

UX design expert Don Norman, in Emotion and Design [28], describes a study where ATM cash machines were designed functionally identical but with varying aesthetics [28][21]. The research demonstrated that more attractive designs simply worked better. Norman attributes this partly to the induction of positive affect. A 1987 study at University of Maryland demonstrated that inducing positive affect improved creative problem solving [16]. A similar study in 1988 performed with eighth grade students achieved the same results suggesting that positive affect may promote creativity and facilitate problem-solving in young adolescents [14].

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B. The Power of Priming

Priming occurs when a stimulus (the Prime) makes the content and subsequent cognitive processes more accessible, potentially influencing all stages of information processing: attention, comprehension, memory retrieval, inference, and response generation [13]. The most effective priming stimuli are supraliminal (observable but not obvious to the individual) where changing the context of an environment can create effects with little or no perceptual awareness. A picture, for example, can create bias and affect how a person thinks [17] or placing codes (A vs. F) on pre-test forms can affect academic performance [9].

A 1997 retail study [29] provides an excellent example of the subtle, yet effective nature of supraliminal priming. In the study, European retailers tested the effect of varying in-store music related to countries of origin. Four types of French and German wine were displayed equally prominently in a supermarket drink area over a two-week period. The wines were similar in price and dryness. Over that period, French accordion and German Bierkeller music played intermittently. When the French music played 76.9% of the bottles of wine sold in the area were French wine. When German music played, 73.3% of the bottles of wine sold in the area were of German origin. When respondents were asked whether they thought the music influenced their choice of wine, most felt that there was little or no effect.

Priming positive emotions (positive affect) has been shown to improve information organization and creativity. In the previously mentioned University of Maryland study [16], positive affect was induced in study participants by viewing a few minutes of a comedy film or by receiving a small bag of candy. Another group received a neutral stimulus, while two more groups engaged in a physical exercise meant to represent affective arousal. In performing two tasks of creative ingenuity, the positive-affect groups, primed with candy or funny movies saw improved performance while the control and exercise groups saw no performance increases. The researchers concluded that positive affect had improved creativity. In certain situations, positive mood has also been shown to improve divergent thinking [39] and many other cognitive tasks [2].

C. Learning Theories

Priming efficacy directly benefits from repetition [44] and authentic experiences where priming effects can be woven subtly into the environmental context [4], [5]. As such, of particular interest for our research was Kolb’s Experiential Learning Theory (ELT) [22]. With ELT, learning begins with having a concrete experience, followed by a reflection of that experience, the conceptualization of abstract concepts that incorporates the new insights from the experience, and finally active experimentation of the lessons learned. The cycle, as presented in Figure 1, continues to repeat as the learner’s conceptual worldview is repeatedly refined. Learning is best achieved as a process: a continuing reconstruction of experience.

Hence, the ELT cycle can provide iterative experiences and timed trigger points where various priming interventions may be activated. Trigger points may occur before, after, or during the experience. Such guided priming can lead to increased motivation, better situational context, and ultimately better learning outcomes [15]. Stephen Krashen’s Affective Filter hypothesis with second language learning, advocates for creating experiences that reduce anxiety, while increasing motivation and self-confidence [23], [24]. The ELT cycle offers opportunities for priming interventions to improve affective elements and improve academic performance.

Situated Learning Theory (SLT) [7], [25] recognizes the value of social and contextual experiences within a community of practice. Within a specific situation learners can see, hear, do, and feel the experience resulting in higher retention and improved performance. Based on SLT, technology solutions that offer improved situational contexts and modalities should increase engagement and performance. For example, placing someone in an animation studio could amplify the understanding of an animation related idea or concept [7], [25] and given this improved understanding and improved self-confidence, perhaps increase their willingness to participate in the process [23], [24].

D. VR as a “Prime” Enabler

While priming is most effective in the context of authentic, supraliminal, and repetitive experiences [15], ELT and SLT similarly depend upon continuity/repetition and authentic experiences that allow the learner to repetitively reconstruct their knowledge and understanding of the subject matter. [24]

VR offers affordances that address common ELT, SLT, and priming requirements. As a procedural tool, VR provides the ability to simulate, repeat, and reconstruct learning experiences with successive iterations. The 3D visualization and interactive capability of VR provides a powerful capability that could be applied in the conceptualization and experimentation phases of ELT and within the same situated learning environment. While the reflection phase of ELT might seem inherently “low tech”, the procedural, repetitive simulation capability of VR lends itself to Artificial Intelligence (AI) and Machine Learning (ML).
where new insights could be applied as reflective priming interventions.

Further, VR provides the facility to design ubiquitous situational contexts: environments, artifacts, and avatars with narrative storytelling capabilities [33], [34] that would not be possible otherwise. As a social and learning tool, myriad VR applications (e.g., Oculus Horizons, Workrooms, AltspaceVR) are already bringing together globally distributed social groups and communities of interest for education, collaboration, and entertainment purposes. These virtual situational environments can legitimately bring expert, learner, and the community together in a common situational context that transcends geography and culture [3], [7], [25].

Most recently, game-based learning experiences and gamification techniques have gained increasing marketplace momentum [41]. These techniques can be combined with VR enabled educational programs to augment and improve experiential learning, reducing anxiety, and priming positive mindsets within the learning experiences [1], [15].

Central to the concept of VR is the quantifiable concept of immersion and the more subjective idea of presence or the feeling of being there. Based on these immersive possibilities and the ability to create a sense of presence, VR is an ideal environment to create scenarios to evoke different forms of conscious awareness [11]. For designers, VR offers the possibility to create learning spaces that are more conducive to learning while “designing out” potential anxiety-inducing barriers. In a 2013 study, 3D virtual environments were used to test the effects of priming on creativity. The results showed that when teams created ideas in the Primed virtual environments, they created more ideas and of higher quality than the control groups [1], [35], [36].

Customizable, inhabitable avatars and computer-controlled Non-Player Characters (NPCs) within specific learning situations offer compelling priming advantages to increase inclusivity and broaden sociocultural contexts by allowing participants to adapt cultural environments and/or inhabit personas of other races, cultures, or genders that challenge existing situated learning norms, an acknowledged concern regarding situated and experiential learning [18]. As such, the combination of VR, ELT, SLT, and context priming show great promise in reducing stereotype threats that have been shown to negatively impact academic performance [3], [31].

### III. Methodology

We conducted a user study to perform an evaluation of environment context priming effects within immersive virtual reality environments. In previous research, we investigated the potential value of pre-learning activities like VR video games and meditation as priming methods [15]. This study will deploy a similar remote research process where a VR Head Mounted Device (HMD) is provided and managed by each participant in their own home. Our study was approved by the University’s Research Ethics Board and followed all the guidelines, including those for safe experimentation during the COVID-19 Pandemic.

#### A. Study Overview

The study, a between-subjects test with one independent variable (Priming context), explored the effectiveness of VR-based context priming. A 27-minute seminar “The Creative Process of Making an Animated Movie” was presented to 51 participants within three VR learning spaces: two Prime and one No Prime. The Prime conditions included two situated learning environments: 1) an animation studio and 2) a theatre with animation artifacts. The No Prime condition was the same theatre with no subject matter artifacts. The priming conditions were selected based on SLT [2], [9] that emphasizes the role of authentic and realistic environments in learning.

The study used three dependent variables (academic score, user experience, and affective improvement). Academic score is our main subject and represents the learning effect of the context. It was measured with a 20-question multiple choice test completed immediately after the seminar. While there is little empirical evidence suggesting that context priming in VR can improve the perceived UX or affective response, we remained curious nonetheless to investigate any possible impact on the UX.

The test and the survey are described in Section 3.3. Affective factors: Anxiety and positive affect, were measured using a pre and post course short-form State Trait Anxiety Inventory (STAI) [28], [40] and Positive Negative Affect Schedule (PANAS) [45] surveys respectively. The STAI measured changes in self-reported anxiety levels while the PANAS similarly measured changes in self-reported positive and negative affect. Based on anticipated priming and situational learning effects, we investigated the following hypotheses:

**H1:** (a) Prime conditions (both) will improve academic performance over the No Prime condition. (b) There will be no significant difference between two priming contexts.

**H2:** (a) Prime conditions (both) will improve subjective assessments of UX results compared to the No Prime scenarios. (b) There will be no significant difference in UX results between the two priming conditions.

#### B. Participants

The study was performed with 51 participants over three priming conditions (17 in each condition). Most participants were existing university students in Ontario, Canada with the balance or adult lifelong learning students with an interest in exploring VR educational technology. Due to COVID restrictions, some of the students (foreign students), were living remotely in other countries. The participants, upon acceptance, were randomly placed in one of three groups corresponding to priming or non-priming scenarios. Participants were paid $20 CDN (via e-transfer) upon completion of the course and the post seminar questionnaires.

#### C. Apparatus

Participants were provided with an Oculus Quest or Quest 2 VR HMD that automatically loaded the necessary testing...
software to the registered participants from the Oculus App Lab developer module. Testing and questionnaires were completed on personal computers or mobile tablets within a standard browser.

The 27-minute seminar “The Creative Process of Making an Animated Movie” was presented in an audio-visual format on a large screen with the professor, an experienced animation producer (embodied in a human-like avatar), located behind the podium (see Figure 4 below). The content consisted of charts and videos that described the creative process including sections related to the idea, story structure, characters, aesthetics, prototyping, and key creative roles. Popular movie examples were first analyzed (The Lion King, Monster’s Inc), a new movie idea was presented and walked through each stage of the process to demonstrate how to approach the problem from scratch.

Experiential learning theorists might advocate for a more participatory role in the learning process, but this content is not a hands-on process or skill. This subject matter (digital storytelling) within the community of practice (an animation studio or animation theatre) facilitates peripheral participation in the manner presented in this VR seminar. An expert producer, creator, or showrunner would share ideas and examples while the student writers or interns attend the creative sessions, observe, and listen. The process becomes more collaborative over time, but earlier stages of creative projects typically focus on dispensing information to create a common understanding of the process, culture, roles, and key creative challenges.

To properly isolate and measure the specific context priming effect of the VR environments independent of other priming or ad hoc teaching influences, we opted to create a very simple, predictable teaching format; a lecture presented as a pre-recorded, non-interactive experience. The audio and visual course content was identical for all conditions (rendered from the same source files). Within the second Prime condition (theatre with animation artifacts), the artifacts were comprised of popular culture animation movie icons and imagery that iterated every 2-3 minutes above the main content presentation screen (similar to web banner). The artifacts/posters at the sides of the classroom did not change with the specific intent of limiting visual distractions away from the main content screen at the front of the theatre.

The multiple-choice questions (20) related directly to the content presented in the seminar. Certain questions (15) required the student to apply what they had learned from the theory while others (5) challenged the student to choose solutions that applied what they had learned from the new movie idea presented. Presented below are two examples; the first, a theory question based on story structure, the second, an applied question based on a new idea provided.

1) Example Question 1:
Joseph Campbell suggests that the “Hero’s Journey” represents myths and rituals that are typically associated with the following in most cultures.

A. Battles between good and evil.

B. A story to explain nature and cosmic events.

C. An initiation process.

D. None of the above.

2) Example Question 2:
Parallel Parker is a universe hopping animated hero with a big job; to save the world. Based on your new insights, what would make a good log line for our new Parallel Parker movie?

A. Parker is young and fearless and with the help of her intergalactic friends, she is destined to save the universe.

B. A stressed-out pre-teen, whose main skills are avoiding school and binge-watching TV suddenly realizes that she, along with her cosmo alter egos, must stop an evil supervillain intent on stealing all that is good from the universe.

C. A super-villainy, interdimensional entity decides to wreak havoc on the universe by sucking up all the positive energy, leaving the rest of the universe to slowly rot.

D. A young, reluctant girl is faced with the decision of her life. Stay home and chillax or get off her butt and save the world. When the chilling thing goes wrong, she’s forced to save the world instead.

The UX survey consisted of 22 questions related to the various aspects of the experience and a further 6 questions related to feelings of presence. To compare the presence responses, we used the Slater-Usoh-Steed (SUS) version administered immediately after the main UX questions were presented [35][42]. To measure anxiety, we used the short-form State-Trait Anxiety Inventory (STAI) questionnaire [27]. The STAI survey presented six multiple choice questions related to anxiety levels while affect was measured with the Positive Affect Negative Affect Schedule (PANAS) [40]. The PANAS survey presented 20 questions in a multiple-choice grading format to assess positive and negative aspects of mood.

Fig. 4A. No Prime.
D. Procedure

Given the limitations caused by the COVID-19 social distancing requirements, we designed a study that could be performed independently by participants at their homes. The apparatus was dropped off and picked up at participant sites by the research team. Proper disinfection rules were followed between each device use. Each participant received a unique participant code which was used to link the pre and post seminar questionnaires and results. Participants were also provided a link to a website that provided the following information.

- Short Video Guide
- Consent Form
- Pre-Post Test Surveys (STAI and PANAS)
- Post Seminar VR User Experience Survey
- Post VR Seminar Content Test

Upon completion of the short video guide (a 2-minute explanation of the process), and signed consent, participants were asked to complete a short STAI and PANAS survey, then proceed to the immersive VR seminar within the HMD. The VR experience was available as a VR application that was loaded automatically onto the HMD using the Oculus App Lab utility. Upon completion of the seminar, participants returned to the website to complete the UX, STAI and PANAS surveys and multiple-choice content test.

IV. RESULTS

We had a 1x3 experiment design with one independent variable (Priming condition – Prime vs. No Prime) and three dependant variables (academic performance, UX satisfaction, and affect). After reviewing the outlier data, we opted to eliminate the highest value from each of the three conditions to avoid skewing results based on potentially contaminated data. These high values occurred for academic score and were more than twice the average. They came from participants who were very familiar with the subject. Hence our sample size was reduced to 16 participant inputs per condition. With an equal number of participants (16) we first conducted a single factor ANOVA test for academic score and data samples.

After confirming significance of mean departure within the conditions (p=.0099), we performed a post-hoc t-test with 2 samples, assuming equal variance. We observed significance in both priming conditions compared to the No Prime condition (Prime (artifacts) vs. No Prime (P=.0023) and Prime (animation studio) vs. No Prime (P=.0103)), With t stats of 3.05 and 2.44 respectively (>2.0) we are confident with the results. There was no significant difference observed between the two Prime conditions. See comparisons of academic performance for both Prime conditions vs. No Prime condition in Figure 5 below.

<table>
<thead>
<tr>
<th>T-Test: Two-Sample Assuming Equal Variances</th>
<th>Artifacts Prime</th>
<th>No Prime</th>
<th>Animation Studio Prime</th>
<th>No Prime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>11.94</td>
<td>9.6875</td>
<td>11.44</td>
<td>9.6875</td>
</tr>
<tr>
<td>Variance</td>
<td>4.86</td>
<td>3.83</td>
<td>4.4</td>
<td>3.83</td>
</tr>
<tr>
<td>Observations</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Pooled Variance</td>
<td>4.35</td>
<td></td>
<td>4.11</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
<td>0</td>
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<td>df</td>
<td>30</td>
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<td>t Stat</td>
<td>3.05</td>
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<td>2.44</td>
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<td>P(</td>
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<td>t Critical one-tail</td>
<td>1.6973</td>
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<td>P(</td>
<td>t</td>
<td>&lt;t</td>
<td>two-tail</td>
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<tr>
<td>t Critical two-tail</td>
<td>2.0422</td>
<td></td>
<td>2.0423</td>
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</tbody>
</table>

Both PANAS and STAI observed positive changes, most likely because of the immersive VR experiences that have been shown to elicit positive affective responses [15], but in line with research related to the supraliminal aspects of priming [29], we did not observe a significant difference in either case comparing the Primes to the No Prime condition. The average presence results for all conditions were strong (>5).

The UX and Affect results are presented in Figures 6, 7 and Table 1 below. In Figure 6, we consolidate the positive and negative affect results from Table I, to visualize the net positive effect.
There were dozens of unique comments that validated designs and/or recommended improvements to the VR experience. A sample of the more salient comments are presented below. We do not differentiate comments between Prime and the No Prime conditions as all VR conditions elicited both positive and negative feedback, which was consistent with the affective data.

2) Example Positive Comments
- Felt real and engaging
- When in VR classroom, you feel totally immersed
- Far better than wearing a mask for 2 hours trying to hear what your prof is saying.
- It reminds me of the university setting but with the elimination of the anxiety.
- When focused on the lecture I enjoyed the information and was surprised at how much it felt like a real classroom.

3) Example Negative or Mixed Comments
- Not quite real enough though better than zoom
- Sometimes images would distort which reminded me that I was in a virtual space rather than a real one.
- Issues of image resolution and inability to take notes.
- I found myself very tired and not able to focus
- During my experience, I'd repeatedly remind myself that as real as it seems it's merely a virtual world.

V. DISCUSSION

In reviewing the first hypothesis (H1), both Prime conditions observed significant improvement over the No Prime condition, while there was no significant difference between two priming contexts. Hence, H1a and H1b are both supported. The priming conditions improved academic performance. In reviewing the second hypothesis (H2) (UX), neither Prime condition demonstrated significance over the No Prime condition. Hence, H2a was not supported. The Prime conditions did not observe significance between themselves with respect to UX results. Hence, H2b is supported. In summary, Prime conditions did not improve the perceived UX compared to the No Prime condition or between Prime conditions.

There was a great deal of relevant feedback provided through the UX study that will inform future design. In general, it was a very positive experience where most participants felt a strong sense of presence and were sufficiently engaged in the content.

That said, image resolution and blurriness appeared to be a distraction for some and as such, most likely reduced immersion, and presence effects. Striving to eliminate issues of blurriness, aliasing, or any image resolution issues should be a major focus in future environment and character designs for VR spaces.
Further, the seminar for this study was a creative process that was conducive to collaborative, community-based learning and was suited well for both the ELT cycle and an SLT learning effect. For future research, determining the effect of context priming for different subjects of study will be necessary. Would science or math-related courses gain more from priming activities than the creative arts? Also, it is critical to explore additional priming methods within the ELT cycle, such as preparatory, motivational, and reflective priming, and the combined effect of deploying multiple priming intervention methods concurrently.

Finally, as accessibility is critical and not everyone can use a VR HMD, assessing the effectiveness of priming in non-immersive VR environments could inform the design of new or varying priming strategies.

VI. LIMITATIONS

Part of the Information Technology (IT) challenge with VR HMDs is that one size does not fit all participants. Some participants may have benefitted from optical lenses that improve the visual experience without the need for glasses. In a non-COVID study, where participants would have had immediate, in person feedback from researchers, most of the visual distortion issues could have been easily mitigated on the spot. The challenges of testing remotely with new technology were significant. Technology glitches or even minor issues are easily alleviated with “in person” IT support and multi-person sessions that can be scheduled in advance. The deployment of each HMD required at least one and most often 2 to 3 email or phone exchanges to support or help the participant feel comfortable. That said, the remote process was the only possibility solution for university researchers in 2021 and the research team was able to complete the testing and maintain the integrity of the process.

There were limitations to be considered for future research. First, these studies are small numbers and could benefit from a much larger study. Affective surveys (anxiety and positive affect) were subjective user responses. Ideally, to properly assess positive affect and anxiety levels, an fMRI to monitor brain activity and/or a molecular imaging solution to measure dopamine release and other neurotransmitter levels could be used while content is observed, and the tests are administered.

While the UX and affective measurements were secondary to the core study, comparing the UX and Affect data in Primed and Non Primed VR environments did provide insights into future designs and the overall emotional impact of the technology solutions.

VII. CONCLUSION

Motivated by the disruptive potential of immersive VR, we wanted to understand the priming potential of VR environments to improve student performance. In our study of 51 participants, with three conditions (2 Prime, 1 No Prime) we observed a clear priming effect that we attribute to the impact of situated learning induced by simulated animation studio and the effect of subject matter artifacts situated in the VR learning space.

We discussed future areas of research that included further priming methods, varying subject matter, and exploring the effects of concurrently deploying multiple methods of priming.

We proposed further study related to other potential trigger points within the ELT that could Prime positive motivation and reflective activities to facilitate the student to better reconstruct knowledge and experience. We also proposed further research to better understand the neuropsychological mechanisms at play with various priming methods.

ACKNOWLEDGMENTS

Special thanks to Edin Ibric, Jonathan Jackson, Nathalie Malette, Hayley Anderson, and Toonrush Inc. for design, editing, and support services.

REFERENCES

Determinants of the - - - - bias.


Comparing Student-Based Context Priming in Immersive and Desktop Virtual Reality Environments to Increase Academic Performance

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Abstract—Research suggests that 3D virtual environments can be designed to prime engagement, creativity, and improve performance on many cognitive tasks. In this paper, we report on a study that compares the efficacy of context (environmental setting) on the priming of these desired effects within Desktop Virtual Reality (DVR) environments compared to Immersive VR (IVR), viewed from within a VR Head Mounted Device (HMD). We presented a 27-minute seminar “The Creative Process of Making an Animated Movie” to 68 participants within 4 different learning spaces: two with IVR (Prime and No Prime) and two with DVR (Prime and No Prime). The priming scenarios for both IVR and DVR environments included subject matter and popular culture visual artifacts related to animated movies and characters placed within a theatre classroom. This was intended to create a situated learning effect. The No Prime condition was presented in a standard classroom theatre without visual artifacts or any subject matter augmentation. A 20-question multiple-choice content test and UX survey were administered following the seminar while an affective questionnaire measuring anxiety and positive affect were provided before and after the seminar. Increased academic performance was observed with a significant difference in both DVR and IVR priming scenarios compared to the no priming conditions.

Index Terms—Context, priming, situated learning, immersive, DVR, artifacts, experiential, ELT, applied computing, education, computer-assisted instruction, human-centered computing, human computer interaction, interaction paradigms, virtual reality

I. INTRODUCTION

Research suggests that the context of virtual learning environments can affect performance. In fact, 3D virtual environments can be specifically designed to prime engagement, creativity, and improve performance on many cognitive tasks [2]. While similarly designed environments in real-world space would also likely improve performance, the costs would be considerable and difficult to achieve ubiquity. Virtual Reality (VR), a 3D technology that provides the tools to visually simulate real-world environments, allows us to improve context by creating custom learning spaces intended to prime (act as stimuli that improves subsequent cognition) engagement and academic performance [20], [21], [2].

An important aspect of understanding the contextual effect of custom virtual environments is the level of immersion the user is experiencing. While there is little research on the comparable effect of VR immersion on user perception of context, the degree of immersion may well have an impact. This study expands on the notion of context from “what virtual environment the user sees” to “what physical context the user has”. In this paper, we seek to understand whether varying levels of immersion changes the effectiveness of context priming interventions to improve academic performance within virtual environments. As such, we compare the priming effects of Immersive VR (IVR) environments to Desktop VR (DVR) environments. IVR is experienced from within a VR Head Mounted Device (HMD) while DVR is typically experienced on a desktop, laptop, or tablet-based computer.

Prime conditions were designed to induce a positive situated learning effect [3][14] intended to improve academic performance. While our main goal is to investigate the effect on academic performance, we also measure for affective elements (anxiety and positive affect) and additional affective filter elements (motivation and self-confidence) [11][12] that may be relevant to the VR experience and/or academic performance.

After reviewing related IVR, DVR, priming, and experiential learning we follow with study description, hypotheses, results, and user feedback that will inform the design of future IVR/DVR experiences. We conclude with discussion, limitations and propose further study of varying subject matter within IVR and DVR environments.

II. RELATED WORK

A. IVR and DVR Research

VR technology has been evolving and becoming increasingly sophisticated over the past 57 years since Ivan Sutherland introduced the concept of the ultimate display to academia in 1965 [25]. While the technology has achieved recognition in popular culture, the evolving technology has been mostly relegated to academic research. Only recently with the release of low-cost sophisticated HMDs like the Oculus Quest has VR become an accessible mainstream product/service gaining popularity and growing in many fields:
entertainment, education, learning, travel/tourism experiences, and myriad others. While IVR offers a fully immersive experience and an enhanced feeling of presence [20], [21], DVR environments have been shown to similarly create positive learning effects [2].

A 2020 study comparing a DVR field trip, IVR field trip, and an actual geoscience field trip observed that both DVR and IVR participants preferred the VR field trips to the actual field trip experience [33]. Further, both IVR and DVR yielded higher learning outcomes than the actual field trip experience. While participants expressed higher motivation and feelings of presence in IVR compared to the DVR, there was no learning performance difference between the IVR and DVR conditions [33]. Researchers have acknowledged that other visual simulation applications may have benefitted more from the IVR (e.g., procedural memorization and data visualization) [13], [18], [19], [23]. In line with this insight, a 2020 study focused on optimizing the use of VR for pedagogical value, discovered that both methods have merit and while many students are comfortable and more familiar with DVR, there may be cases where a first-person perspective could better serve the learning situation [15].

B. Priming and VR

Priming occurs when a stimulus (the prime) makes the content and subsequent cognitive processes more accessible [8]. Most often, priming stimuli are supraliminal (observable but not obvious) where changing the context of an environment can create effects with little or no perceptual awareness. A picture can create bias and affect how a person thinks [7] or placing codes (A vs. F) on pre-test forms can affect academic performance [4].

Central to the concept of VR is the quantifiable concept of immersion and the more subjective idea of “presence” or the feeling of being there. Based on these immersive possibilities and the ability to create a sense of presence, VR is an ideal environment to create scenarios to evoke different forms of conscious awareness [20]. For designers, VR offers the possibility to create learning spaces that are more conducive to learning while “designing out” potential anxiety-inducing barriers. In a 2013 study, 3D virtual environments were used to test the effects of priming on creativity. The results showed that when teams created ideas in the primed virtual environments, they created more ideas and of higher quality than the control groups [2]. While these early priming studies are promising, much research is required to determine how the feelings of presence in VR trigger emotions and engagement leading towards better cognitive outcomes [28], and how to design VR experiences for maximal priming and cognitive effects within learning environments [5].

C. Learning Theories

Priming efficacy directly benefits from repetition [32] and authentic experiences [1] where priming effects can be woven subtly into the environmental context. As such, of particular interest for our research was Kolb’s Experiential Learning Theory (ELT) [10]. With ELT, learning begins with having a concrete experience, followed by a reflection of that experience, the conceptualization of abstract concepts that incorporates the new insights from the experience, and finally active experimentation of the lessons learned. The cycle continues to repeat as the learner’s conceptual worldview is repeatedly refined. Learning is achieved as a process: a continuing reconstruction of experience.

The ELT cycle can provide iterative experiences and timed trigger points where various priming interventions may be activated. Trigger points may occur before, after, or during the experience. Such guided priming can lead to increased motivation, better situational context, and ultimately better learning outcomes [5]. Stephen Krashen’s Affective Filter (AFH) hypothesis with second language learning advocates for creating experiences that reduce anxiety, while increasing motivation and self-confidence [11][12]. The ELT cycle offers a fertile substrate where priming interventions to reduce these affective filters could improve academic performance.

Situated Learning Theory (SLT) [3], [14] recognizes the value of social and contextual experiences within a community of practice. Within a specific situation learners can see, hear, do, and feel the experience resulting in higher retention and improved performance. Based on SLT, technology solutions that offer improved situational contexts should induce confidence through better understanding, increase motivation to try something new and ultimately improve academic performance. For example, placing a student within an animation studio could amplify the understanding of an animation-related idea or concept [6] [3][14] and given this improved understanding, perhaps increase their willingness to participate in the process.

Hence, by combining insights on priming, experiential/situated learning, and VR, we intend to better understand the comparable effectiveness of IVR and DVR in primed environments to improve academic performance and related affective elements.

III. METHODOLOGY

We conducted a user study to perform an evaluation of context priming efficacy to impact academic performance in IVR and DVR environments by comparing data from a previous IVR study [6]. This study will deploy a remote research process where a DVR web link is accessed by each participant in their own home. Our study was approved by the University’s Research Ethics Board and followed all the guidelines, including those for safe experimentation during the COVID-19 pandemic.

A. Study Overview

The study, a 2x2 between-subjects test with two independent variables (Prime condition, immersive context), compared the effectiveness of VR-based priming in IVR and DVR environments. A 27-minute seminar “The Creative Process of Making an Animated Movie” was presented to 34 participants and compared with 34 participants from a previous study [6] to create four unique conditions, 2 Prime and 2 No Prime.

1) IVR with Prime environment (17)
2) IVR with No Prime environment (17)
3) DVR with Prime environment (17)
4) DVR with No Prime environment (17)
The Prime conditions included a situated learning environment: a theatre with animation artifacts vs. the No Prime; theatre without animation artifacts. The priming conditions were selected based on SLT [3][14] that emphasized the role of authentic and realistic environments in learning. The immersive context was either IVR or DVR. The IVR study participants observed the same classrooms and priming conditions as DVR participants but from within an Oculus Quest VR Head Mounted Device (HMD) [6]. The study used three dependent variables (academic score, user experience, and affective improvement).

Academic score is our main subject and represents the learning effect of the context. It was measured with a 20-question multiple choice test completed immediately after the seminar. Affective factors: anxiety and positive affect, were measured using a pre and post course short-form State Trait Anxiety Inventory (STAI) [16] and Positive Negative Affect Schedule (PANAS) [29] surveys respectively. The STAI measured changes in self-reported anxiety levels while the PANAS measured changes in both positive and negative affect. Other affective elements (motivation and self-confidence) were queried in the UX survey with two 5-point Likert scale questions. The questions were 1) How motivated do you feel to participate in the creation or production of an animated movie? and 2) How confident do you feel in your ability to create your own animated story?

Hypotheses

**H1:** The Prime conditions will improve academic performance compared with the No Prime condition in **H1:** a) IVR and **H1:** b) DVR environments, supporting the notion that environment context priming maintains efficacy between varying levels of immersion.

**H2:** There will be no improvement in academic performance observed due to immersion in both Prime conditions: **H2:** a) (Prime IVR vs. Prime DVR) and **H2:** b) (No Prime IVR vs. No Prime DVR).

**H3:** Key affective filter elements [11] will be reduced because of the ELT/SLT learning process including **H3:** a) Anxiety **H3:** b) Motivation and **H3:** c) Self-confidence.

**B. Participants**

The user study was performed with 34 DVR participants compared with 34 IVR participants from a previous study [6]. Participants were from a varying programs within a university student audience, 18+, and ongoing adult education students with an interest in exploring VR educational technology. Participants were paid $20 CDN (via e-transfer) upon completion of the course and the post seminar questionnaires.

**C. Apparatus**

Participants were provided with a Desktop VR link from Youtube VR360 to be viewed on a desktop PC, laptop, or computer tablet. The IVR participants in the previous study [6] observed the same VR environments but from within an Oculus Quest HMD. Similarly, testing and questionnaires were completed on desktop PC or mobile tablets within a standard browser for both IVR and DVR participants. A link to the Prime and No Prime DVR conditions are provided below.

No Prime Classroom
https://www.youtube.com/watch?v=68e_XW1nQYY&t=1162s
Prime Classroom (with Artifacts)
https://www.youtube.com/watch?v=VkayjGBUVaQ&t=13s

The 27-minute seminar, “The Creative Process of Making an Animated Movie” was presented in an audio-visual format on a large screen with the professor, an experienced animation producer (embodied within a human-like avatar), located behind the podium (see Figure 1A and 1B). The content consisted of charts and videos that described the creative process including sections related to the idea, story structure, characters, aesthetics, prototyping, and key creative roles. Popular movie examples were first analysed (The Lion King, Monsters Inc), then as an example, a new movie idea was presented and walked through each stage of the process to demonstrate how to approach the problem from scratch. While the audio and visual course content was identical (rendered from the same source files), the Prime environments presented popular culture animation icons and artifacts that iterated every 2-3 minutes above the main content screen. The artifacts/posters at the sides of the classroom did not change in order not to create visual distractions away from the front of the classroom. The multiple-choice questions (20) related directly to the content presented in the seminar. Certain questions (15) required the student to apply what they had learned from the theory while others (5) challenged the student to choose solutions that applied what they had learned from the new movie idea presented.

**D. Procedure**

Given the limitations caused by COVID-19, we designed a study that could be performed independently by participants at their homes. Each participant received a unique participant code which was used to link the pre and post seminar questionnaires and results. Participants were provided with a Youtube 360VR link for the main seminar content and a link to a website that provided the following information:

- Short Video Guide
- Consent Form
- Pre-Post Test Surveys (STAI and PANAS)
- Post Seminar VR User Experience Survey
- Post VR Seminar Content Test

Upon completion of the short video guide, (a 2-minute explanation of the process and surveys/tests that we expected the participants to complete), participants were asked to complete a consent form, STAI and PANAS surveys and then proceed to the Youtube 360VR link. Upon completion of the seminar, participants returned to the website to complete the post seminar STAI and PANAS surveys, multiple choice test and UX Questionnaire.
IV. RESULTS

We had a 2x2 experiment design with two independent variables (Prime condition, immersion) and three dependent variables (academic performance, UX satisfaction, and affect). While this test only sampled two conditions, we also wanted to test the results against results in Study 2a with the comparable immersive environments. After reviewing the outlier data, we opted to eliminate the highest value from all four conditions (two immersive and two desktop) to avoid skewing results based on potentially contaminated data. These high values occurred for academic score and were more than twice the average. They came from participants who were very familiar with the subject matter. Hence our sample size was reduced to 16 participant inputs per condition, 64 in total. The independent test scores for all four condition groups are presented in Table 1 below.

With an equal number of participants (16) we conducted a two factor ANOVA with independent samples to test for differences in academic score (Table 2). After confirming a significant difference in means between columns (Prime vs. No Prime) (p=.0002), we used a Tukey HSD post-hoc test at ( .05 ) to determine significance for the various combinations. For Tukey test results, see Table 3 below. Both IVR and DVR Prime conditions compared to their No Prime conditions were significant whereas Prime IVR compared to Prime DVR and No Prime IVR compared to No Prime DVR were nonsignificant.

<table>
<thead>
<tr>
<th>Table I. Test Results for Academic Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data for 2x2 Anova (Prime Condition, Immersion)</td>
</tr>
<tr>
<td>Prime</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>10</td>
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<tr>
<td>8</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table II. 2F ANOVA (Prime/No Prime, IVR/DVR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anova: Two-Factor for Independent Samples</td>
</tr>
<tr>
<td>SUMMARY</td>
</tr>
<tr>
<td>IVR</td>
</tr>
<tr>
<td>Count</td>
</tr>
<tr>
<td>Sum</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>Variance</td>
</tr>
<tr>
<td>DVR</td>
</tr>
<tr>
<td>Count</td>
</tr>
<tr>
<td>Sum</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>Variance</td>
</tr>
<tr>
<td>Source of Variation</td>
</tr>
<tr>
<td>Sample</td>
</tr>
<tr>
<td>Columns</td>
</tr>
<tr>
<td>Interaction</td>
</tr>
<tr>
<td>Within</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table III. Tukey HSD Test Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tukey HSD Test (.05)</td>
</tr>
<tr>
<td>Rows</td>
</tr>
<tr>
<td>Columns</td>
</tr>
<tr>
<td>Results Table Comparison</td>
</tr>
<tr>
<td>IVR Prime vs No Prime</td>
</tr>
<tr>
<td>DVR Prime vs No Prime</td>
</tr>
<tr>
<td>Prime IVR vs Prime DVR</td>
</tr>
<tr>
<td>No Prime IVR vs No Prime DVR</td>
</tr>
</tbody>
</table>

No affective changes were observed in anxiety reduction (STAI) for DVR (p=.423) or IVR (p=.3876) or positive affect (PANAS) for DVR (p=.4188) or IVR (p=.1937). We did
however observe a significant positive impact on both motivation and self-confidence through the UX feedback comparing Prime to No Prime conditions. The post-test UX question assessing the priming effect of motivation to participate in creating an animated movie observed significance, in both IVR (p=.0285) and DVR (p=.0242) scenarios compared to the control conditions. See Figure 4. Similarly, the post-test UX question assessing self-confidence in their ability to create an animated movie observed a significant difference comparing Prime to No Prime conditions in both IVR (p=.0067) and DVR (.0282) scenarios. See Figure 5.

1) UX Commentary Feedback
The UX commentary provided relevant feedback related to the design of the VR experiences. As the comparable priming conditions were not shared with the participants, most feedback was related to the general design of the UX experience in either IVR or DVR contexts. In general, the immersive conditions from the comparable study [6] seemed to generate slightly more favourable commentary as was shown in previous studies comparing IVR and DVR. A few examples of the more salient comments in each condition are presented below.

2) Example IVR Comments
- When in VR classroom, you feel totally immersed
- It reminds me of the university setting but with the elimination of the anxiety.

3) Example DVR Comments
- It feels like you are in attendance
- It was clear that I was not actually in the environment, but it did still feel like I could interact with and explore the environment.

### Table 1: Self Confidence in your ability to create an animated movie

<table>
<thead>
<tr>
<th></th>
<th>IVR Prime</th>
<th>IVR No Prime</th>
<th>DVR Prime</th>
<th>DVR No Prime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.6875</td>
<td>2.625</td>
<td>2.8125</td>
<td>2.0625</td>
</tr>
<tr>
<td>Variance</td>
<td>0.7625</td>
<td>1.85</td>
<td>0.9625</td>
<td>0.729167</td>
</tr>
<tr>
<td>Observations</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Pooled Variance</td>
<td>1.30625</td>
<td>3.8/5835</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>2.629</td>
<td>2.3066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.0967</td>
<td>0.014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>1.9773</td>
<td>1.6972</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.013</td>
<td>0.0282</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.0422</td>
<td>2.0422</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5. UX feedback on self-confidence (Likert Scale 1-5).

### V. DISCUSSION AND LIMITATIONS

In this study, we focused on extending our understanding of context priming to increase cognitive function and improve the user experience within desktop VR environments.

Our hypotheses were designed to test the priming effects of our Primed Desktop VR environment compared to our No Prime condition and to compare the relative effect of immersion. While IVR has the advantages of full immersion and novelty, DVR is more familiar and less complicated. Existing literature is not conclusive on the effect of immersion and superiority of IVR or DVR. So, our research adds to an increasing body of research on the subject.

In reviewing the first hypothesis, the DVR Prime condition observed significant improvement over the No Prime condition. This is consistent with the previous IVR study. Hence, H1 a) and H1 b) are supported. Further, the DVR Prime condition did not observe a significant difference in academic performance compared to the IVR Prime condition, nor did the DVR No Prime condition observe a difference in academic performance relative to the IVR No Prime condition. As such, H2 a) and H2 b) are supported.

Our final hypothesis sought to determine if the affective filters (Anxiety, Motivation, and Self-Confidence) would be reduced because of the varying levels of immersion. As presented above, STAI results did not observe a significant reduction in anxiety. Hence H3 a) is not supported. A significant difference was observed in increased motivation (IVR (p=.0285) and DVR (p=.0242)) for DVR and increased self-confidence IVR ((p=.0067) and DVR (p=.0282)) for both IVR and DVR. Hence, H3 b) and H3 c) are supported (for DVR) and H3: c) is supported for both IVR and DVR. The priming effect of the virtual environments did not decrease anxiety but did increase motivation and self-confidence compared to the No Prime conditions for both IVR and DVR environments.

The UX and affective feedback did provide some relevant information for further reflection, however. There appeared to be a slightly different tone in the qualitative feedback even
though we did not observe a significant difference in affect or subjective UX between Prime and No Prime conditions in either medium. The commentary for the IVR participants seemed to be slightly more positive when compared to the DVR conditions suggesting that the affective elements of learning between immersive and desktop conditions warrant further study. It's very possible that the immersive activity can serve as somewhat of an escape, allowing students to filter out distractions from their real-world environments including smartphone and personal interruptions. In desktop conditions, students remain subject to influences within their real-world environments, and as such may have experienced the learning session more like a typical computer application rather than a fully immersive learning experience.

There were limitations to be considered for future research. First, these studies were small numbers (16 per condition) and could benefit from a much larger study. Further, the affective surveys (anxiety and positive affect) were subjective user responses and could be more accurately ascertained using F-MRI and/or galvanic skin response technology. While most of the participants had little or no history with the subject matter of the course, it would have helped to include a pre-test measure to ensure that students were evenly distributed. This could have helped avoid the outlier effects. We were also concerned with the timing of the survey and the potential for COVID-19 situational effects. The study was performed in the summer and early fall of 2021, a time when most students were at home with no commuting requirements for work or school due to COVID-19. As such, we noticed that pre-test anxiety levels were on the low side while positive affect appeared high compared to previous studies which may have mitigated a priming effect for these affective elements.

Finally, while we achieved an academic performance improvement for both IVR and DVR contexts, effectiveness between IVR and DVR may differ depending on specific types of content within other learning domains. In this study, there was no requirement for 3D visualization but likely experiences with high 3D visual requirements would be served better in IVR. The seminar for this study was a creative process that was conducive to collaboration, community-based learning, and the ELT cycle. Similar testing should be performed on varying subject matters with different types of content experiences related to geography, history, mathematics, music, and other creative arts to determine the optimal immersive environments.

VI. CONCLUSION

Motivated by the results of context priming within IVR environments, we wanted to understand if we could apply these priming methods to DVR environments to achieve a similar effect.

In our study of 34 participants, combined with 34 participants from an earlier study [6] with two conditions (1 Prime, 1 No Prime) we observed a clear priming effect that we attribute to the subject matter artifacts and a potential situated learning effect, consistent with the IVR study. Also, consistent with established research on supraliminal priming, as deployed in previous studies, [5][6] the UX feedback, STAI, and PANAS did not observe a significant difference between Prime and No Prime conditions. We did note a general affective trend, where the immersive conditions elicited more positive commentary than the less immersive conditions. While anxiety and positive affect did not show improvements, motivation and self-confidence showed positive priming effects in both IVR and DVR compared to the No Prime conditions.

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Investigating the Mobile Augmented Reality Acceptance Model with Pre-Service Teachers

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Abstract—The aim of this study was to investigate the factors that might affect pre-service teachers’ intention to use Mobile Augmented Reality in their future teaching. The Mobile Augmented Reality Acceptance Model (MARAM) was used as the study’s theoretical framework. In addition, this work was a validity study for MARAM. Empirical data was collected from 137 pre-service teachers who had developed their own Mobile Augmented Reality applications during an undergraduate university course. The findings of the regression analysis revealed that the MARAM’s variables can explain the variance of perceived ease of use, perceived usefulness, attitude, and intention to a satisfactory degree. Mobile self-efficacy and facilitating conditions were predictors of perceived ease of use. Both perceived enjoyment and perceived relative advantage were predictors of perceived usefulness. In addition, both perceived usefulness and perceived enjoyment were predictors of attitude. Finally, attitude and perceived usefulness were predictors of pre-service teachers’ intention to use Mobile Augmented Reality in their future teaching. However, perceived ease of use failed to be a predictor of attitude and perceived usefulness. These results have implications for pre-service teachers’ education, school leaders and researchers in the field of augmented reality acceptance models.

Index terms—Mobile Augmented Reality, Technology Acceptance Model, pre-service teachers, education

I. INTRODUCTION

The technological and learning affordances of smart mobile devices (i.e., tablets, smartphones) have contributed to an increased use of Mobile Augmented Reality (MAR) applications in teaching and learning [1], [2]. The existing research that has accumulated over the last 15 years regarding the utilization of AR in education shows that, compared to other technologies, AR offers pedagogical added value to many subjects, contributes to the combination of formal and informal learning environments, and can enhance mobile learning [3]–[8].

Recently, both industry and researchers have been offering platforms and systems for the utilization of MAR in printed documents [9]–[12] such as books and maps (i.e., image-based AR systems), as well as various sites of special cultural, historical and/or environmental value (i.e., location-based AR systems) [13], [14]. One of the major benefits of such platforms is that they allow users with no programming skills to develop their own applications with various augmented reality objects such as 3D models, pictures, videos, animations, audio, texts as well as hyperlinks to several pages [9], [10]. These new capabilities and the ease of use offered by the new generation of mobile AR development tools could be utilized in schools for the creation of new immersive experiences for teaching and learning. However, the success of any digital technology in teaching [15], such as AR, depends on its acceptance by teachers. Numerous researchers believe that, in order for teachers to be more positive towards the acceptance of AR, it should be included in the curriculum of undergraduate university courses [16], [17]. A recent study [18] has shown that pre-service teachers have realized the benefits of using AR (e.g., AR books) in teaching. Therefore, understanding pre-service teachers’ acceptance of digital technologies such as AR is critical for the improvement of their digital and pedagogical readiness during their undergraduate studies. Furthermore, it will assist schools to design policies that are more likely to facilitate the use of MAR by the new generation of teachers.

In this context, numerous studies were conducted to examine factors that are related to pre-service teachers’ acceptance of digital technologies in classrooms, using known models of technology acceptance, such as the Technology Acceptance Model (TAM) and other, modified versions of it [19]–[21]. However, a limited number of previous studies have examined the factors which influence pre-service teachers’ acceptance of MAR in their future teaching [22]–[24]. Some of these studies use modifications of TAM by adding new variables, such as User-interface Design [23]. Some other studies use variables of the Unified Theory of Acceptance and Use of Technology model (UTAUT) [22], [24]. However, research has shown that the acceptance of MAR is also affected by other factors such as satisfaction, social norms [25], perceived enjoyment, facilitating conditions, and mobile self-confidence [26]. Therefore, there is a need to conduct more research regarding pre-service teachers’ acceptance of MAR.
The limited number of studies on the factors that influence the acceptance of MAR by pre-service teachers was the motive for the conduction of the present study. Initially, in an undergraduate course, we taught pre-service teachers to design and develop their own applications for various units of primary school subjects and, subsequently, we examined their acceptance of MAR in their future classrooms. More specifically, in the current research, building upon a previous study [26], we aim to identify the factors affecting pre-service teachers’ intention to use MAR in their future teaching. The Mobile Augmented Reality Acceptance Model (MARAM) [26] has been used as the framework to investigate these factors. MARAM includes the variables of TAM (i.e., attitude, perceived usefulness, perceived ease of use) as well as the following variables: perceived relative advantage, perceived enjoyment, facilitating conditions, and mobile self-efficacy. As explained in the following section, we believe that this model provides a better picture regarding the acceptance of MAR in schools than other augmented reality acceptance models. Therefore, another aim of this study is to examine whether MARAM is a valid model to explain pre-service teachers’ intention.

In the following section, the theoretical framework and related literature regarding AR and technology acceptance models are presented. Then, the model and the method used by this study are briefly described. Thereafter, the results are presented and discussed. Finally, conclusions, limitations, and suggestions for future research are presented.

II. THEORETICAL FRAMEWORK

Over the last 30 years, research has been conducted in the field of social psychology and information systems to identify the factors which influence pre-service teachers’ intention to use digital technologies in their future classrooms. For that purpose, the majority of studies used, among others, two of the most widely used theoretical models: the Theory of Planned Behaviour (TPB) [27] and the Technology Acceptance Model (TAM) [28]. Both these models were expanded from the Theory of Reasoned Action (TRA) [29]. According to TRA, human behaviour is influenced by intention which is in turn influenced by attitude towards the behaviour and subjective norm. Attitude is defined as “the individual’s positive or negative evaluation of performing the behaviour” [29, p. 6], while subjective norm is defined as “the person’s perception of the social pressures put on him to perform or not perform the behaviour in question” [29, p. 6]. TPB added to TRA results to perceived behavioural control which affects intention and behaviour [27]. This new variable of TPB refers to individuals’ perceptions of their ability or inability to perform a specific behaviour.

TAM, contrary to TPB, was created exclusively for the acceptance of technology. TAM utilized TRA’s variables of intention and attitude, while the variables of perceived usefulness (PU) and perceived ease of use (PEOU) were added. Perceived usefulness is defined as “the degree to which a person believes that using a particular system would enhance his or her job performance” [28, p. 320], and is considered to affect attitude and intention. Perceived ease of use is the person’s subjective belief that using a particular technology/information system will be free from effort, and it affects perceived usefulness and attitude. TAM together with its extensions (e.g., TAM2, TAM3) has become one of the most widely used models in education to explore the adoption of a broad range of digital technologies in teaching and learning [30], [31]. These include pre-service teachers’ intention to use technology in their teaching in general as well as intention to use certain technologies, such as robots [32] and social media [33]. However, research exploring pre-service teachers’ intention to use MAR in the future educational workplace is very limited.

For instance, [22] used the Unified Theory of Acceptance and Use of Technology model (UTAUT) to examine the factors that might influence 75 Malaysian pre-service teachers’ use of Mobile Augmented Reality Learning Cardiovascular (MARLCardio). The content of this mobile AR technology was cardiovascular disease and its risk factors. It consisted of the MARLCardio booklet and the MARLCardio application. The results showed that the variables of effort expectancy, social influence and facilitating conditions had a positive impact on the pre-service teachers’ use of MARLCardio. In addition, [24] used UTAUT to investigate 70 Chinese pre-service teachers and 50 in-service teachers’ acceptance of AR technology. The results regarding pre-service teachers showed that social influence and performance expectancy had statistically influenced their behavioural intention to use AR. In a more recent study, [23] examined 303 Malaysian pre-service teachers’ readiness regarding the integration of mobile AR technology (MART) into their learning as well as in their future classrooms. They used TAM as the theoretical framework. Furthermore, they added user-interface design as an external variable. The results showed that perceived usefulness affected the use of MART. In addition, user-interface design affected both perceived usefulness and perceived ease of use.

The technology acceptance models that have been proposed for the examination of the acceptance of MAR by in-service teachers are also limited. For example, Ibili et al. [25] (i.e., AR Geometry Tutorial System) added the variables of satisfaction, social norms, and anxiety to TAM to investigate mathematics teachers’ intention to use a mobile AR application. Jang et al. [34] used an extended TAM in order to examine in-service teachers’ intention to integrate AR and VR technologies in teaching. This new model (eTAM) included the variables of TAM as well as the variables of social norms, motivational support, and technological, pedagogical, and content knowledge. Also, recently, Koutromanos and Mikropoulos [26] proposed the Mobile Augmented Reality Acceptance Model (MARAM). The aim of their study was to propose a model that demonstrates the variables which influence in-service teachers’ intention to use MAR in their teaching. The proposed MARAM was based on attitude, perceived ease of use, and perceived usefulness of TAM. Additionally, four variables from previous studies, i.e., relative advantage, perceived enjoyment, facilitating conditions, and mobile self-efficacy, were incorporated into MARAM. The results of this study showed that MARAM predicted a satisfactory percentage of the variance of in-service teachers’ intention, attitude, perceived usefulness, and perceived ease of use.

Based on the studies mentioned above, it appears that most of the already existing extended technology acceptance models that have been proposed or used for both pre-service and in-
service teachers, though important, have certain limitations. Firstly, there are models that explore the acceptance of one specific AR application in one particular subject [22], [25]. We believe that even if pre-service teachers have a positive attitude to accept a MAR application for a specific subject, this does not guarantee that they will use MAR in other subjects in their future teaching. Secondly, there are models, such as eTAM [34], which do not exclusively examine AR but, instead, VR and AR together. We believe that each of these two technologies has different characteristics and possibilities and should thus not be examined as one entity. Thirdly and most importantly, almost all the studies investigated either pre-service or in-service teachers’ acceptance of the use of exclusively ready-made AR applications in their teaching.

We believe that it is important to investigate pre-service teachers’ acceptance of MAR as they become familiar with this technology through the design and development of their own AR applications for teaching purposes. A model that was designed with this philosophy in mind and relates more to the acceptance of MAR in teaching and learning is MARAM [26]. Therefore, we use MARAM in this study as the most appropriate model to evaluate MAR acceptance by pre-service teachers.

III. MARAM

As it was presented in [26], MARAM consists of eight variables. As seen in Fig. 1, its core structure is based on TAM. The model hypothesizes that, for someone to have a positive intention to use MAR in their teaching, they should have a positive attitude towards it, consider it useful for their teaching (i.e., perceived usefulness) and easy to use (i.e., perceived ease of use). It has been found that these variables influence the intention of in-service [30], [31] and pre-service teachers to use various digital technologies in teaching as well as to use various MAR applications in their teaching [25]. In addition, in order for educators to use MAR, they need to feel they have all the necessary circumstances and conditions that will facilitate the use of MAR. These circumstances and conditions are, among others, equipment (e.g., tablets), connectivity, knowledge, and time and are included in MARAM in the variable of facilitating conditions [35]. Previous TAM studies have found this variable is an important factor in the acceptance of digital technologies and positively influences the variables of intention and perceived ease of use [36]. Furthermore, MARAM argues that, in order for educators to use MAR, they have to believe that it has added value in their teaching compared to other digital technologies. For this purpose, the variable of Perceived Relative Advantage (PRA) [37] was added to MARAM. This new variable influences perceived usefulness [26]. Aside from the abovementioned factors, MARAM suggests that, for educators to utilize MAR, they have to feel it is enjoyable or interesting. Therefore, the variable of Perceived Enjoyment (PE) [38] was added to the model. Previous research by [39] has demonstrated that the variable of perceived enjoyment influenced pre-service teachers’ attitude and perceived usefulness to use digital technologies in their teaching. Finally, MARAM added the variable of Mobile Self-Efficacy (MSE) [33]. According to MARAM, educators with mobile self-efficacy may believe that it is much easier for them to use MAR applications and are thus more willing to adopt these in their teaching.

Therefore, we propose the following hypotheses for pre-service teachers:

H1a. Pre-service teachers’ perceived ease of use (PEOU) has a positive effect on their perceived usefulness (PU).
H1b. Pre-service teachers’ perceived ease of use (PEOU) has a positive effect on their attitude (Att).
H2a. Pre-service teachers’ perceived usefulness (PU) has a positive effect on their intention (I).
H2b. Pre-service teachers’ perceived usefulness (PU) has a positive effect on their attitude (Att).
H3. Pre-service teachers’ attitude (Att) has a positive effect on their intention (I).
H4a. Pre-service teachers’ perceived facilitating conditions (FC) have a positive effect on their intention (I).
H4b. Pre-service teachers’ perceived facilitating conditions (FC) have a positive effect on their perceived ease of use (PEOU).
H5. Pre-service teachers’ perceived relative advantage (PRA) has a positive effect on their perceived usefulness (PU).
H6a. Pre-service teachers’ perceived enjoyment (PE) has a positive effect on their attitude (Att).
H6b. Pre-service teachers’ perceived enjoyment (PE) has a positive effect on their perceived usefulness (PU).
H7. Pre-service teachers’ Mobile Self-Efficacy (MSE) has a positive effect on their perceived ease of use (PEOU).

![Fig. 1. The Mobile Augmented Reality Acceptance Model (MARAM).](image)

IV. METHOD

The study was conducted from March to June 2021, at a spring semester during the COVID-19 pandemic. As presented in the previous section, the model for the current study was based on MARAM. The participants were pre-service teachers at the University of Ioannina, Greece.

A. Participants

The participants were 137 (115 women and 22 men) pre-service teachers (i.e., undergraduate students - future primary school teachers). They were attending the last, fourth year of their studies at the Department of Primary Education, University
of Ioannina, Greece. The students’ age was 24.15 (SD = 5.92) years.

B. Instrument

The instrument used in the current study was based on the questionnaire which was developed by Koutromanos and Mikropoulos (2021) according to MARAM. For its development, Koutromanos and Mikropoulos [26] adapted validated items from previous TAM studies [29], [28], [33], [35], [40]–[45]. The questionnaire for the current study was reviewed by two academic experts on digital technologies in education as well as pilot-tested by five pre-service teachers. The only modification to the questionnaire was the addition of the word “future” before the word “teaching”. More specifically, it was an online questionnaire (Google Forms) and consisted of two parts. The first part included questions regarding demographic characteristics of the pre-service teachers (i.e., gender and age). The second part was comprised of 29 items. The first and second column in Table I shows the number of items in each of the eight variables used in the questionnaire. Table II shows the English version of the 29 items. The pre-service teachers rated their level of agreement with each of these items using a 5-point Likert scale (i.e., from 1=Strongly disagree to 5=Strongly agree).

C. Procedure

The pre-service teachers were attending the course “Project Development with Emerging Learning Technologies”. Each pre-service teacher had to design and develop a series of Augmented Reality applications using the marker-based AR tool BlippAR (https://www.blippar.com). The 137 pre-service teachers chose among the 52 digital primary school textbooks. Each pre-service teacher had to augment one chapter among these 52 textbooks, with at least 10 augmentations. Specifically, pre-service teachers designed and developed 3–4 augmentations per month from March to June 2021. Each chapter involved 3D objects, animations, videos, links as well as links to other android applications or calls. The 10 augmentations per chapter were connected to certain parts of the textbook through learning objectives that students had to express according to the revised Bloom’s cognitive taxonomy. Each pre-service teacher worked alone at home. The professor acted as a facilitator, giving only technical advice to the students through teleconference meetings. After the practical stage was completed, the pre-service teachers were asked to fill in the study’s online questionnaire, in Google Forms. Fig. 2 shows two examples from the augmented books.

D. Analysis

SPSS version 26 was used for the encoding and analysis of the data. Initially, factorial analyses were conducted. The results supported the unidimensional structure of each of the eight variables of MARAM. In addition, this study used Cronbach’s coefficient alpha in order to examine the internal consistency of the MARAM variables. Then, descriptive analysis (i.e., mean and standard deviation) of each of the eight variables and of their items was conducted. With the purpose of examining whether there are statistically significant correlations between the variables of MARAM, Pearson correlation (two-tailed) analyses were conducted. Afterwards, the 11 hypotheses presented in the previous section were examined using hierarchical regression analyses.

V. RESULTS

A. Internal consistency and descriptive analysis

Table I shows the Cronbach’s alpha results for each of the eight variables of MARAM. As we can see, there is a satisfactory level of internal reliability, as Cronbach’s alpha coefficients for all variables exceeded the value of 0.70. This means that the eight variables of the questionnaire are reliable and valid. Table II shows the means (M) and standard deviations (SD) among the eight variables and their 29 items. The overall mean scores of the eight variables show that they ranged from 3.45, for facilitating conditions, to 4.12, for attitude. Generally, pre-service teachers had relatively positive to positive scores in most variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Number of items</th>
<th>Cronbach alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention (I)</td>
<td>3</td>
<td>.917</td>
</tr>
<tr>
<td>Attitude (Att)</td>
<td>3</td>
<td>.900</td>
</tr>
<tr>
<td>Perceived ease of use (PEOU)</td>
<td>3</td>
<td>.876</td>
</tr>
<tr>
<td>Perceived usefulness (PU)</td>
<td>3</td>
<td>.915</td>
</tr>
<tr>
<td>Perceived relative advantage (PRA)</td>
<td>5</td>
<td>.906</td>
</tr>
<tr>
<td>Facilitating conditions (FC)</td>
<td>3</td>
<td>.755</td>
</tr>
<tr>
<td>Perceived enjoyment (PE)</td>
<td>4</td>
<td>.930</td>
</tr>
<tr>
<td>Mobile Self-Efficacy (MSE)</td>
<td>5</td>
<td>.822</td>
</tr>
</tbody>
</table>

More specifically, the results show that the pre-service teachers had a relatively positive intention to use MAR in their future classrooms, positive attitudes, positive perceived usefulness, and positive perceived enjoyment. Moreover, pre-service teachers tended to have positive perceived relative advantage and relatively positive mobile self-efficacy. However, pre-service teachers showed a moderate degree of perceived ease of use of MAR as well as a moderate degree of perception regarding the existence of facilitating conditions in their future teaching.
Furthermore, perceived usefulness, perceived relative advantage and perceived enjoyment are explained by attitude, perceived usefulness and facilitating conditions.

The use of AR applications makes me feel good.
The use of AR applications gives me pleasure.
Using AR applications is truly fun.
It is desirable to use AR applications.

For the purpose of this study, the research model is presented as follows: 

Hypotheses testing

In order to examine the 11 hypotheses of this study, four hierarchical regression analyses were performed. The results of these analyses are presented in Table IV. As shown in this table, pre-service teachers’ intention to use MAR in their future classrooms was predicted by attitude (beta = 0.463, p < 0.05) and perceived usefulness (beta = 0.347, p < 0.05), and these two independent variables together explained 59.4% of the total variance. The variable of facilitating conditions had no effect on this explanation.

### Table II. Means (M), and Standard Deviations (SD) for Variables of the Proposed Model MARAM

<table>
<thead>
<tr>
<th>Variables</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention</td>
<td>3.93</td>
<td>.697</td>
</tr>
<tr>
<td>I intend to use AR applications in my future teaching</td>
<td>4.06</td>
<td>.715</td>
</tr>
<tr>
<td>I plan to use AR applications in my future teaching</td>
<td>3.84</td>
<td>.769</td>
</tr>
<tr>
<td>I predict I would use AR applications in my future teaching</td>
<td>3.89</td>
<td>.773</td>
</tr>
<tr>
<td>Attitude</td>
<td>4.12</td>
<td>.646</td>
</tr>
<tr>
<td>Using AR applications is a good idea</td>
<td>4.28</td>
<td>.630</td>
</tr>
<tr>
<td>I like using AR applications</td>
<td>4.00</td>
<td>.748</td>
</tr>
<tr>
<td>It is desirable to use AR applications</td>
<td>4.07</td>
<td>.740</td>
</tr>
<tr>
<td>Perceived ease of use</td>
<td>3.48</td>
<td>.785</td>
</tr>
<tr>
<td>My interaction with AR applications is clear and understandable</td>
<td>3.62</td>
<td>.850</td>
</tr>
<tr>
<td>It is easy for me to become skillful at using AR applications</td>
<td>3.53</td>
<td>.867</td>
</tr>
<tr>
<td>I find AR applications easy to use</td>
<td>3.31</td>
<td>.912</td>
</tr>
<tr>
<td>Perceived usefulness</td>
<td>4.03</td>
<td>.751</td>
</tr>
<tr>
<td>Using AR applications enhances my teaching effectiveness</td>
<td>4.05</td>
<td>.831</td>
</tr>
<tr>
<td>AR applications are useful for my teaching</td>
<td>4.06</td>
<td>.829</td>
</tr>
<tr>
<td>Using AR applications increases my teaching productivity</td>
<td>4.00</td>
<td>.776</td>
</tr>
<tr>
<td>Perceived relative advantage</td>
<td>3.70</td>
<td>.630</td>
</tr>
<tr>
<td>AR applications would be more advantageous in my future teaching than other technologies</td>
<td>3.65</td>
<td>.744</td>
</tr>
<tr>
<td>AR applications would make my future teaching more effective than other technologies</td>
<td>3.62</td>
<td>.749</td>
</tr>
<tr>
<td>AR applications are relatively efficient in my future teaching compared to existing technologies</td>
<td>3.69</td>
<td>.703</td>
</tr>
<tr>
<td>The use of AR applications offers new learning opportunities compared to existing technologies</td>
<td>3.95</td>
<td>.731</td>
</tr>
<tr>
<td>Overall, AR applications are better than existing technologies</td>
<td>3.58</td>
<td>.764</td>
</tr>
<tr>
<td>Facilitating conditions</td>
<td>3.45</td>
<td>.749</td>
</tr>
<tr>
<td>I have the resources (e.g., Internet connection, tablets) necessary to use AR applications in my future teaching</td>
<td>3.55</td>
<td>1.028</td>
</tr>
<tr>
<td>I have the knowledge needed to use AR applications in my future teaching</td>
<td>3.42</td>
<td>.889</td>
</tr>
<tr>
<td>I have the time needed to use AR applications in my future teaching</td>
<td>3.38</td>
<td>.815</td>
</tr>
<tr>
<td>Perceived enjoyment</td>
<td>4.01</td>
<td>.717</td>
</tr>
<tr>
<td>Using AR applications is truly fun</td>
<td>4.09</td>
<td>.766</td>
</tr>
<tr>
<td>I know using AR applications to be enjoyable</td>
<td>4.07</td>
<td>.769</td>
</tr>
<tr>
<td>The use of AR applications gives me pleasure</td>
<td>3.96</td>
<td>.808</td>
</tr>
<tr>
<td>The use of AR applications makes me feel good</td>
<td>3.91</td>
<td>.812</td>
</tr>
<tr>
<td>Mobile Self-Efficacy</td>
<td>3.70</td>
<td>.707</td>
</tr>
<tr>
<td>I could complete a job or task using a mobile device</td>
<td>3.67</td>
<td>.924</td>
</tr>
<tr>
<td>I could complete a job or task using a mobile device if someone showed me how to do it</td>
<td>3.91</td>
<td>.989</td>
</tr>
</tbody>
</table>

### Table III. Pearson Correlations

<table>
<thead>
<tr>
<th>Variables</th>
<th>Att</th>
<th>PU</th>
<th>PEOU</th>
<th>PRA</th>
<th>FC</th>
<th>PE</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>.717* (.000)</td>
<td>.664* (.000)</td>
<td>.441* (.000)</td>
<td>.474* (.000)</td>
<td>.426* (.000)</td>
<td>.561* (.000)</td>
<td>.362* (.000)</td>
</tr>
<tr>
<td>Att</td>
<td>.609* (.000)</td>
<td>.432* (.000)</td>
<td>.555* (.000)</td>
<td>.443* (.000)</td>
<td>.618* (.000)</td>
<td>.384* (.000)</td>
<td></td>
</tr>
<tr>
<td>PU</td>
<td>.386* (.000)</td>
<td>.571* (.000)</td>
<td>.364* (.000)</td>
<td>.543* (.000)</td>
<td>.310* (.000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEOU</td>
<td>.444* (.002)</td>
<td>.651* (.000)</td>
<td>.457* (.000)</td>
<td>.444* (.000)</td>
<td>.309* (.000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRA</td>
<td>.437* (.000)</td>
<td>.454* (.000)</td>
<td>.349* (.000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. Pearson correlations analysis

Table III summarizes the results of the Pearson correlations of all variables of the research model used in this study. As shown in this table, all the correlation coefficients for the eight variables of MARAM were statistically significant, according to our 11 hypotheses. In addition, all variables were significantly intercorrelated. More specifically, intention was correlated significantly and strongly with the other three direct variables of MARAM in the following order of decreasing correlation: attitude, perceived usefulness and facilitating conditions. Similarly, positive and relatively strong correlations were found between attitude and the other three variables as hypothesized by the research model, in the following order of decreasing correlation: perceived enjoyment, perceived usefulness and perceived ease of use. Furthermore, perceived usefulness correlated strongly, as hypothesized by the research model, with perceived relative advantage and perceived enjoyment, and relatively low with perceived ease of use. Finally, perceived ease of use was strongly correlated with the variables of mobile self-efficacy and facilitating conditions.
The aim of this study was to examine the factors which influence pre-service teachers' intention to use Mobile Augmented Reality (MAR) in their future teaching. The theoretical framework was based on the Mobile Augmented Reality Acceptance Model (MARAM). In addition, it was examined whether this model is valid. The results of the descriptive analysis showed that pre-service teachers had a positive intention to use MAR in their teaching, and rated positively most of the model's variables. Generally, these results can be regarded as encouraging, considering that these pre-service teachers came into contact with a newly emerging technology like AR, by creating for the first time their own AR applications for primary school books.

The results of Pearson correlations showed that there was a positive relation between the variables of MARAM. This means that the more positive the independent variables, the more positive the dependent variables that influence the intention of pre-service teachers, namely attitude and perceived usefulness. Finally, the findings of the regression analysis revealed that the model's variables can explain to a satisfactory degree the variance of perceived ease of use, perceived usefulness, attitude, and intention. The percentage of the variance is quite satisfactory in explaining these variables compared to other models of acceptance of several digital technologies or to other studies that explained the acceptance of AR by either pre-service or in-service teachers [22], [26]. These results enhance the validity of the MARAM model and show that it can also be implemented in samples other than in-service teachers, for whom it was initially intended. Although it was found that the perceived ease of use of MAR had a significantly positive relation to attitude and perceived usefulness, it was not found to be a significant predictor of these two dependent variables. This finding is consistent with a previous study [26]. In this case, it appears that pre-service teachers may have a positive attitude towards MAR not because they consider it easy to use but, rather, useful and enjoyable. Similarly, pre-service teachers may have a positive perception of the usefulness of MAR not because they consider it easy to use but, rather, because they believe it has a certain advantage compared to other digital technologies and is enjoyable. Another interesting finding is that the facilitating conditions did not constitute a statistically significant variable in the prediction of intention. This result contradicts what was identified in a previous study [22]. It is possible that, in the prediction of pre-service teachers' intention, their positive attitudes and positive perceived usefulness play a more important role than whether the appropriate conditions to use MAR in their schools exist.

The present study has several implications. Firstly, this study has implications for the education of pre-service teachers in universities. This study educated pre-service teachers for a short period, during an undergraduate course, on designing and developing their own MAR applications for several units of schoolbooks on various subjects that they will teach in schools in the future. Their education took place in the context of emergency remote teaching due to the COVID-19 pandemic. Despite the limitations of time and remote teaching, the results of the present study were encouraging and revealed that pre-service teachers had generally positive perceptions of various aspects of AR. Therefore, universities could integrate emerging technologies such as MAR in their programs and, through the enhancement of technological and pedagogical readiness of their pre-service teachers, prepare them better for the future.

### TABLE IV. REGRESSION ANALYSIS OF THE MARAM VARIABLES ON PRE-SERVICE TEACHERS' INTENTION

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Adjusted R²</th>
<th>Independent variable</th>
<th>F</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intention</td>
<td>.594</td>
<td>Perceived usefulness</td>
<td>67.266</td>
<td>.463</td>
<td>6.416</td>
<td>.000*</td>
</tr>
<tr>
<td>Perceived usefulness</td>
<td>.547</td>
<td></td>
<td></td>
<td>.500</td>
<td>6.000</td>
<td>.000*</td>
</tr>
<tr>
<td>Facilitating conditions</td>
<td>.094</td>
<td></td>
<td></td>
<td>1.530</td>
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<td>.128</td>
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<tr>
<td>Attitude</td>
<td>.495</td>
<td>Perceived usefulness</td>
<td>43.409</td>
<td>.373</td>
<td>5.028</td>
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<tr>
<td>Perceived ease of use</td>
<td>.099</td>
<td></td>
<td></td>
<td>1.353</td>
<td></td>
<td>.178</td>
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<tr>
<td>Perceived enjoyment</td>
<td>.364</td>
<td></td>
<td></td>
<td>4.544</td>
<td></td>
<td>.000*</td>
</tr>
<tr>
<td>Perceived usefulness</td>
<td>.431</td>
<td>Mobile Self-Efficacy</td>
<td>33.571</td>
<td>.023</td>
<td>.294</td>
<td>.770</td>
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<tr>
<td>Perceived enjoyment</td>
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<td></td>
<td></td>
<td>4.405</td>
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<td>.000*</td>
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<tr>
<td>Perceived relative advantage</td>
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<td></td>
<td></td>
<td>5.405</td>
<td></td>
<td>.000*</td>
</tr>
<tr>
<td>Perceived ease of use</td>
<td>.529</td>
<td>Facilitating conditions</td>
<td>71.195</td>
<td>.363</td>
<td>5.458</td>
<td>.000*</td>
</tr>
</tbody>
</table>

*p-values < .05
acceptance of this technology in schools. The education of pre-service teachers could focus on the factors identified in this study. More specifically, university education could help pre-service teachers develop positive attitudes regarding the use of AR, with the adoption of practices that manifest the usefulness of this technology in teaching and learning as well as the advantages it could have compared to other technologies. Given that the current study identified a moderate degree of perceived ease of use, this education of pre-service teachers could enhance the perception of ease of use of several tools of MAR so that pre-service teachers can create their own applications. Furthermore, this education could focus on mobile learning, since the present study identified that mobile self-efficacy positively influenced perceived ease of use.

Secondly, this study has implications for school leaders. Although the regression analysis results did not reveal an impact of the facilitating conditions variable on pre-service teachers’ intention, it had an impact on perceived ease of use. This implies that, in order for pre-service teachers to regard the use of MAR as easier in their future teaching, schools should provide them with all the conditions and circumstances that would facilitate them to use it as newly appointed teachers. Such conditions relate to resources (e.g., Wi-Fi, smart mobiles, and tablets) and time, among other things. These results are in agreement with the study by Dengel et al. [46], which emphasizes the importance of the “teacher” factor in Immersive Learning Environments. Finally, the current study has implications for researchers in the field of augmented reality acceptance models. The study found that MARAM is a new model that can explain to a significant degree the intention of pre-service teachers through certain variables. The results of this study provide a theoretical framework that could constitute the basis for the MAR research community to enhance the predictability power of MARAM by adding other factors which may explain a larger percentage of the variance of intention.

The present study has three limitations. Firstly, the prediction of the intention was based on the impact of the examination of the direct variables rather than indirect variables such as perceived enjoyment or perceived relative advantage. Secondly, this study did not examine the impact of external variables (e.g., pre-service teachers’ knowledge of digital technologies, frequency, and skills of the use of mobile learning applications) on the prediction of intention. Thirdly, since the majority of the sample of pre-service teachers were women and of the same age group (e.g., 21-22 years), it was not possible to see if there were statistically significant differences between the demographic characteristics and the eight variables of the research model.

VII. CONCLUSION AND RECOMMENDATIONS

The present study is among the few ones to focus on the acceptance of MAR by pre-service teachers once they first gain experience in the design and development of their own applications. Its results offer insight into the factors which influence their perceived ease of use, attitude, perceived usefulness, and intention to use MAR in their future teaching. This study also contributes to the literature regarding augmented reality acceptance models in education. The independent variables of MARAM which were used in this study explained a sufficient percentage of the variance of dependent variables ranging from 43.1% to 59.4%. This model appears to be valid and could be used as a basis for other studies.

Future research should take into account the limitations of the current study mentioned in the previous section. Some of the variables appeared to be strongly correlated, which may be further investigated in future studies. Nevertheless, in this study, multicollinearity was not an issue in affecting the regression analyses, as supported by the correlation matrices, VIFs and tolerances. Moreover, future research should examine the acceptance of MAR among educators of different specialties. Lastly, regarding the MARAM model, future research could utilize it in a sample of both pre-service and in-service teachers and examine possible similarities and differences between them.

REFERENCES

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Using First-Person View Drones through Head-Mounted Displays: Are They Suitable for Education?

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Abstract—This study examined in-service teachers’ perceptions regarding spatial presence, simulator sickness and usability of First-Person view drones through Head-Mounted Displays in order to determine the suitability of their use in teaching and learning processes. The sample consisted of 60 in-service teachers of primary education. Data was collected via the Temple Presence Inventory Scale, Simulator Sickness Scale and the System Usability Scale. Results showed that the teachers rated an increased level of spatial presence. Additionally, the simulator sickness was relatively low, and the drone’s usability was rated as excellent. These findings contribute to the better understanding of the potential of First-Person view drones as learning tools.

Index terms—first-person view drone, educational drones, head-mounted display, spatial presence, simulator sickness, usability

I. INTRODUCTION

In the last decade, there has been an increased research interest regarding the aerial robots commonly called drones [1], [2]. These are unmanned flying vehicles capable of performing an autonomous flight or of being remotely operated by a user [3]. Drones have already been implemented in several fields (e.g., agriculture, media and entertainment, telecommunication, security, insurance, infrastructure) [4]–[7] including education [8]–[10]. Recently, drones intended for educational use, known also as educational drones such as Ryze Tello EDU [11], Makeblock Airblock for STEAM education, Parrot Mambo EDU and Bitcrazy Crazysite have become available. Their in-flight capabilities include hovering, photographing and video recording through bird’s-eye view provided by the drone’s camera, as well as collection of various data (e.g., speed, distance, height) through their sensors. Though limited research data so far concerning drone utilization in education, they reveal positive results in teaching and learning, such as active involvement and student engagement [8], intellectually stimulating experience [12], hands-on experiences [9], solving real-world problems [10], ease of use and ease of flying [13], ability to examine STEM and STEAM disciplines [14], and an overall positive impact on teaching [15].

Drones operation is usually conducted through a special type of controller, i.e., gamepad, smartphone, tablet, body gestures, and computer [16]. More recently, in order to improve the experience of flying drones, new smart technologies are used in combination with them. Such technologies are smart gloves [17], [18] and smart wearable glasses (virtual & augmented reality Head-Mounted Displays) [19].

More specifically, smart wearables manufacturing companies have recently configured the already available wearable Head-Mounted Displays (e.g., Epson Moverio, Vuzix Blade, Zeiss VR One, Utopia 360, Walkera Goggle 4, and Oculus Quest) to be paired with drones. Through these Head-Mounted Displays (HMDs), the user can see before his/her eyes the content recorded by the drone’s camera in real-time, thus offering him/her an optimized experience of bird’s-eye view. This new experience is contrasted with the usual manner of flying a drone, where the user pairs it with his/her smartphone or tablet and, in order to guide the drone, is frequently required to look at the camera content transmitted by the drone onto the screen of the mobile device. This current way of flying a drone through smartphone or tablet has certain disadvantages. For instance, under conditions of intense sunlight or in case the screen of the smartphone or tablet is small, the user’s view of the drone camera content is hindered. Moreover, the drone’s flight through a mobile device offers neither immersion, nor the sense of presence compared to the one offered by HMDs [20], [21].

In addition to the above, drone manufacturing companies have already begun to provide ready-to-sell bundles consisting of HMDs and drones [22]. With these bundles, drone flight is made easier. Users are only required to charge the HMDs and the drone and then pair them with each other. The manufacturing companies have combined the two devices’ hardware and offer software solutions so that the user has a seamless experience without the need for either additional configuration, or programming knowledge. For instance, such types of bundles are offered by DJI’s DJI Goggles® [22], and Parrot’s VR Drone Goggles® [23].

Based on the above technological developments, HMDs for flying drones, through the immersion they provide into the drone camera’s bird’s-eye view, could be utilized in education, thus offering new immersive experiences in learning environments, specifically in outdoor spaces e.g., of environmental, historical and/or cultural value. Specifically, the bird’s-eye view of the drone’s camera and the projection of its content on the HMDs could contribute to the improvement and development of students’ spatial skills, such as orientation, visualization,
rotation, as well as immediate acquisition of spatial measurements (e.g., height, distance) [20], [24].

Despite the increased research interest regarding these technologies [25], to the best of our knowledge no studies have been conducted so far that investigate the utilization of HMDs combined with drones in education. The aim of the present study was to investigate the factors that influence the use of HMDs with drones, in order to determine the suitability of their combined use in teaching and learning. The objectives of the study were to investigate primary education teachers a) Spatial Presence (SP), b) Simulator Sickness (SS), and c) usability of First-Person view (FPV) drones through HMDs.

II. DRONES, BIRD’S-EYE VIEW AND HEAD-MOUNTED DISPLAYS

In the past, before the emergence of drones, capturing bird’s-eye view content was achieved through video recording from a helicopter or airplane. Today, this is possible through the drone’s camera. Bird’s-eye view is the view of content/objects from above, which gives the viewer the feeling of flying (Fig. 1). This advantage could be utilized in education and provide students with various experiences through the collection of data (e.g., images, videos, distance, temperature) on several subjects such as Geography, Mathematics, Physics, Environmental education, and Meteorology.

Students can see through bird’s-eye view either in real time, i.e., at the same time the drone flies (and collects data midflight) or later, when the flight has been completed. A basic characteristic regarding bird’s-eye view is the way in which the drone is operated. As already mentioned, drone operation is done through various means. Today, two are the most popular means of operating consumer drones. The first one is through specially designed gamepad type controllers, and the second one is with the help of smart devices (e.g., smartphone or tablet).

A gamepad resembles a traditional gaming console controller and bears physical buttons and joysticks which allow the user to operate the drone, perform in-flight maneuvers (e.g., throttle, pitch, yaw, roll), as well as take and save pictures and videos in its memory. In this type of flight, the drone operation is usually conducted through Visual Line of Sight (VLOS) (Fig. 2) [26]. This means that the user is required to always keep the drone in his/her visual field in order to fly it. The processing and viewing of the data collected by the drone is done via computer after the drone has completed its flight. Hence, in the case where a gamepad is used, a user can watch the bird’s-eye view content solely through the computer screen and not in real time.

In the case of drone operation through smartphone or tablet, the user is required to download a drone flight mobile app. One such app could be designed by either the drone manufacturer, or third-party developers [27]. A typical drone flight mobile app provides a virtual controller for flying the drone. The device’s screen shows several data in real time, which are not available in flight via the gamepad as described above. These data include speed, distance, height/altitude, temperature, and barometric pressure [28]. In addition, the content recorded by the drone’s camera is projected on the screen in real time.

One limitation in both abovementioned cases (i.e., gamepad, and smartphone/tablet) is that bird’s-eye view content is projected on a screen (i.e., computer monitor, smartphone screen), which does not offer immersion and first-order experiences. With the aim of providing the user with a greater immersive experience of both drone flying and watching of the bird’s-eye view content, a third alternative was recently presented that combines virtual and augmented reality HMDs (Fig. 3). In this case, the user can operate the drone through a controller of his/her choice (e.g., gamepad, joystick), and the content recorded by the drone’s camera is projected in real time onto the HMD he/she wears. This type of flying is named First-Person view (FPV) flying [29]. Through this FPV, there is an enhancement of the bird’s-eye view experience.

Today, a very small number of studies have been conducted concerning the utilization of HMDs in drones. Tezza et al. [29] studied the learning experiences of 515 FPV drones’ pilots regarding First-Person view flying. Their results revealed, that First-Person view flying offered positive learning outcomes compared to other types of flying. Bonali et al. [30] examined the perceived usefulness of an immersive virtual reality activity in geoscience. The researchers collected data from geological landscapes via a drone, which they recreated later through photogrammetry and presented via VR HMDs (i.e., Oculus Rift). The users could move within the virtual environment in three modes: through human walking (walk mode), through airplane (flight mode), and through a drone (drone mode). The sample consisted of 459 people of different ages, and data collection was done through questionnaire. One of the most important results was that most participants regarded the drone mode, i.e., content viewing through bird’s-eye view, as “the most popular navigation mode during immersive virtual reality exploration” [30].
Moreover, there are several researchers who propose various ways of using drones through HMDs. For instance, Unal et al. [20] proposed the utilization of drones combined with AR smart glasses to provide tourists with an immersive experience of cultural heritage. More specifically, they analyzed how they would use drones, photogrammetry, and AR glasses to recreate the Roman Baths, a cultural heritage monument in Turkey. Pavlik [31] proposed various ways in which the use of drones with AR and VR HMDs could be implemented in journalism e.g., presenting less accessible regions through FPV regarding the subject of climate change. Kim et al. [32] developed a FPV drone flying system in a mixed reality environment. They combined real and virtual objects, between which the drone can easily fly.

The above studies reveal an emerging research interest in the utilization of FPV drones in several fields, and related studies so far appear to be in their initial stages. Meanwhile, no studies appear to have been conducted regarding the utilization of HMDs in FPV drone flight for educational purposes. The present study aims to fill this gap by investigating teachers’ perception regarding the spatial presence, usability, and sickness of this modern technology.

III. METHODOLOGY

The present study was conducted in January 2022. For the preparation and implementation of this study, all the necessary measures for the prevention of COVID-19 were taken.

A. Sample

The sample consisted of 60 primary in-service teachers participating in postgraduate programs of the Department of Primary Education at the National and Kapodistrian University of Athens, Greece. Of them, 45 (75%) were women, while 15 (25%) were men. The teachers had an average of 9.48 years of teaching experience. The teachers participated voluntarily.

Table I. shows the teachers’ experience in computers, drones, and AR/VR.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer experience</td>
<td>3</td>
<td>7</td>
<td>5.43</td>
<td>.945</td>
</tr>
<tr>
<td>Drone experience</td>
<td>1</td>
<td>7</td>
<td>2.28</td>
<td>1.391</td>
</tr>
<tr>
<td>AR/VR experience</td>
<td>1</td>
<td>7</td>
<td>2.17</td>
<td>1.520</td>
</tr>
</tbody>
</table>

Scale: 1=None, 7=Very much

B. Data collection and Instrument

An online questionnaire in Google Forms was used for collecting data; it consisted of four sections: (a) demographic information, (b) spatial presence, (c) sickness; and (d) usability. In order to develop this questionnaire, validated scales from previous studies were used and modified to the FPV drone’s context. More specifically, teachers’ spatial presence regarding the experience with FPV drone was measured using the Temple Presence Inventory (TPI) scale developed by Lombard et al. [33] (see items in Table II). The TPI scale in our study consisted of 6 items (7-point Likert scale). From the original scale we excluded the item regarding the sound as it does not apply to the current FPV drone. In addition, the original item “Did the experience seem more like looking at the events/people on a movie screen or more like looking at the events/people through a window?” was modified to fit the research context. The words “movie screen” and “a window” were replaced by the words “screens” (e.g., computer monitor, tablet screen) and “reality” respectively.

The perceived FPV drone sickness was measured by the Simulator Sickness Questionnaire (SSQ) scale developed by Kennedy et al. [34]. The SSQ consists of 16 items which measure three distinct symptom clusters. The first cluster is the Nausea and includes symptoms such as nausea, stomach awareness and burping. The second cluster is the Oculomotor and includes symptoms such as eyestrain and headache. The third cluster is the Disorientation and includes symptoms such as dizziness and vertigo. All items were measured using 4-point Likert scale.

The perceived usability of FPV drones was measured with the System Usability Scale (SUS) that was developed by Brooke [35]. The SUS consists of 10 items (5-point Likert scale). For the purpose of this study, the word “system” was replaced with “First-Person view drone” in every item (question). The SUS was adapted and validated in Greek language by Katsanos et al. [36].

C. Equipment

For the purpose of the study, the FPV bundle by DJI (Fig. 3) was used. This consists of the DJI FPV drone®; the DJI FPV Goggles V2®, which is the HMD unit included in the bundle; and the DJI FPV Remote Controller 2®. The DJI FPV drone® weighs 795 grams and has a built-in camera with a 12-megapixel sensor. The HMD weighs 420 grams, has two 2-inch screens with 1440*810 resolution and a 144Hz renew rate. The latency between the drone and the Head-Mounted Display is <28ms. The low latency enables real-time transmission of the content recorded by the drone’s camera.
Before the conduction of the study, the bundle’s devices (drone, Head-Mounted Display, controller) were activated and paired so that the participants of the study were not required to perform this procedure. Furthermore, the aforementioned devices were charged, while power banks were also available in case any of the bundle’s devices (i.e., controller or Head-Mounted Display) required charging midflight.

D. Procedure

The study was conducted in three stages, in one of the University’s outdoor spaces. In the first stage, each teacher was individually informed about drones in education, their affordances, and their applications. A presentation of the FPV bundle used and its affordances followed. This first stage lasted 10-15 minutes.

In the second stage, each teacher interacted with the FPV drone. Initially, she/he conducted a five-minute flight without the use of the HMD, in order to comprehend the way of operating the drone and familiarize her/himself with its controller. Afterwards, each teacher wore the HMD and flew the drone for approximately 15 minutes performing a certain activity. The activity required each teacher to lift the drone off the ground, approach four items (boxes) placed by the researchers in several spots of the area, photograph them, and then land the drone back on its initial spot. To carry out this activity, each teacher was required to perform a series of movements, such as multiple degree rotation, hovering, and flying the drone in various heights and angles (viewpoints).

In the third stage, the participants completed the online questionnaire, while they had the time to discuss with the researchers about drones and the experience they gained from the FPV flight. The completion of the questionnaire required 5-7 minutes.

E. Analysis

Data analysis was done with SPSS (version 25). For each item of the Temple Presence Inventory (TPI) scale, the Simulator Sickness Questionnaire (SSQ) scale and the System Usability Scale (SUS), we calculated the minimum and maximum score, the mean, and the standard deviation. The calculation of the three clusters of the Simulator Sickness Questionnaire (SSQ) was done according to the guidelines by Kennedy et al. [34]. The total score occurred from calculating the sum of the three clusters (Nausea, Oculomotor, Disorientation) and then multiplying it with 3.73. Lastly, Cronbach’s alpha was calculated for the questionnaire of TPI and SUS.

IV. RESULTS

The following three tables present the results regarding spatial presence, simulator sickness and usability of the FPV drone. The results in Table II show that the overall mean score (M=5.30, SD=.730) of the TPI questionnaire for Spatial Presence (Cronbach’s alpha = .667) was relatively high. As can be seen, the highest mean scores, i.e., the ones greater than 6.00, regarded three questions (Q1, Q4, Q6) focusing on the sense of “being at the same place” with the objects/people that teachers saw through the FPV drone. Question 2 (Q2) had also a high mean score (M=5.67), which was related to the FPV drone using teacher’s feeling that he/she could reach out and touch the objects and/or people he/she saw. Conversely, questions 3 and 5 (Q3, Q5), which were related respectively to how often teachers wanted to avoid and touch something they saw, had the lowest mean score.

<table>
<thead>
<tr>
<th>Question</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. How much did it seem as if the objects/people you saw were at the same place as you were? (1=Not at all, 7=Very much)</td>
<td>4</td>
<td>7</td>
<td>6.07</td>
<td>.918</td>
</tr>
<tr>
<td>Q2. How much did it seem as if you could reach out and touch the objects/people you saw? (1=Not at all, 7=Very much)</td>
<td>1</td>
<td>7</td>
<td>5.67</td>
<td>1.174</td>
</tr>
<tr>
<td>Q3. How often when an object seemed to be headed toward you did you want to move to get out of its way? (1=Never, 7=Always)</td>
<td>1</td>
<td>7</td>
<td>3.62</td>
<td>1.403</td>
</tr>
<tr>
<td>Q4. To what extent did you experience a sense of being there inside the environment you saw? (1=Not at all, 7=Very much)</td>
<td>3</td>
<td>7</td>
<td>6.07</td>
<td>.918</td>
</tr>
<tr>
<td>Q5. How often did you want to/or try to touch something you saw? (1=Never, 7=Always)</td>
<td>1</td>
<td>7</td>
<td>4.32</td>
<td>1.578</td>
</tr>
<tr>
<td>Q6. Did the experience seem more like looking at the events/people through screens (i.e., computer monitor, tablet, etc.) or more like looking at the events/people in reality? (1=screens, 7=reality)</td>
<td>3</td>
<td>7</td>
<td>6.05</td>
<td>.999</td>
</tr>
</tbody>
</table>

Table III. presents the results of the descriptive analysis of the Simulator Sickness Questionnaire for each of the 16 symptoms as well as the overall score for Nausea, Oculomotor, and Disorientation. Furthermore, it presents the overall score of all these three clusters. According to the results, among the lowest mean scores were those of burping, stomach awareness, salivation increasing, sweating, and dizziness with eyes closed. Some of the symptoms with the relatively higher mean score were fullness of the head, general discomfort, and dizziness with eyes open. Moreover, according to the findings, disorientation and oculomotor had the highest scores. Although there are no studies that measure SSQ for FPV drones, relevant studies that investigated similar technology of smart wearable glasses have shown similar results [37].

Table IV presents the results for SUS (Cronbach’s alpha=.759). The high mean scores in items 1 (M=4.52), 3 (M=4.28) and 5 (M=4.42) show that, to a relatively high degree, teachers wanted to use the FPV drone frequently, considered its use particularly easy, and its functions very well integrated respectively. Furthermore, according to the mean scores of items 7 (M=3.92) and 9 (M=3.78), teachers believed that most people would learn to use the FPV drone very quickly and, although they did not have assistance in using it, they felt...
confident flying it at a satisfactory degree. Moreover, the mean scores of the negative items in Table IV. (see items 2, 4, 6, 8, 10) show that teachers did not consider the use of the FPV drone difficult, did not need support by a technical person to fly it, and did not have to learn additional information before flying it. Lastly, the overall usability score, calculated according to the guidelines by Brooke [35], was 84.91%, which reveals that the ease of using and learning the FPV drone was excellent.

**TABLE III. SIMULATOR SICKNESS QUESTIONNAIRE (SSQ)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>General discomfort</td>
<td>0</td>
<td>2</td>
<td>.40</td>
<td>.616</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0</td>
<td>2</td>
<td>.17</td>
<td>.418</td>
</tr>
<tr>
<td>Headache</td>
<td>0</td>
<td>3</td>
<td>.20</td>
<td>.546</td>
</tr>
<tr>
<td>Eye strain</td>
<td>0</td>
<td>3</td>
<td>.33</td>
<td>.681</td>
</tr>
<tr>
<td>Difficulty focusing</td>
<td>0</td>
<td>3</td>
<td>.32</td>
<td>.651</td>
</tr>
<tr>
<td>Salivation increasing</td>
<td>0</td>
<td>1</td>
<td>.07</td>
<td>.252</td>
</tr>
<tr>
<td>Sweating</td>
<td>0</td>
<td>2</td>
<td>.12</td>
<td>.415</td>
</tr>
<tr>
<td>Nausea</td>
<td>0</td>
<td>3</td>
<td>.30</td>
<td>.619</td>
</tr>
<tr>
<td>Difficulty concentrating</td>
<td>0</td>
<td>3</td>
<td>.30</td>
<td>.619</td>
</tr>
<tr>
<td>Fullness of the Head</td>
<td>0</td>
<td>3</td>
<td>.43</td>
<td>.722</td>
</tr>
<tr>
<td>Blurred vision</td>
<td>0</td>
<td>3</td>
<td>.28</td>
<td>.640</td>
</tr>
<tr>
<td>Dizziness with eyes open</td>
<td>0</td>
<td>3</td>
<td>.37</td>
<td>.712</td>
</tr>
<tr>
<td>Dizziness with eyes closed</td>
<td>0</td>
<td>3</td>
<td>.15</td>
<td>.577</td>
</tr>
<tr>
<td>Vertigo</td>
<td>0</td>
<td>3</td>
<td>.28</td>
<td>.715</td>
</tr>
<tr>
<td>Stomach awareness</td>
<td>0</td>
<td>1</td>
<td>.07</td>
<td>.252</td>
</tr>
<tr>
<td>Burping</td>
<td>0</td>
<td>0</td>
<td>.00</td>
<td>.000</td>
</tr>
<tr>
<td>Nausea (general discomfort, salivation increasing, sweating, nausea, difficulty concentrating, stomach awareness, burping)</td>
<td>0</td>
<td>86</td>
<td>11.92</td>
<td>19.291</td>
</tr>
<tr>
<td>Oculomotor (general discomfort, fatigue, headache, eyestrain difficulty focusing, difficulty concentrating, blurred vision)</td>
<td>0</td>
<td>106</td>
<td>15.16</td>
<td>21.119</td>
</tr>
<tr>
<td>Disorientation (difficulty focusing, nausea, fullness of the head, blurred vision, dizziness with eyes closed, vertigo, stomach awareness)</td>
<td>0</td>
<td>209</td>
<td>29.70</td>
<td>47.428</td>
</tr>
<tr>
<td><strong>Total Score</strong></td>
<td>0</td>
<td>138</td>
<td>20.13</td>
<td>28.384</td>
</tr>
</tbody>
</table>

**TABLE IV. SYSTEM USABILITY SCALE (SUS)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I think that I would like to use this First-Person view drone frequently.</td>
<td>2</td>
<td>5</td>
<td>4.52</td>
<td>.725</td>
</tr>
<tr>
<td>2. I found this First-Person view drone unnecessary complex.*</td>
<td>3</td>
<td>5</td>
<td>4.42</td>
<td>.591</td>
</tr>
</tbody>
</table>

V. DISCUSSION

This study examined in-service teachers’ perceptions regarding spatial presence, simulator sickness and usability of First-Person view drones through Head-Mounted Displays.

Regarding spatial presence, the results showed that teachers believe that the FPV drone offers an increased sense of presence. They felt they were in the same place as the objects and/or people they saw and that they wanted to approach or touch them. Similar results regarding spatial presence and immersive experiences offered by FPV drones are mentioned in literature about their use for non-educational purposes [38], [39]. Given that the results relating to spatial presence are positive, an implication from the current study could be the creation of educational activities for the development of spatial skills.

Regarding the simulator sickness results, it was revealed that two categories (disorientation and oculomotor) had the highest scores. Given that the present study is one of the first to investigate simulator sickness of FPV drones, there are no relevant studies to compare corresponding results. On the other hand, comparing the findings to those of other studies investigating simulator sickness of smart wearable devices of a similar type as HMDs, our results are revealed to be relatively low on the sickness scale [37], [40].

Regarding the usability of FPV drones, the results have shown that the teachers acknowledged their perceived usability and are positive towards their use in the educational process. More specifically, the majority would like to use them in their teaching and considers them easy to use. An important note is that, although the sample was not familiar with neither drones nor wearable technologies such as HMDs, the majority
believed they would not need technical support to use them and stated that they did not have to learn anything additional before the drone flight. The acknowledgement of FPV drones’ usability by teachers could encourage their use in education and the consideration of best practices regarding their utilization in various disciplines.

One limitation of the current study is related to the equipment that was used. DJI’s bundle was selected with the aim of creating a seamless and easy to use experience. No configuration was done to the bundle and the factory presets were used. Possibly, by using a custom kit may yield different results.

VI. CONCLUSION AND RECOMMENDATIONS

The present study is among the first ones to investigate spatial presence, sickness, and usability of FPV drones through HMDs in education. The results showed that the teachers of this sample considered FPV drones very easy to use and that they can also create a sense of spatial presence. Although teachers had no prior experience in the use of drones or in VR/AR, the results regarding sickness of FPV drones through HMDs are satisfactory. The results of the current study could constitute the basis for additional studies on the utilization of FPV drones in education. Furthermore, the present study could provide information to educational drone manufacturers for both the creation of specially designed FPV drones and the development of applications and FPV drone-related activities in the context of teaching and learning.

Future studies could focus on the purpose of the present study using different types of FPV drone bundles which could be used in education, and compare their results of spatial presence, simulator sickness and usability with those of the present study. Moreover, future studies could investigate spatial presence, simulator sickness and usability of FPV drones through Head-Mounted Displays with students.

REFERENCES


Advancing Extended Reality Teaching and Learning Opportunities Across the Disciplines in Higher Education

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Abstract—The emergence of Extended Reality (XR) technologies in diverse fields, along with research demonstrating opportunities for innovation in teaching and learning, warrants further exploration. However, investigation into the supports required by instructors for experimentation, design, and deployment of XR technologies is needed. This study explores the benefits and challenges of XR technologies for teaching and learning, and reviews XR pedagogical initiatives at three universities. The research aims to discern strategies to promote and support XR initiatives in higher education, develop best practices for using and integrating XR technologies into university courses, and guide future research into XR technologies in higher education. To develop an empirical understanding of the opportunities and challenges faced by instructors using XR technologies, we performed a thematic analysis of sixteen semi-structured interviews to capture insights from instructors’ experiences. We found that instructors were cognizant of the many benefits associated with XR use in terms of experiential learning, making learning content more accessible, and the potential for its application. However, the findings also highlight the lack of guidance and support available to instructors in the implementation of these technologies in educational contexts. Our results provide recommendations for future institutional supports that could advance XR and expand the current teaching and learning opportunities available to instructors and students.

Index Terms—extended reality (XR), teaching, learning, higher education

I. INTRODUCTION

XR provides innovative opportunities that can extend the learning experience in the classroom, the LMS, and distance learning. XR technologies are advancing rapidly and emerging in teaching and learning [1]. XR provides experiential learning opportunities and access to immersive virtual communities that will become more pervasive over the next decade. As such, institutionally guided entry points to XR exploration and support are needed to enable instructors to investigate innovative teaching and learning within the context of different disciplines. The potential for XR technologies is reflected in the rise in the number of jobs that are projected to be enhanced by XR technologies worldwide from 2019-2030, from 8 million in 2019 to 23 million in 2030 [2]. It is essential for administrators and academics in higher education to build capacity in the field and explore how to support sustainable XR deployment.

A. Definitions

*Extended Reality (XR)*: a general term to describe computer-generated graphics and/or environments using real and/or simulated elements. It refers to a spectrum of technologies, with virtual reality (VR) on one end, augmented reality (AR) on the other, and mixed reality (MR) in between [3].

*Immersion* refers to the degree to which a person feels actually “present” in a virtual environment; the degree to which the virtual environment supplants that person’s actual surroundings; the degree to which a person feels actually “embodied” in a virtual environment. Immersion creates a virtual experience that closely resembles reality, which helps a person resonate with the experience as if it were real. XR technologies range from fully immersive (head-mounted display) to non-immersive (PC or smartphone screen).

*Virtual Reality (VR)* refers to “…the interactions between an individual and computer-generated environment stimulating multiple sensory modalities, including visual, auditory, or haptic experiences” [4]. VR immerses the user into a digitally rendered environment. This experience is marked by the occlusion of an individual’s vision with an immersive digital experience that replaces their physical surroundings. Uses of simulated interactions are emerging across various fields, including flight training, engineering, medicine, architecture, language learning, gaming, and entertainment. In industry, VR is emerging as a training, warehouse, and management solution, and a way of combining the virtual and real to test physical functioning [5]. An example of fully immersive is an application that renders a 2D image (such as a schematic for a product) into a detailed and manipulatable object in 3D [6]. Such uses of immersive VR are effective for experiential learning [7].

*Augmented Reality (AR)*: at the non-immersive end of the XR spectrum is AR, which “layers” information over a real object or real environment – for example, an application that superimposes the names and appearance of internal organs when a smartphone is pointed at a human subject. AR incorporates computer-generated visual imagery and information and interlays it with a real-world environment [8], [9]. Augmented reality is already used in our day-to-day lives, such as wayfinding apps like Google Maps, star-gazing apps, retail apps like Ikea Place, fitness apps, and many more.
Mixed Reality (MR) combines virtual reality and real-life elements to create a blended environment [3]. These experiences are marked by a human-computer interaction that uses human and environmental input to create a new form of reality. The term “mixed reality” can refer to any type of reality that features a combination of digital and physical features. The level of immersion in the virtual environment determines the location of the experience on the XR spectrum.

B. Goals and Purpose

This study explores the challenges and opportunities experienced by instructors and academic staff when deploying XR technologies. We carried out structured interviews with educators to discern their perceptions regarding integration of XR within their disciplines, ease of use, and problems associated with implementation. This paper highlights areas of further research and development to facilitate the deployment of XR and promote innovative pedagogical initiatives and strategies.

Section II presents a literature review describing the uses and challenges of XR in education. The term XR will be used interchangeably with VR, AR, or other technologies that rely on computer-generated realities. A section on Methodology and Data Analysis follows, identifying themes discerned in the Findings, and a final section on the Discussion of the results.

C. Benefits of XR in Teaching and Learning

This study aims to understand the potential of XR technology in education. XR technologies (that is, virtual reality (VR) and augmented reality (AR)) span the disciplines: engineering [10], geography [11]; philosophy [12]; language learning [13]; engineering [14]; museology [15]; and more. Furthermore, the medium provides opportunities for engagement, motivation, experiential learning, collaboration, application of theory, and storytelling [1], [16], [17] in online, blended, and in-class contexts.

XR technology can significantly enhance the teaching and learning experience because it can generate three-dimensional “synthetic objects for students to interact with” [18]. Arvanitis et al. [19] concur with this observation and explain how students can inspect and interact with these three-dimensional projections from various spatial perspectives, enhancing their understanding of the concept being taught. Additionally, AR can use place-based learning through the use of mobile-AR with location-registered technology. De Lucia et al. [20] consider how AR environments can take advantage of mobile technology and project models into the actual space where the student is, making the learning experience extraordinarily interactive and exciting. Through such technologies, learners can have an interactive experience wherein they go to certain digital locations to access new information and learning opportunities through their smartphones [21]. Wu et al. [18] describe this as, “One of the potential benefits of place-based learning is to bring a sense of authenticity to students.”

Among all the different categories of XR environments, including but not limited to simulation or game-, problem-, and studio-based learning, game-based is one of the most popular [18]. XR games can be defined as “games played in the real world with the support of digital devices that create a fictional layer on top of the real-world context” [22]. Completing the XR game helps the student learn how to solve problems and issues associated with a particular topic area. The learner plays an active and interactive role in the game's progress [23].

This simulated reality is especially relevant in XR games designed for medical education, such as Outbreak, where medical students work to curtail a deadly pandemic [24]. XR technology is especially relevant to the study of the medical sciences [25]. Using XR, medical students can “see” inside the human body and interact with different organs from different perspectives [4]. Zweifach and Triola [25] also acknowledge these benefits: “XR also allows learners to dynamically remove certain layers of tissue, or organ systems, to isolate specific structures of interest better.”

Additionally, using holographic projections of human anatomy, medical students can see systems in motion. For example, they can view the beating heart and the digestive system as it works [26]. According to researchers [27], XR technology can also be used in the practical assessment of students before putting them in real-life situations. For example, trainee doctors can perform simulated operations and procedures without risk.

Recent studies have shown that XR can increase motivation in learners. Researchers found that participants’ “attention aspect of learning motivation” increased by 31% [28]. Sattar found that students’ level of motivation was higher when using XR than when using either text-based or video-based materials (p. 169) [29]. A recent study concluded that “virtual reality had a strong impact on students’ learning motivation” [30]. A 2019 study found that recall performance of participants using XR was almost 12% higher than those using conventional desktop PCs [31]. The immersive and interactive nature of XR can leverage learners’ potential in all disciplines.

D. Designing Educational XR Applications

To support widespread adoption of XR technologies for innovation in pedagogy, it is essential to understand the framework of the technologies. To optimize the benefits of XR, applications should be designed using pedagogical strategies that will achieve intended learning outcomes [32]. These strategies may involve situated learning to interact with the content through experience [33]. Other strategies such as spaced learning, interleaving, and spaced retrieval can be incorporated to maximize XR’s impact. Empirical studies are needed to assess the efficacy of XR [34]. Each XR application will need its own design guidelines to achieve intended learning outcomes.

As well as pedagogical design, guidance on accessible approaches and accessible content is needed. Moreover, related to the creation of XR is the assessment of Open Educational Resources (OER) and ‘off-the-shelf’ XR applications and resources that can be integrated into existing course materials.

E. Challenges with Widespread Implementation and Use

While medical schools and other research institutions recognize the different ways that XR technologies can enhance learning, the use of those technologies remains relatively low [35]. This is due in part to cost: the cost for development, staff training, and student hardware may be high. [35]. The average price of a quality HMD can go as high as CAD $399.
Some institutions may be reluctant to adopt XR because traditional methods of teaching have been sufficiently effective for a long time [36]. However, even more of an obstacle are issues pertaining to safety, accessibility, and privacy, which must be considered in any multiuser experience [37].

Moreover, XR hardware may have its own drawbacks. The HDM hardware may not easily fit all students and may be cumbersome and uncomfortable. XR experiences can also result in cybersickness, inhibiting students' learning [38].

F. Needed Supports and Infrastructure

Reminiscent of the early 2000s, when online educators were creating customized LMS-type systems (before the advent of LMS standardization), instructors and teaching centers that are now exploring XR innovation are struggling to provide their own development and support solutions. Enterprise XR support systems for XR creation and deployment are emerging (e.g., ENGAGE, EON) that provide access to the spectrum of XR experiences but are expensive for technology in experimental stages. Until institutions are ready to embark on Enterprise XR systems, instructors require guidance on technology choices for specific XR needs.

Being aware of specific uses and learning affordances of XR technologies within each discipline would enable instructors to make informed pedagogical decisions [39]. As one example, the results of this study indicate 360 VR virtual tour technology is a promising application in the GeoScience field. In terms of investment, 360VR is relatively low-cost and easy to create. Institutions may make inroads by supporting XR via low-cost, low-stakes applications to support specific XR technologies.

Another challenge related to XR arises from the design end. While there is an existing knowledge base of design guidelines adapted to popular forms of XR technologies and educational multimedia designs, these design principles need to be updated to meet the new functionality and affordances of XR educational experiences. However, XR design is in its infancy, and the creator community is still building knowledge.

Different types of XR technologies require unique deployments, design, infrastructure, training, and technological support. Some XR technologies, including virtual tourism, can be integrated within an LMS [40]. Institutions will need to provide central support and financial support for instructors to effectively incorporate technologies to meet existing (and new, due to COVID-19) institutional priorities and quality standards to ensure sustainability.

G. The Future of XR in Education

Numerous studies have suggested that education and training processes can be significantly enhanced through XR technology [53]. However, incorporating XR technologies into education has been a slow and challenging process because of “issues with its integration with traditional learning methods, costs for the development and maintenance of the AR system, and general resistance to new technologies” [41].

As XR technologies proliferate, instructors and academic support staff will need to discern relevant instructional design practices. As Jonathan Kinsey says, “currently implementing VR and AR is very difficult because there are no best practices, and no pedagogical guide has been established” [42]. Some Learning Management System (LMS) companies, such as D2L, have already explored ways for instructors to integrate VR content into their courses. Other researchers have proposed new XR-based LMSs [43].

II. METHODOLOGY

A. Research Approach

To develop an understanding of the challenges instructors face when adopting XR technologies, we conducted two-stage, semi-structured interviews. In Stage I, participants were asked to undertake a preliminary questionnaire. Then, only participants who reported experience using XR technologies were invited for a detailed stage II interview. Thirty-six participants completed this preliminary questionnaire (nineteen from University of Manitoba, fourteen from University of Waterloo, and three from University of Guelph).

Following the preliminary questionnaire, twenty-two selected participants were invited for a 60-minute interview via Zoom videoconferencing tool or via an in-depth, online Qualtrics survey. In these interviews or surveys, participants had an opportunity to offer additional insights into their experience with XR technologies. The survey interview link was emailed to the study participants and participants filled their responses to the study questions in large text boxes. Participants were given a week to submit their responses, which ensured they had adequate time to complete the survey.

Stage II data were collected from a diverse group, including thirteen faculty members from the University of Waterloo, six faculty members from the University of Manitoba and three faculty members from University of Guelph. Among these twenty-two, stage II participants, four completed the interview asynchronously via the survey, whereas the others did so synchronously via Zoom video conferencing. The faculty members belonged to various departments, including Geography & Environmental Management, Management Sciences, Electrical and Computer Engineering, Systems Design Engineering, and Nursing.

During the second-stage interview with instructors, we asked questions concerning (1) how did instructors use XR technologies in their teaching? (2) what prompted them to do so? (3) in what way did their students engage with it? (4) what kind of support did their XR initiative receive from their faculty or department? (5) what challenges did they encounter in deploying XR technologies? (6) to what extent did their XR initiative help students meet their intended learning outcomes? (7) will they continue to use XR in their courses? (8) to what extent did their students embrace or resist using XR technologies in their course?

B. Data Collection

This study uses primary qualitative data collected using semi-structured interviews conducted with a sample of n=22. This data is analyzed using an inductive thematic analysis method. This allows us to understand the most prevalent themes present in the interviews and understand XR use experiences across a range of participants. However, it does not capture the magnitude of their prevalence. Therefore, we carried out a
thematic content analysis of the interviews to highlight the following themes: pedagogical potential, alternative content, technical support, learning issues, and accessibility. Thematic content analysis entailed a detailed review of interview transcripts to create a codebook for themes. Clarke and Braun (2013) listed the seven steps involved in this analysis: transcription of interviews, review and familiarization, coding, identifying themes, reviewing themes, defining themes, and the final analysis. This process was followed to analyze the interview data collected in this study.

The recorded interviews were conducted via Zoom. Next, the recordings were transcribed using Otter.ai and reviewed and corrected. Finally, the transcriptions were analyzed in a three-stage process outlined in literature [44]. We exported transcriptions to NVivo to carry out coding and thematic analysis.

In the second stage, a set of semantic and latent codes were created to categorize the answers to the questions. These codes helped us understand the themes and sub-themes associated with the data. In addition, these codes were used to extrapolate more prominent themes that encompassed the areas addressed by the interview respondents.

The third stage involved theme development. First, the codes generated by NVivo were used to identify brother themes in the data. After that, NVivo was used to calculate the prevalence of these themes by identifying the number of times the respondents referred to each category and subcategory [45]. Although these stages were carried out sequentially, they produced redundant data. For this reason, the themes were aggregated into the final seven themes: pedagogical potential, technical support, delivery of alternative content, learning issues, recommendations for future use, and assessment of XR in learning.

C. Ethics

The study received ethics clearance by ensuring that the respondents gave informed consent at the beginning of the interview. The participants were informed that their data would be collected and reproduced with strict confidentiality and used anonymously. The study was reviewed and received ethics clearance through the Research Ethics Board of the University of Waterloo, the University of Manitoba, and University of Guelph.

III. FINDINGS AND THEMATIC ANALYSIS RESULTS

A. Mediums and Devices Used By Instructors

Our findings showed the mode most used by instructors was VR (n=15), followed by AR (n=7), and MR (n=4).

Oculus Rift was most commonly used by instructors for VR, followed by Microsoft HoloLens and Quest 1. Additional details on the use of XR devices are given in Figure 1 below.

B. Initial coding of themes from key participant interviews

Participants came from either University of Waterloo (n=13), the University of Manitoba (n=6), or the University of Guelph (n=3). Using the data from these interviews, we coded our findings into seven overarching categories of significance: pedagogical potential; equitable access to learning; issues developing, delivering, and assessing course content via XR technologies; technical challenges for instructors; time and cost consumption; issues faced by students; and recommendations for future use. The codes have not been reproduced here, but our summarized findings will highlight the different codes used for each theme. This summary will also highlight the multitude of perspectives held by the respondents gathered from our data.

1) Pedagogical Potential

All participants expressed that XR technologies offer several educational benefits: (1) they are enjoyable and motivating to use, (2) they improve critical problem-solving skills, (3) they encourage students to investigate, contemplate, connect, and apply new forms of information, which enhances the knowledge retention, and (4) they improve the learning capacity of students. In addition, many participants expressed how temporal and spatial learning can be encouraged using XR technologies.

We created tours for them to actually view ... and improve their ways of thinking like a geoscientist. We've got four ways of thinking, spatial thinking, temporal thinking, time and space, and field thinking like we're actually in the field. So, this immersive [experience] helps all of those types of thinking.

Students were very receptive to it... It presents an additional, even an alternative method of teaching, as opposed to a set of PowerPoint slides.... Students were very quick to say that this was just something enjoyable to use, and they were very receptive to it. They'd like to see it used more.

Participants also felt that students were generally intrigued about XR technologies and could absorb multifaceted and intricate concepts with greater ease. This was primarily because instructors were able to simulate real-life situations, which stimulated greater engagement. Instructors also stressed that concepts easily understood using XR technologies were challenging for certain students to conceptualize when only
traditional teaching material was used. Some participants highlighted that learners could immerse themselves in highly realistic environments while engaging in social and collaborative interactions with other learners.

Yeah, they loved using technology because it's fun, and it's something different, and you're immersed, so some had never found it before.

I think [XR was able to] engage students in a new type of learning, as well as use a new type of technology to help students learn in ways that weren't previously possible, simply with like the immersive capabilities of VR.

2) Equitable Access to Learning

Some of the instructors interviewed were teaching courses that required students to explore curriculum in outdoor field settings. Some students could not access field environments due to accessibility issues or, more recently, due to the COVID-19 pandemic. In addition, at times, there are weather constraints and impending security risks that hamper access to outdoor environments. XR technology enables instructors to create Virtual Field Experiences (VFE) accessible to students regardless of their physical abilities, mobility issues, weather constraints, security risks, or extreme circumstances, such as a global pandemic.

Using XR technologies was clearly a response to the pandemic and the fact that we physically couldn't get outside. But sort of that idea of not being able to get outside is a constant threat as to why we were interested in using [XR], because going out to the field is very expensive... There are inherent safety risks, you know, taking 80 students, out into the field. So not only like driving to get to the location, but then like, kids hiking around and stuff like that. So, it's a growing field. We call it VFE -- virtual field experiences.

Part of [why we were using XR] was accessibility. There are these field ecology courses where students need to access rugged terrains, and some environments are simply inaccessible to someone who might have a mobility issue or be in a wheelchair. And rather than show them pictures, a video, or a PowerPoint presentation about the site, we wanted to make something a bit more engaging and immersive and... equitable.

3) Issues Developing, Delivering, and Assessing Course Content via XR Technologies

With only traditional forms of teaching support generally available, some instructors found it challenging to adapt existing course content for XR environments. There were few exemplars and little support available that allowed instructors to undertake this transformation process effortlessly.

Some instructors emphasized that they lacked sufficient guidance and supplementary material to help transform traditional learning material into compelling and intuitive virtual experiences. There were also inherent challenges in translating certain types of content into XR settings, such as mathematical computation.

If there were ready-made, like teaching, like packages or tutorials that I could know about, that would be valuable. Like, it'd be nice not to have to develop that lesson on my own or be able to clone stuff that already exists.

Instructors found it challenging to transform traditional forms of teaching delivery into XR settings. For example, they did not have a ready-made plan of how to brief and debrief students when using XR technology. In addition, instructors were unsure how to address student queries when delivering content in XR. Instructors were generally familiar only with teaching techniques native to the traditional classroom.

Respondents also highlighted a need for a student-centric evaluation system to assess the efficacy of such technologies in teaching and learning. However, respondents also noted there needs to be more adoption of such technologies before a proper assessment framework can be developed.

I mean, maybe it could look like specific survey questions, or maybe an assessment, I guess, one tiny portion of the course that kind of help out in determining how well the accent technology is actually helping students meet their learning outcomes... But yeah, I think it'd be great to hear back from the students as to how it's working for them and what kind of assistance they need.

I have not formally assessed the impact, though my collaborators may have. I think there needs to be more adoption of XR in courses before we can develop a formal assessment as the “sample” is still too small/specific for it to scale up.

4) Technical Challenges for Instructors

Another important theme highlighted in the interviews related to technical issues faced by instructors. Again, there was widespread agreement among the participants that incorporating XR technologies required significant technical guidance, support material, and clarity.

On the technical side, especially in the earlier days of working with these technologies, nothing was straightforward and required a lot of troubleshooting, watching online tutorials, reading obscure forum posts.

The instructors commented on the lack of technical resources available in terms of the software and online platforms available to create XR environments for education. Participants reported difficulty with software that required “too much coding”. Instructors sought help from online forums such as Unity forums, Stack Overflow, and Online MOOCs found them too vague, insufficient, and confusing.

Moreover, instructors cited the lack of existing examples and experiences that could be used in XR adaption. The lack of specialized services to create and use mixed realities made it difficult for instructors and developers to quickly shift to experiential learning in virtual environments. Even when there were fewer software and hardware requirements, the instructors found it challenging to develop effective virtual environments due to a lack of design guidelines.

There was always a shortage of material that could help us design virtual environments that could accommodate complex scenarios and ideas. It all required a lot of venturing out on our own.

Nevertheless, some participants did not experience any problems because they kept their goals for the course and technology straightforward and manageable.
But I wouldn't say I had any real challenges because my goals were very small. My goal was simply to add a little bit of interest for the students and try this out and start to see how it works in a way that didn't distract them from the actual material.

5) Time and Cost Consumption

Instructors were also concerned about the time and cost of XR technologies. They discussed the high costs associated with acquiring specialized XR apparatus, including the hardware, e.g., headset; the software, e.g., XR-design software for premium use; viewing software; and the hiring of additional support personnel, e.g., XR design experts, co-op students, additional teaching assistants, etc.

They also talked about the additional time needed to create XR compatible course content or transform existing content. Additionally, there was discussion about the time required to develop applications adapted to the needs of students and instructors, guide students on their use, troubleshooting, and overall technology adoption. The respondents also addressed the need for guidance on the most optimal use of these applications. Some instructors highlighted that these costs and time constraints were more challenging considering the amount of bureaucratic paperwork required to gain the necessary support and approval to implement these technologies.

Time is a major constraint when it comes to using XR in teaching. In an ideal world, I’d want to speed up the process and hire enough people for support.

6) Issues Faced by Students

Participants expressed concern regarding the students’ ability to adapt to an unfamiliar mode of education. There was also concern regarding the learning curve associated with new XR platforms.

One of the bigger issues of using new XR technology in [the] classroom is that students do not always have sufficient familiarity with the technology. You want to prevent instances where students are focusing more on understanding the technology than the educational content.

If students have to spend too much time trying to figure out how to navigate around the system, you lose them.

Also, from the end-user perspective, there were always hardware and software issues that impacted students. Students did not have access to compatible hardware i.e., when instructors wanted students to use their own devices it was not always compatible to the platforms used by the instructors for the course. Additionally, instructors felt XR technologies need to have a sophisticated and contemporary “look and feel” to ensure student engagement. Students were generally not receptive to low-fidelity, low-quality XR technology.

If [XR technology] wasn’t polished, then we’d get a little bit more hesitancy from the students in embracing it.

The biggest challenge we had with platforms we’re using is that not all students have capable devices. Even when you are using the low-end stuff that’s just meant to work on a phone, not everyone’s phone will support what you need.

Some of the new devices didn’t handle the software as well as some of the older ones.

7) Recommendations and Future Use

We asked for recommendations from instructors who used XR technologies. Most participants advised that instructors must understand how XR technology functions and how it can enhance the learning experience. Participants highlighted the benefits of developing an instructional plan when using XR technologies and emphasized that instructors should explore how XR can add value to the course. Participants emphasized the time needed for experimentation and to ensure that the technology is best suited for the needs of students.

Whatever VR that you implement in your course needs to be done purposely and in a way that aligns explicitly with course objectives, learning outcomes that you want to achieve. I think there needs to be a balance because VR can detract from specific objectives if you don’t keep those in mind when designing it.

Sometimes the best thing is a textbook or a picture. And I often see professors trying to do cool things for the sake of doing cool things. And that doesn’t improve the learning experience. I can give you an example of a project I started teaching, so it was in chemistry. And I can’t remember the cost, but they created an animation to demonstrate a concept. It’s basically a cartoon, like a chemical reaction with bouncing balls and it was developed at a high cost. I always questioned that because you could teach that concept with a whiteboard and a felt pen with a cost of zero and probably be as effective or more effective than this animation. And that’s the same principle with respect to VR.

8) Remote Learning and the Global Pandemic: A catalyst to XR use

Remote learning has created a need to explore XR technologies for solutions to remote challenges (e.g., offering hands-on labs remotely) [46]. This exigency motivates institutions to explore and collaborate to create new approaches.

When remote teaching is necessary due to events such as a pandemic, XR technologies can be integrated into LMSs to create VR classrooms. These classrooms can support interactive learning and simulations [40], [47]. After the COVID-19 outbreak, initiatives were undertaken by firms such as Vitri, which introduced an XR-based training program, and VictoryXR, which worked on developing and deploying XR-based educational content. XR will bolster institutions’ ability to provide quality instruction as they evolve on-campus and online teaching over the next decade [48].

9) Summary of Discussion

Two major themes are associated with the use of XR technologies: opportunities and challenges. There is consensus that many good reasons exist for adopting these technologies, but there are also obstacles to their adoption and implementation.

The most significant opportunities provided by XR technologies are its potential for innovative content alternatives and for boosting interaction and engagement with course content. All respondents referred to its potential for learning (the second most prevalent theme in the interviews). Adopting XR can help instructors create content accessible by students with mobility issues and in situations such as remote learning in the pandemic. Indeed, 41% of the respondents mentioned using XR to deliver alternative content for special-needs students.
Moreover, as seen in both the existing literature and the data collected in this study, these technologies can enhance students’ interaction with the course material by allowing for greater experiential learning through temporal and spatial learning.

Despite the perceived learning potential of XR, there are issues associated with its adoption in education. These issues relate to equitable access to learning, pedagogical issues, and technical challenges for instructors. All respondents mentioned the issue of insufficient technical support in adopting XR. This means that instructors struggle with acquiring, creating, and designing course content. In addition, 66% of respondents highlighted these issues from the student end. Students may have trouble using these technologies on their PCs and smartphones, as well as navigating these systems and focusing on the educational material instead of the technology itself.

There is great potential for XR technologies and their incorporation into higher education. While XR has, to date, been mostly limited to entertainment and training simulations, it could become a widely-used and well-integrated resource to enhance learning and make education more equitable. While existing platforms enable non-experts to design and create XR environments, these platforms may have limited potential for educational content, present difficulties in customization, and require specialized hardware and software pre-requisites.

This paper highlights the gaps in design guidelines, the existing potential to improve the design of XR applications to maximize its efficacy as a pedagogical tool, and the need to offer greater technical assistance to make XR accessible to non-experts.

10) Limitations

This study relied on an inductive thematic analysis of interviews yielding rich insight into experiences related to XR. However, no quantitative analysis was conducted to provide evidence related to the magnitude of the opportunities and challenges associated with the implementation. Moreover, the study sample did not include students.

IV. CONCLUSIONS

Teaching and learning sectors in education have continually evolved over the last few decades, with new pedagogical techniques and ideas being incorporated to make the process streamlined and effective. With the advent of new technologies over the past few decades, learning has seen innovation in various ways. In a rapidly changing and progressing society, it has always been important to continually innovate the teaching and learning strategies to leverage new opportunities provided by new technologies. Extended reality (XR) is a technology that can dramatically enhance how we teach and learn new skills and information.

To effectively include XR in education, there are a few broad recommendations that can be implemented. First, greater cross-campus coordination can create synergies that help with the awareness and implementation of XR in different fields and lessons. This will generate greater support for new initiatives within and across institutions. Second, there should be an emphasis on formal assessment and research into the educational effectiveness of XR tools with proper institutional support to better understand the benefits of XR implementation. It is important for academics in each subject area to understand the potential learning benefits within their discipline and assess how XR experiences are emerging in discipline-associated industries. This awareness can ultimately lead to more significant funding and development. Moreover, this can allow educators to expand their pedagogical practices to incorporate advancements in this field, e.g., Enterprise XR, to update the functionality of LMSs. Greater awareness can also help instructors, students, and LMS specialists identify entry points that allow exploration of XR learning across different facets of education delivery.

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What Is Immersive Learning?

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Abstract—The article investigates possible perspectives on Immersive Learning. After discussing the need for the term, the perception of non-mediation is identified as its key concept. Immersive Learning can be defined as learning with artificial experiences that are perceived as non-mediated. The research area Immersive Learning (Immersive Education) investigates educational benefits provided by such experiences. The internal process Immersive Learning is the active construction and adaption of cognitive, affective, and psychomotor models through these experiences. Immersive Learning as an educational method (Immersive Teaching) uses these experiences as a learning supply.

Index Terms—immersive learning, immersive teaching, definition, presence, constructivism, immersion

I. INTRODUCTION

Numerous studies have shown that learning with immersive media such as virtual and augmented realities can enhance learning in different application areas: STEM Education [1], Language Education [2], History and Cultural Heritage Education [3], Medicine [4], Computer Science Education [5], Teacher Education [6], and other application areas [7]. Probably the majority of the articles in this year’s iLRN conference proceedings could be added to these meta-studies as well, supporting the growing evidence that "Immersive Learning seems to work". But what exactly do we mean when we talk and write about Immersive Learning? The title anticipates what readers can expect from this article: Getting a definition for "Immersive Learning". But this is the last bit of this paper, because, spoiler-alert: Different authors mean different things when conceptualizing this term (just as with many scientific definitions). It is the questions building up to this definition that might give a new perspective on Immersive Learning:

1) Why do we even need the term?
2) What kind of concept are we even talking about here?

By tackling these research questions first, we investigate the essence of Immersive Learning and what components will be essential for drafting out a definition. In a final step, we will bring together the reasons and key components and ask

3) How can Immersive Learning be defined?

We will discuss this definition of Immersive Learning critically and compare it to theoretical frameworks conceptualizing the term. By working out this definition, I want to contribute to resolving some issues of inconsistency in the field, which I will describe in detail throughout this article.

II. WHY DO WE NEED A TERM LIKE IMMERSIVE LEARNING?

The simplest definition is the description of an educational process (learning or teaching) that is somehow supported by immersive media. This definition would be similar to Li and Ip’s approach of coining the term “VR-enabled learning” describing “the use of VR for educational purposes” [8]. Similar educational technologies that gained popularity in recent years are smartphones, tablets, and interactive whiteboards (let me exclude computers in general here, as most digital media rely on some sort of computer). Related terms such as “tablet learning” [9] or “interactive whiteboard teaching” [10] refer directly to the used technology. In terms of “mobile learning”, a broader definition, but still referring to distinct technologies, was used by Quinn: "It’s e-learning through mobile computational devices: Palms, Windows CE machines, even your digital cell phone" [11]. I dare say that these media can be identified quite easily by their distinctive technical characteristics (even though I should note here that newer definitions for mobile learning, too, are moving away from merely describing technological features to expressing the features of the learning processes enabled through the technology, see [12]).

But this is where the first problem occurs: What exactly are immersive media? Opinions tend to differ when it comes to the characteristic “immersive” as part of a technology: If I were about to claim that a head-mounted-display, such as the HTC Vive or the Oculus Quest, is, indeed, an immersive technology, most people might agree with me. But what about a Mobile VR headset, a CA VE system, a curved display, a panorama painting, a surround sound system, or a book even? We could apply a simple view such as "If I turn my head and nothing happens, it ain’t VR" [13]. But other than this definition focusing mainly on visual and auditory stimuli, what about technologies that have not even been invented yet such as implantable brain-machine interfaces (e.g. Neuralink, for a critical comment see [14]) that might not even require moving any body parts? Even the most up-to-date approaches like the suggested three-dimensional taxonomy concerning the immersion of VR-enabled learning [8] with various levels of stimulation fidelity and interactivity cannot cover such future technologies. The technological spectrum of the research area is too diverse to be covered by a single term such as “immersive technologies".
The educational virtual environment (EVE) or the virtual learning environment (VLE) can be defined as "a virtual environment that incorporates one or more educational objectives, pedagogic metaphors, provides users with experiences they would otherwise not be able to experience in the physical world and redounds specific learning outcomes" [15]. Let me note here that the second and third characteristics might be too restrictive: A VLE does not necessarily require the use of pedagogical metaphors and there is also no need for the experiences to be impossible or inaccessible in the real world. Especially in everyday classrooms, a virtual experience might just be more convenient for the busy schedules of teachers and students (just think of a regular field trip that could be carried out virtually in just an hour).

All aspects mentioned in this paper can also be transferred to mixed/extended environments, such as Augmented Realities. While we could also use terms such as "Educational Extended Environments" (EVEs) or "Extended Learning Environments" (ELEs), for the sake of clarity I will consistently just use the term "artificial experience" throughout this paper comprising all environments that consist of or at least include simulated components. Further, I will prefer the term "experience" over "environment" to move away from the perception that the experience needs to provide a three-dimensional visual component. There is also no need to integrate the learning or educational term in the description of the virtual experience, as learning, especially implicit learning (see [16]), can also happen in experiences not purposefully designed for education.

As you can see, Immersive Learning is not simply "learning with immersive media" and requires a proper definition as the term immersive media itself lacks consistency and relies on individual perception of what is provided through a medium: an artificial experience. While there are technological features that are connected to the perception of this experience, which we will talk about in the next section, this is our first takeaway:

**Note 1:** Immersive Learning means learning with artificial experiences.

This definition is unsatisfying. It is very broad as it includes everything from reading a novel over pretend play and digital vocabulary trainers up to fully embodied spaceship simulations. So after broadening the perspective to all artificial experiences, we will narrow down the features that make an experience "immersive" in the next section.

### III. IMMERSIVE EXPERIENCES ARE PERCEIVED AS NON-MEDIATED

The features of immersive experiences (i.e. Virtual Realities) contributing to learning are free navigation, first-person point of view, natural semantics (intuitive interaction), size (accessing macro-/micro-worlds), transduction (the users’ capability to 'feel' data), reification (transforming abstract concepts into perceptible representations), autonomy (independent change of the environment), and presence. Of these features, presence, as the user’s ‘sense of being there’, is described as the premier feature that contributes to positive learning outcomes in case studies analyzed by Mikropoulos [15].

Slater argued for distinguishing the technology from its effect on the individual by using the terms immersion for describing the (objective and quantifiable) technological characteristics of a medium and presence for the individual response that "arises from an appropriate conjunction of the human perceptual and motor system and immersion" [17]. By applying this distinction, Dengel and Mägdefrau [18] separate Immersive Learning into a supply-side (the educational medium) and a use-side (subjective, active learning processes moderated through the feeling of presence). By focusing on the effect of the medium on the perceptual and learning processes rather than on the technological features, Immersive Learning gains a timeless perspective, independent from current technological innovations.

According to Biocca, presence oscillates between the physical environment, the imaginal environment, and, if available, a virtual environment (here: artificial experiences in general). Presence can be distinguished into physical presence (the illusion of 'being there'), social presence (relating to a perceived other intelligence), and self-presence (the mental model of the self) [19]. It has to be noted that Lee later separated these types of presence again into the characteristics (completely) artificial and para-authentic (mediated versions of actual objects) and these characteristics might affect the learning process. Technological factors such as vividness (such as the quantity and quality of sensory stimuli) and interactivity (e.g. latency, range of interaction possibilities, and natural mapping) have been identified as predictors of presence [20].

But, the reason why defining immersive media and, thus, Immersive Learning, is so difficult is that it is not just the technology that influences the perception of the experience. Other factors influencing presence include affective and cognitive factors [21]–[24], but also a willing suspension of disbelief [25]. During a willing suspension of disbelief, "the person truly ‘knows’ that s/he is in one place while experiencing inputs to his/her sense organs that to some extent provide the experience of being somewhere else" [26]. Presence has been identified as an important predictor of learning outcomes in artificial experiences on multiple occasions [27]–[30].

An investigation of the Immersive Learning research landscape shows that there are not only inconsistencies but completely different and even opposite uses of the terms presence and immersion. There are good arguments for using immersion not just as a technological characteristic, but also as a description of the effect on the user, e.g. a subjective impression that a user participates in a world to induce a willing suspension of disbelief, see [31], [32]. Also, a view on immersion as "a phenomenon experienced by an individual when they are in a state of deep mental involvement in which their cognitive processes (with or without sensory stimulation) cause a shift in their attentional state such that one may experience disassociation from the awareness of the physical world" [33] has been used widely in Immersive Learning literature (e.g. [34], [35]). For the development of the research community, this is concerning, as these two concepts are arguably the most important key terms in Immersive Learning.
### TABLE I
DEFINITIONS OF IMMERSIVE LEARNING

<table>
<thead>
<tr>
<th>Research Area</th>
<th>Internal Process</th>
<th>Educational Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>Immersive Learning investigates the educational benefits provided by artificial experiences that are perceived as non-mediated.</td>
<td>Immersive Learning is the active construction and adaption of cognitive, affective, and psychomotor models through artificial experiences that are perceived as non-mediated.</td>
</tr>
<tr>
<td><strong>Focus</strong></td>
<td>Researcher</td>
<td>Learner</td>
</tr>
<tr>
<td><strong>Perspective</strong></td>
<td>internal &amp; external</td>
<td>internal</td>
</tr>
<tr>
<td><strong>Synonyms</strong></td>
<td>Immersive Education</td>
<td>Immersive Learning</td>
</tr>
</tbody>
</table>

For a definition, using terms that are not agreed upon in the research field is difficult. This requires a small workaround: While slightly different aspects are addressed, what is meant by presence or “subjective immersion” can be described by the illusion of nonmediation. This term has been coined by Lombard and Ditton: An illusion of nonmediation "occurs when a person fails to perceive or acknowledge the existence of a medium in his/her communication environment and responds as he/she would if the medium were not there" [36]. One could argue that all experiences are mediated by our intrapersonal sensory and perceptual systems, but the term “nonmediated” here means "experienced without human-made technology" [36]. By using this perspective on the subjective perception of the artificial experience, the definition becomes clearer:

**Note 2:** Immersive Learning means learning with artificial experiences that are perceived as non-mediated.

This idea aligns with Li and Ip’s approach of “defining VR-enabled learning as a unique type of learning experience” [8], where the “uniqueness” derives from the connection between (technological) immersion, presence, pedagogy, intended learning outcomes, and learner specifics. This is a second step toward a definition, but it adds additional challenges: The focus moves away from the medium toward its perceptual effects and benefits for learning. In the next section, we will take a closer look at the learning process.

### IV. IMMERSIVE LEARNING IS BASED ON THE IDEAS OF CONSTRUCTIVISM

The elaborated model of learning in 3D VLEs [28] focuses on five learning affordances: 3D VLEs can be used to facilitate
- the development of enhanced spatial knowledge representation of the explored domain,
- experiential learning tasks that would be impractical or impossible to undertake in the real world,
- increased intrinsic motivation and engagement,
- improved transfer of knowledge and skills to real situations through the contextualization of learning,
- richer and/or more effective collaborative learning than is possible with 2D alternatives.

Affordances describe the features that determine the possible utility of an object or environment [37]. In other words, we no longer ask about the technical aspects of a medium but rather about what this medium can provide in terms of benefits for the learning process. The affordances derive from the effect of the characteristics representational fidelity and learner interaction of the used medium on the user/learner [28]. These technological features induce a sense of presence ("being there"); co-presence ("being there together"); and the construction of identity (linking the visual representation of the user to him-/herself) (very similar to Slater’s approach mentioned in section II in [17]). Dalgarno and Lee assume that “the greater fidelity of a 3-D VLE leads to a greater sense of presence, and consequently, greater transfer [28]”.

Again, we will broaden this view to artificial experiences in general and we will use the term “perceived as non-mediated” to cover the mentioned types of presence/psychological immersion. At this point, it might be useful to distinguish between three uses of the term: a definition of the research area “Immersive Learning”, the individual, internal learning process “Immersive Learning”, and the use of the term as an educational method. Immersive Learning as a research area covers all aspects of educational benefits deriving from the use of artificial experiences, which is why “Immersive Education” could also be used in this context. Our findings lead to a preliminary definition:

**Definition 1:** The research area Immersive Learning (Immersive Education) investigates the educational benefits provided by artificial experiences that are perceived as non-mediated.

The connection between technology and learning makes the research area inevitably cross disciplines. Beck states that “[...] immersive learning experiences are created across multiple media using myriad techniques and employing a wealth of knowledge that spans many disciplines” [38].

For Immersive Learning as an internal learning process as described in the "Educational Framework for Immersive Learning” [18], the term “learning” needs clarification. From everything described above, we can rule out a behaviorist view of learning: An equation such as "better technology=more
learning” with the perceptual and cognitive processes as black boxes is obsolete. Most theoretical models describe constructivism as the underlying learning theory (e.g. [18], [28], [31], [39]). Related learning methods are situated and experiential learning (e.g. [28], [32], [39], [40]). The process of learning from this (complex) constructivist view can be seen as “the active construction and adaptation of one’s internal models of reality based on the interaction between oneself and one’s environment [...]” [41]. With reference to Bloom’s taxonomy, these models can come from certain domains: cognitive, affective, or psychomotor [42]. A definition of Immersive Learning as an internal learning process could be:

Definition 2: The internal process Immersive Learning is the active construction and adaptation of cognitive, affective, and psychomotor models through artificial experiences that are perceived as non-mediated.

Besides defining Immersive Learning as a research area or an internal process, we also want to take a look at its intentional use in the classroom. The application of artificial experiences as a pedagogical supply (similar to Helmke’s supply-use-model [43]) refers to the process of teaching rather than that of learning, thus coining the term Immersive Teaching [44]. Research shows that the integration of artificial experiences in the form of Immersive Teaching can be beneficial [45]–[47]. With this in mind, we can define this term as well:

Definition 3: Immersive Learning is an educational method (Immersive Teaching) where artificial experiences that are perceived as non-mediated are used as learning tools.

These three definitions (see Table I) might help to address questions regarding the research, the internal process, and the educational process of learning with artificial experiences that are experienced as non-mediated. Still, because of the strong inconsistencies in our field’s terminology, there are several limitations: All definitions are rather broad and not necessarily highly distinctive. This becomes obvious when it gets to adjacent research areas, such as game-based learning and multimedia learning. Let me elaborate on what this means, with a reference to Figure 1: First of all, many game-based learning approaches use multimedia games. But there are also various other educational games (especially analog games) that do not include multiple perception channels. Also, not all multimedia materials are games. In terms of Immersive Learning, many applications using artificial experiences can be considered games, but not all of them (some might be, for example, virtual environments without any gamified objective). Not all games can be perceived as not mediated, too (just think of regular card games). The same applies to multimedia learning: Many applications are multi-sensory, but not all (e.g. purely visual environments or audio-only surround sound experiences). Also, not all multimedia experiences can be perceived as non-mediated (e.g. your everyday presentation slides with speech/audio).

Fig. 1. Relationship between Immersive Learning, Game-Based Learning, and Multimedia Learning.

V. CONCLUSION

By defining Immersive Learning through its potentials and research perspectives instead of the used technologies, the term gains a future-oriented perspective. Thus, the core of the research area becomes independent of technological innovations and developments (even though, of course, the technology can still be considered as a main correlate of the investigated educational benefits).

But with this definition outside of the technological characteristics, some interesting questions regarding “Can XY be considered Immersive Learning?” arise, which have to be clarified in further research. This might also be useful to be connected with terms such as game-based learning and multimedia learning, as described in the limitations.

As Immersive Learning research continues to produce outputs exploring the potentials and challenges of teaching and learning with artificial experiences, the role of different factors within the academic and practical landscape will become more clear. Still, this first draft of a definition is supposed to add clarity to the discussion about what can be considered part of Immersive Learning and what is not.

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Contextualizing Educational Robotics Programming with Augmented Reality

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Abstract—The development of technology in recent years has led to the research of innovative tools in education. Technologies, such as Augmented, Virtual, and Mixed Reality can be utilized in immersive environments for educational purposes. Educational Robotics has also been prevalent in K-12 and STEM education. In this paper, we describe a mobile augmented reality learning environment to support robotics programming. An augmented reality application was developed and evaluated by two experts. Two experiments were conducted, including the non-AR and the AR condition. The participants were primary school students. Both observation and interviews were conducted. Our results showed that augmented reality attracts students’ interest in robotics programming, prompts them to participate in the learning process and is easy to use. Limitations and advantages of the AR approach in educational robotics were pointed out. The results indicate that contextualizing robotics with augmented reality is promising and should be further studied.

Index Terms—augmented reality, immersive learning, robotics

I. INTRODUCTION

The rapid development of technology in recent years has led to the research on the integration of new and innovative technologies in people’s lives, such as Augmented, Virtual and Mixed Reality. At the same time, advances in immersive learning tools have opened new horizons in exploring educational methods in immersive environments [1]. According to Wang et al. [2], innovative applications of Immersive Learning Environments (ILEs) have been implemented in the field of Education, with educators adopting AR, VR and MR in their teaching.

Augmented Reality learning systems have become increasingly popular among the 21st-century digital generation. Through AR technology, the real world is enhanced with virtual objects and computer-generated graphics being superimposed on the user’s environment [3]. AR supports immersive learning, providing the ability to show digital content in modified worlds [4]. To be more specific, augmented immersive reality (AIR) technologies enhance users’ perception of reality by augmenting it with additional components, such as 3D and 2D elements, audio, video and GPS data [5].

In addition to Augmented Reality, Robotics has also become more present and researched [6]. In the field of Education, Robotics can be useful in motivating students, while attracting their interest [7]. Robotics also contributes to the development of students’ social and cognitive skills [8].

Augmented Reality appears to be an ideal platform for human-robot collaboration [9], offering an enhanced relationship and interaction between them [10]. In the educational settings of the 21st century, the use of both Augmented Reality and Robotics shows great potential to benefit students and the learning process. However, limitations and challenges should be addressed. In this paper, we propose a learning system that utilizes educational robots, their programming environment, and a mobile AR application. The objective is to design and implement an immersive learning experience that intrigues and motivates students.

II. RELATED WORK

The development of educational robotics and its application in Education has increased significantly [12]. Robotics motivates students [13] by encouraging them to participate actively in the educational process. The purpose of educational robotics is to enhance the scientific curiosity and interest of students, while promoting initiative, responsibility, autonomy and teamwork [12]. AR technology is also a useful tool for Education [14] with positive outcomes for students [15]. Through the use of AR in learning, students are encouraged to interact with the virtual elements that appear in the real environment [16].

The utilization of Augmented or Mixed Reality along with robots has already occurred in the field of Education. In Chen and Chang’s study [17], learner’s experience with educational robotics was enriched with the use of a mixed reality game stage. Their aim was to implement task-based language learning by creating authentic experiences for the students [17]. According to Chang and his colleagues [18], integrating robots into MR environments enhances students' authentic learning experiences by increasing their motivation. The researchers designed the RoboStage system, using Mixed Reality and robots. The results of the research indicated that the proposed system significantly improved the sense of authenticity of the activity [18]. AlNajdi, Atrashidi and Almohamadi [19], examining the effectiveness of the use of AR in educational robotics in the context of the Pedagogical Virtual Machine model (PVM), found that the AR approach is more effective in terms of learning outcomes, enjoyment of the activity and usefulness of this learning system.
An augmented learning environment can improve the motivation and participation of the students in the learning process [20]. At the same time, through educational robotics, computational thinking skills are developed, while students are involved in interactive experiences and learning through play [20]. A learning system utilizing both Robotics and Mixed Reality technology offers new possibilities, especially in STEM [11]. AR technology helps students to detect and correct errors in robot programming and manipulation [21]. Communication between students, problem-solving and finding solutions in robot programming are also improved as AR promotes discussions among students regarding the data of the robot sensors [21]. According to Cleaver and his fellow researchers [22], AR can provide a visual aid on key concepts, while students interact with educational robots in the real environment.

The research of Radu and his colleagues [23] showed that the presence of AR technology contributed to the balanced communication among students. At the same time, according to the pre - post tests and the observations, students’ learning outcomes were also improved [23]. In Yusuf, Efendi and Yuana’s study [24], an AR app for mobile devices, called ARROBO, was designed and developed. The researchers concluded that the application, utilizing AR potentials, helped students understand robotics concepts through three-dimensional virtual models, thus constituting a useful, portable and applicable means in robotics education [24].

The current conditions along with the evolution of technology create new possibilities regarding the teaching of robotics, either in distance learning [25] or in person. Research has already shown positive aspects of the use of Augmented Reality systems in Robotics applications, leading to the design and development of more contemporary, improved and enriched learning experiences for the students.

III. PRESENT STUDY

Based on the research described in the previous section, we designed an Augmented Reality application for robotics education. The aim of our study is to examine the implementation of an immersive learning environment in educational robotics. To be more specific, we integrated AR technology in a robotics lesson to support robot programming. By using this learning system, we wish to discover the issues that arise and the reactions and views of students regarding this type of learning. According to our first hypothesis, we expected that participants would evaluate their experience with AR and robotics programming positively. Comparing the AR condition with the non-AR condition regarding robotics learning, we hypothesized that students would be more interested in using AR to program their robot. The study was qualitative to study things in their natural settings, attempting to interpret phenomena in terms of the meanings people bring to them [26].

Augmented Reality Application Design

The laboratory nature of robotics raises needs, such as specialized equipment, additional props and tarpaulin activity mats (based on the context of each lesson) where robots move. The proposed AR application was developed using Unity 3D engine and Vuforia SDK. It was built for Android mobile devices. Its purpose was to supplement robotics teaching by replacing the common, tangible robotics mat with a virtual one. Two markers were used. The one made a virtual three-dimensional city come to life through AR. The second one was placed on top of the robot and acted as a trigger for the AR application to show a 3D delivery van, as shown in Fig. 1.

Augmented Reality was utilized to provide the context in which students would start programming their Mindstorms EV3 robot. The virtual city was superimposed on the users’ real environment through the use of smartphones and tablets where the AR application was installed. There were also some interactive 3D elements in the virtual terrain which pointed at the places that the robot had to be in order to complete the activity. When the robot with the suitable marker on top reached the desired place in the augmented city, an animation occurred and the corresponding interactive arrow disappeared. Thus, positive feedback was given to the students at the time they accomplished an activity.

IV. QUALITATIVE RESEARCH

A. Augmented Reality Application Evaluation

Two experts, specialized in programming and robotics education, participated in the evaluation of the AR application for robotics learning. Those participants were chosen on the one hand for their expertise in the field and on the other hand for their pre-existent experience with the AR app in distance learning robotics courses [25]. Both educators were male.

For the evaluation of innovative and immersive learning systems, the interview method has been used [27]. Semi-structured interviews were used to highlight the affordances along with the possible limitations of the proposed AR application. The two experts were informed about the context the AR app would be in. Then, the researcher asked for their genuine opinion, based on their experience with new technologies in learning. The interview duration was about 20'.

According to the answers of the two experts, AR is considered to be a useful tool in robotics education. It is an easy-to-use technology, as well. To be more specific, both participants pointed out that the way this AR application is designed attracts students’ interest and keeps them activated. “AR is something very new for the students and this is the reason they will gladly use it for robot programming”, Expert 1. Additionally, students from a young age are familiar with graphics, video games, mobile apps which leads to their excitement and desire to use AR in their learning. Expert 2 pointed out that “Augmented reality makes the lesson more experiential and there is the element of interaction which is very
important for teaching because it keeps students motivated and not passive receivers of information”. A valuable feature of the AR application for robotics programming is the feedback it provides when students complete a programming task. The fact that it is game-based makes AR appealing to students.

Regarding the limitations and difficulties that may appear, the experts noted that they are technical. For example, Expert 1 saw that there should be enough lighting in the room in order for the AR application to work best. Another factor they both mentioned was the mobile device’s camera resolution. Pure resolution makes the virtual objects disappear or seem unsteady. “There is no technology that works perfectly, there is always room for error or for something to fail and AR is no exception”, Expert 2.

B. Non-AR Condition

1) Participants

The participants of this experiment were 5 primary school students who attended educational robotics lessons. They were all familiar with the Lego Mindstorms EV3 robotics kit. Four of them were 3rd-grade students and one was a 4th-grade student. The majority of the participants were boys (4 out of 5).

2) Data Collection

For this condition, data were collected using an observation sheet. Observation is suitable for small-scale research [28]. The observations during the robotics lesson were made by two observers, specialized in educational robotics. Based on Junker's field observer roles [29] and Gold’s analysis [30] on their characteristics, the first researcher’s role was the complete observer, simply observing the activities without interacting with the participants. The other researcher was the participant observer, being immersed in the activities, interacting and communicating with the participants. Both observers took notes, focusing on students’ expressions, reactions, difficulties they encountered, participation, interest in the learning process, teamwork and time they spent on each task. At the end, students were asked about their impressions of the lesson.

3) Procedure

The implementation included a 2-hour robotics lesson, using the Mindstorms EV3 robot. Students were asked to build a robot – vehicle following certain instructions. After building their robots, a robotics mat depicting a city was laid in front of them, as shown in Fig. 2. Students, working in two teams, were asked to program the robots to navigate in the city and stop in specific places to complete the given tasks.

![Fig. 2. The real, tangible robotics mat of a city with EV3 robots.](image)

4) Results

From the researchers’ observations, it was evident that students seemed to enjoy the robotics lesson and they carried out the programming tasks successfully. They were participating in the learning process, showing interest. They programmed their robots using trial and error to find the right values for the EV3 programming blocks and worked together quite well.

C. AR Condition

1) Participants

In the AR condition, the same participants with the non-AR condition took part in the experiment (Repeated Measures Design), apart from one participant who was absent on the day of the experiment. Three boys and one girl formed two working pairs. None of the participants knew what augmented reality technology was and no one had prior experience with an AR application of any kind.

2) Data Collection

Before the experiment, parents and guardians of the students were informed through a detailed document about the research and signed a consent form so that their children could participate in the study. For the collection of the data both interviews and observation were used.

To be more specific, semi-structured interviews were conducted, where participants have a significant degree of freedom about what they wish to say, the extent of it and how they can express themselves [31]. Each participant was interviewed individually by one researcher. The questions were open-ended and focused on students’ overall experience from programming the educational robot in an augmented city, their enjoyment and interest in the learning process, the AR application’s ease of use, the behavioral intention to use AR in future robotics lessons, the limitations of the AR application and the comparison of the AR and non-AR condition through students’ perspective. Each interview lasted about 10-15 minutes. Both participants and their guardians were informed from the beginning that the interview was being recorded. At the same time, the researcher who conducted the interviews took notes. For the analysis of the data, the audio recordings of the interviews were transcribed.

In addition to the interviews, both participant and non-participant observation were used to record the participants’ behavior. During the experiment, the researchers completed an observation sheet, the same as in the non-AR condition. It consisted of 8 items in the form of a 5-point Likert scale, regarding students’; active participation, answering questions, testing their program (trial and error), encountering difficulties, collaboratively as a team, problem-solving skills, being bored, showing interest in the lesson. There was also space for remarks.

3) Procedure

The experimental procedure was identical to the one in the non-AR condition. The AR experiment was implemented one week after the non-AR experiment. The programming activities were not repeated. However, the difficulty level of the activities in the AR condition was the same as in the non-AR condition. The robot used was the Lego Mindstorms EV3. The building instructions given were the same so that students were not influenced by other factors rather than the use of AR. Taking into account the answers of the experts described above, a tripod
was used to accomplish a steadier set-up with good lighting, as shown in Fig. 3.

Fig. 3. Students testing the robot programming in the virtual city through AR.

Firstly, each student was given one tablet and two markers so that they become familiar with the AR technology. Then, students were asked to place the smaller marker on top of the EV3 robot and the bigger one on the floor. The tablet was on the tripod, able to scan both markers simultaneously. The designed AR application was used to provide the context in which the robot would be programmed. When the markers were detected, a virtual city and a 3D delivery van appeared.

Students were asked to program their robot to navigate in the virtual city, displayed through AR. To complete the given tasks, students had to make estimations, experiment and test their ideas through trial and error in the Mindstorms EV3 programming environment. Students could see the results of their programming on the mobile device utilizing the AR features of the application. When the robot moved to the desired position in the virtual city, a reward animation was displayed in the AR application, providing students with positive feedback. Thus, the additional 3D elements in the AR application in the form of arrows interacted with the robot and informed students when their tasks were completed successfully. During the experiment, students’ reactions and behavior were observed. At the end of the activities with AR, students were interviewed individually, answering questions regarding their experience with this new context of robot programming.

4) Results

Based on the interviews students seemed to have a positive overall experience using AR for robot programming. They all found the AR application easy to use. As they had never used augmented reality in the past, they were glad to use a new approach. “It was a nice experience, different from the previous lessons we have done, better”, Student 2. One feature they liked was the multiple markers that could be traced simultaneously. One participant was excited by the fact that when the marker was moving, the corresponding virtual object in the AR application was moving, as well.

Three participants found this kind of robot programming enjoyable. However, one was uncertain about it. Regarding the limitations of the AR application, technical issues may appear, e.g. the application may lose sight of the marker and the 3D model will not be visible. The presence of the interactive virtual arrows was characterized as useful. As Student 4 mentioned, the 3D arrows disappeared and made an animation when the robot reached each point and this was beneficial, confirming that the goal has been accomplished and that the programming was right.

Comparing the AR with the non-AR condition, students preferred the use of Augmented Reality technology. To be more specific, “With AR the robotics lesson is better because we could see everything on the tablet and we didn’t need to set up a robotics mat or to remember where to place our robot each time in the robotics mat”, Student 1. Student 2 stated that the lesson was enriched with the use of AR, with the students being able to do more in comparison with the non-AR robotics learning environment. Both environments have their advantages and drawbacks. For example, the virtual city was nicer for robot programming, but the real robotics mat cannot disappoint users in terms of not responding or not working properly, like a mobile application (Student 4). Student 3 seemed to prefer the non-AR approach as it is simpler to measure the distances the robot would move with the robotics mat. However, it was pointed out that the robotics mat does not give any feedback or interaction like occurring in the augmented city (Student 3).

Regarding the observations, the analysis showed that all students participated actively in the learning process, answered questions and experimented with the robot programming. Students worked together really well, as for some activities one student was looking at the tablet and the other member of the team placed the robot on the floor e.g. to measure the rotations of the motors. The students quickly comprehended how to use the AR app, so they did not come across difficulties. They also did not seem to be bored at any time during the use of AR.

V. DISCUSSION AND CONCLUSIONS

An innovative proposal that meets the needs of 21st-century students is the combination of AR technology with Educational Robotics in the context of immersive learning. The present study is a continuation of research conducted in the context of distance robotics learning due to COVID-19 pandemic [25]. Augmented reality techniques allow the enrichment of user experience when interacting with robots [32]. Our study’s novelty is in contextualizing the robotics lessons through mobile AR, rather than providing visual cues regarding the robot’s sensory data [21], [22], [23]. A Mixed Reality environment can improve student motivation and engagement in learning, while Robotics can contribute to the development of their computational thinking [20]. Similarly, the Augmented Reality approach appears to be effective in the learning process [19]. In our research, interactive virtual objects in the shape of arrows helped students reach their goals and provided feedback.

Augmented Reality integration should align with appropriate learning strategies, such as interactive learning, game-based learning, collaborative learning, and experiential learning [33]. In the present study, we utilized AR technology to provide the context of the robotics programming activities. Compared to the non-AR (purely real and tangible) condition, the students argued that the lesson was more interesting in a mobile AR environment. However, there is room for improvement, regarding the AR app. On the other hand, compared to a purely virtual simulation, MR improves the experience [11]. From the observers’ view, students equally participated in both conditions, although they seemed more interested in the AR and collaborated even better due to the nature of the AR activities.

Our results showed that AR provides a more enhanced learning environment. Combining real and virtual words leads to
enriched learning experiences that foster the development of 21st-century skills [34]. More studies with varying age groups and larger sample sizes of students and educators are required to examine the potential of using augmented immersive environments to support learning. Further research should also be made, examining how AR-based interventions influence learning outcomes regarding robotics.

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Improving Adoption of Immersive Technologies at a Norwegian University

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**Abstract**—Adoption of immersive technologies in higher education can potentially offer novel and educative experiences. Despite the increasing amount of available XR content for education, adoption of XR for regular teaching at higher institutions appears to be still lagging. Some reasons for hesitancy in integrating the technologies in university courses are barriers such as lack of content, cost of equipment or expectations on technical knowledge required to use the technology. We run an immersive tech lab to support innovation in education. The lab supports educators with equipment and expertise to include immersive technologies in their courses. In this paper we present the results of a thematic analysis of interviews with lectures at a Norwegian higher education institution. Our contribution is to give further insight into factors the educators consider when adopting immersive technologies in their educational practices.

**Index Terms**—immersive technologies, XR, educational technology, technology adoption

**I. INTRODUCTION**

The potential for immersive technologies (virtual/augmented/extended reality VR/AR/XR) in education has been further highlighted due to consequences of pandemic restrictions in the field of education. Educational institutions, and particularly higher education ones have been forced to adopt different teaching practices, with hybrid learning now being a common term. Educators are planning their teaching with provisions to teach remotely at short notice. It can be argued that educators had to consider using tools for regularly teaching that they would have not considered before. Many had to become proficient in the use of conferencing tools that probably would barely be used for educational purposes before 2020. This situation offers an opportunity to revisit the use and adoption of immersive technologies in higher education. The authors are associated to a laboratory setup at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, as a way to promote innovation in education through the use of immersive technologies. The laboratory is run by our research group IMTEL (Innovative Immersive Technologies for Learning) and combines research development with educational and dissemination activities. The laboratory offers VR, AR and MR equipment for educational activities. Such activities include demonstrating equipment, presenting educational XR applications through guided visits and supporting teaching sessions as well as developing educational XR apps in collaboration with stakeholders. The lab presents applications developed as part of our research as well as commercially or academically available applications. The research group actively engages with educators to promote the use of immersive technologies. Our interest is to gain insight into the decision-making process of lecturers who used or adopted immersive technologies into their higher education courses, which factors were important for those educators and what can be done to increase adoption of such technologies. Those questions were investigated through interviews with lecturers that have used or integrated immersive technologies in their courses at our university. The goal is to help building up knowledge to inform wider adoption of immersive technologies. The interviews were carried out with educators who have used immersive technologies in some capacity. It is not the purpose of this paper to describe implementations or use of the technologies in detail for delivering specific teaching. We believe the existing literature provides enough specific cases of implementations into particular courses. The aim was to learn what the educators have to say about adoption of immersive technologies and evaluate their comments against the body of current literature. This paper is organised as follows: in the next section we discuss some relevant work for our project. The following section discusses the qualitative study carried out, followed by its results and finalising with a discussion and analysis.

**II. RELATED WORK**

The benefits of immersive technologies in higher education are based on affordances of these technologies [1], [2], [3], [4] and are associated to pedagogical approaches such as active and experiential learning [5], [6]. Despite clear benefits of immersive technologies in different fields, there are signs that adoption of the technologies has not been as extended as expected [7], [8]. Infrastructure deficiency is considered a factor affecting adoption in higher education [9], [10]. Matsika and Zhou’s study also identified factors such as costs and perceived complexity. An important barrier for adoption of
XR in education is the inadequate or lacking XR training programs for teachers [11]. The State of XR report highlights that support for using XR at educational institutions is largely either at early stages or that there is no support at all. The report also lists other factors affecting adoption. One of the factors is the difficulty to locate content for educational purposes or content that can be adapted for actual educational needs. Lack of the right equipment (infrastructure) is also seen as an important barrier. Our work investigates adoption in an institution with existing infrastructure and with educators that are aware of the available resources.

III. METHODOLOGY

We selected a method of study that could capture the characteristics of adopting immersive technologies. This work aimed to capture the characteristics of immersive technologies within specific contexts, which is necessary to study the adoption and diffusion of the technologies due to their changing nature [12]. Researchers investigating adoption of technology might investigate adoption informed by the innovation life cycle or established models such as the Technology Acceptance Model (TAM). A study based on theory of planned behaviour carried out in schools in the United States with high school teachers pointed towards factors present in teachers’ decision to adopt technology [13]. It suggested the need for teachers to know how adopting the technology will affect their work, their concern about using the technology effectively as well as consequences for students. The Technology Acceptance Model (TAM) considers factors that influence decision-making when having the option to adopt a technology. The model helps explore factors in use of technology such as perceived usefulness and ease of use [14]. A study carried out with 14 selected teachers using a modified TAM to predict acceptance of digital games in education [15] identified key variables which were later evaluated by a group of experts. Another work extended TAM to determine factors involved in teachers’ intention to use mobile-based augmented reality in education [16]. The study was evaluated with a sample of 127 teachers who had created or download AR applications.

Grounded theory is a way of carrying out qualitative analysis to support building a theory. As such, it is not linked to specific types of data or research lines [17]. This was a motivating factor in carrying out a qualitative study. We aimed to collect data and let the data guide our research. The research was guided by a main research question: How to support integration of XR into educational practices at our university? This question was explored through a subset of questions. The first sub-question was about the status, needs and barriers to adoption at the university. The second question was what are the guidelines, resources and recommendations needed to overcome barriers/support integration into academic plans. A qualitative design was used in this research. Semi-structured interviews were carried out using an interview guide. The interviews were conducted via zoom between December 2020 and June 2021. All interviews were carried out in English. English is not the first language of most of the participants, but they were not screened based on first language nor asked which was their first language. The interviews were transcribed verbatim. All interviews were recorded in audio.

A. Participants

Eight participants were recruited from the staff of the Norwegian University of Science and Technology (NTNU) in Trondheim. The participants work in different campuses in the city of Trondheim, but we did not collect that information in the demographics. All participants were actively teaching in higher education. Five participants in the study were male and three participants were female. No other demographics were collected from the participants. All participants were previously known to the members of the research team. They were approached due to having used immersive technologies in their courses. The participants were given information sheets and consent forms.

B. Data protection and ethics

Approval was obtained from the Norwegian Centre for Research Data (NSD) for collecting and storing data in line with the university’s guidelines. The researchers are responsible for securing privacy rights of the participants. Therefore, the researchers must guarantee that published data does not affect the participants’ privacy. The experiment was conducted in accordance with the university guidelines for research.

C. Analysis method

Thematic analysis was applied in the interview transcripts. The themes were defined based on an inductive approach.

D. Procedure

All interviews were carried out via Zoom by one researcher. Each interview took between 45 and 55 minutes and were recorded in digital audio. No video was recorded but the interviewer could see the participant during the interview. The interviews were transcribed by a member of the team who was not present at the interview.

IV. RESULTS

Eight higher education teachers were interviewed in total. The researchers determined to have reached data saturation when the eighth participant was interviewed. A thematic analysis was carried out and identified several themes. The analysis of the transcribed interviews produced the following themes: Preconditions for immersive technologies, Immersive experience, Logistics of visits to immersive technologies facility, Students’ group size, Awareness/ knowledge of repositories/resources, Use/Creation of 360° films, Awareness of immersive technologies, Champion for immersive technologies, Convenience/expectations regarding immersive technologies, Immersive technologies and pedagogy and Independent use of immersive technologies.

The script for the interview addressed our research question “How to support integration of XR into educational practices at our institution?” We used five main questions to guide the interview.

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Participants were asked first: “What were their experiences with using immersive technologies for teaching at the lab or somewhere else?”.

It was an open question and the interviewer followed up on how they found about the availability of XR equipment and facilities at the institution and the logistics of organising the visit. The answers to these questions were coded under Preconditions for immersive technologies. Subthemes emerged in relation to the cost of equipment, buying or developing content, educator’s confidence in having enough knowledge or expertise to setup or use the equipment, finding or creating content. The answers collected pointed towards the importance that personalised contact by the lab’s leader played in their decision to use the resources available (lab and equipment). Despite awareness of the existence of the lab and equipment, educators highlighted a need for personal contact before making the decision to use XR actively through the lab. There is an overall self-perception of not knowing enough to use all available equipment independently, even among those who had experience in any of the technologies. These are examples of their comments: "In my opinion it’s the content which is the bottle neck here. It’s too costly, it’s too time consuming to build content”, “I must say I’m dependent on students helping me.”, “I don’t know how to set up the treadmill or to set up all the applications with all the equipment, so need students doing that for me. It has to be a part of the package really.” Educators not located in the same campus have considered buying equipment to avoid travelling but see it as costly.

Another open question was “How do you think immersive technologies support your teaching and how can they be integrated in your teaching plan”?

The question aimed to collect evidence on how immersive technologies can support teachers’ needs in a way that is not supported by other means, as well as integration into teaching plans, access to immersive content/apps and pedagogical approaches used in teaching. Two main pedagogical approaches were discussed, one being experiential learning approach, allowing the students to be a part of an experience. The other approach was to use the technology and reflect on what it could be used for. One particular use case is showing students training to be teachers what can be done with the technology, so they see how it works. In this context, several participants used and favoured 360° VR videos as an easy implementation of XR and appreciated the availability of content, particularly for social sciences. An interesting comment was: “In all my teaching, I am into student activities, dialogue, acting, and some way trying out different, call it theoretical applications. And, learning through trying out different perspectives. And in such way, that type of technology contributes to that learning process.”

Participants were also asked: “Do you see any limitations to use immersive technologies for teaching? What are the barriers to adoption?”.

The participants felt very positive about support in the institution for the use and adoption of the technology and generally did not see organizational barriers for adoption. Nonetheless, some raised administrative issues as barriers, despite being positive on organizational support. For example, this comment: “The logistic is actually a challenge, so I think that is why I haven’t done it for at least a year now. Well, it is in another campus than where I’m based, and so I sort of have to organize a little bit around it, and I have to make sure that the students don’t have any other classes before or after, so that they have time to go there. And then there is this question about having some assistants to help out in the lab, and we have to pay for it, and there is some, well, issues in, afterwards, where I have to fill in all these forms and make sure that we pay them”. The university has several campuses in different parts of the city. There is public transportation to all campuses. Nonetheless, it is not seen as ideal to have to travel to another campus.

The participants were also asked “What help and support do teachers need to overcome barriers and integrate immersive tech in their teaching?”.

The participants highlighted the need for technical and operational support. They expect or wish to have support or being able to call for assistance if something does not work. There is, nonetheless, a desire to be able to work independently. Their reluctance to do so is connected to the previously mentioned insecurity that the educators express about their own skill, expertise, or knowledge. The participants were asked if they would be willing to work independently if provided with some type of material such as written instructions or a guideline. The participants mentioned a web page, videos or a PDF. The majority declared to not know or not be aware of any existing guideline for using immersive technologies in teaching.

The interview asked for an opinion on how the participants think the adoption of immersive technologies was affected by the COVID crisis as well as any thoughts on how to integrate immersive technology in teaching at our university.

The general opinion of the participants is that immersive technologies will be adopted across the university but that it will take some time to get there. Apart from one participant, the majority were not aware of any particular action, policy or campaign to increase or facilitate use of immersive technologies in the university.

Other theme that arises from the answers was group sizes. There were limitations regarding the number of students that could simultaneously use the technologies during visits to the VR lab even before COVID-19 pandemic. After the pandemic it has been necessary to limit the number of students simultaneously visiting the facilities. A visit to the VR lab implies that the educator either is with the students in the lab or with the remaining students in another room conducting a different activity. In that context the teacher can be prevented from exploring the full potential of the immersive activity in some cases. The following statement presents an educator’s view on the challenge of having a student group using XR equipment at the lab: “The problem was that we were just too many people, and there were different programs in the different
areas in the VR lab, so, when somebody finished one thing, they moved to the next part, and then they had to wait, so they were allowed to try out something different in the waiting time. So maybe, if I were to do it again, I would have smaller groups, so that it would be more concentrated on specific aspects of the technology”. The analysis of the interviews shows understanding of the benefits of immersive technologies and appreciation for what can be achieved with it in higher education. The technologies are used as a supplement to the courses. This mean that none of the educators is using the technology in every class and rather it is used to complement a particular session or achieve a specific goal. All users of XR expressed to be satisfied with the support received during the visits at the lab.

V. DISCUSSION

The interviews provided interesting information into how we can support integration of immersive technologies (XR) into educational practices at our university. On several points our findings support the conclusions from ILRN State of XR report [11], literature on adoption of XR in higher education [18], [6] as well as existing literature on technology acceptance. We discuss the findings and their implications along the dimensions of three ‘E’s: Educate, Experiment and Explore that are the main pillars of our lab’s strategy (https://www.ntnu.edu/imtel):

• Educate: using the facilities in the IMTEL lab in teaching practices at NTNU (both teaching with XR and about XR); development of innovative teaching and learning methods, also blended/hybrid and remote in the context of COVID-19 pandemic.

Activities at our lab have been used as a supplement to the traditional course work in a number of courses at our university, such as geography, social anthropology, pedagogy and teacher education. This allowed to facilitate a more student-active approach and experimentation, adopt different perspectives on the topic and provoke a reaction to catalyst further conversations (e.g. about climate change). Also, using immersive tech to substitute activities that appeared unfeasible during the COVID pandemic such as field trips. The work carried out at our lab in supporting educators in their visits with students, and offering expert advice in selecting content as well as technical support has been acknowledged by the teachers. There is also a general acceptance among the teachers concerning the need for courses where they can acquire competences in use of immersive technologies. Our lab has already introduced such a course for university teachers and is working on a number of Erasmus+ projects developing guidelines and resources on the use of XR in teaching and learning. Apart from pedagogical considerations and access to educational resources, our findings emphasize the need to develop appropriate logistics for allocating equipment during class visits. These aspects are well-known in the XR community such as the difficulty to have headsets for large groups to support the simultaneous participation in an activity in immersive environments. The laboratory has several high-end headsets, and it would take a considerable investment to have enough stations for a large group. At the same time, the VR lab is currently part of consortium investigating low-cost VR. A realistic solution could be to determine the optimal number of headsets necessary to support teaching with minimal effect in the class. Another important aspect is to develop appropriate administrative practices for the laboratory sharing resources across different departments and study programs.

• Experiment and research: research-based development of educational VR/AR applications, evaluation, scientific experiments, supervision of research students.

Some of the interviewed educators participated in cross-disciplinary R & D projects at the lab, collaborating with groups of IT students to develop XR educational resources to support particular learning goals, e.g raising awareness of climate change. On some occasions, the students visiting the lab as a part of the course also participated in research projects by master students, providing feedback on their projects. We have developed a methodology of supporting development of XR educational resources in cross-disciplinary groups consisting of students, teachers and other stakeholders. Over a number of years, we have developed a repository of such resources (mostly code) that the students have access to and can lean on in their projects. This approach partly addresses the bottleneck of access to suitable content identified by several informants in our study. However, such a repository requires curation over time, both in terms of technical updates and supporting access and further use by stakeholders.

• Explore: facilitating lab visits to learn about on-going projects and XR in education in general; helping explore new approaches and new ways of looking at known problems, engaging public, academic and industrial community.

A clear finding is that teachers mostly find out about the VR lab from the direct action of the lab head. That suggests that alternative communication channels might be desirable in order to increase the number of teachers using the facilities.

A part of our lab strategy is actively encouraging lab visits by educators, local schools and organizations as well as delegations from other cities and even countries. We are also organizing regular Innovation days with local and international speakers on various aspects of Immersive Tech with hands-on sessions in the lab, in physical, online and hybrid formats, to raise awareness of potentials of immersive tech for learning. However, these actions might not be enough in the longer-term and there is a need for a more systematic communication strategy involving several administrative units and stakeholders at our university.

VI. CONCLUSIONS AND FUTURE WORK

The IMTEL VR lab (see Fig. 1) that the authors have been managing currently supports educators from different fields in integrating immersive technologies into their educational practices. Our findings indicate that future work needs to be balanced along two major directions:
On one side, given the physically distributed nature of campuses of our university and the implications of COVID-19 pandemic, it is necessary to consider a more-decentralized approach, providing access to equipment, resources and guidance/technical support to educators locally. This includes interconnected labs/hubs throughout the campus with a variety of equipment available for different educational purposes, from Cardboards Oculus Quests and high-end devices such as VR tethered VR headsets and Hololenses. Such labs/nodes need to support remote activities and collaboration as e.g realized in an existing initiative at our university [19].

On the other side, it would be necessary to establish a joint resource center providing educators with access to educational resources, best practices, technical support and XR apps, coordinating joint initiatives and establishments of cross-disciplinary consortia necessary to develop projects and new XR resources (XR apps). Such a center will also support development of a shared administrative infrastructure, enabling easier sharing of costs and resources and broader adoption of the XR as a part of teaching practices at our university. A centralised initiative will support establishing additional communication channels with the teachers and evaluating the use of immersive technologies in different study programs. At the moment, we are working on several such centralized initiatives such as several externally funded projects and an application for Center for Excellence in Education with the focus on immersive tech.

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Teaching and Learning Immersive Technology in Education Sciences

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Abstract — The immense potential of the immersive technology application in education has irreversibly shifted the status quo of pedagogic emphases across the disciplines and all levels of education. This shift, in turn, demands Higher Education in education sciences to adapt to these changes and to provide programmes and courses, where future specialists and researchers in such fields as technology enhanced learning, education technology solutions and applications can gain their expertise and qualifications. This research was conducted as a case study analysis of teaching and learning immersive technology in the field of education sciences at a university Masters level course “Virtual and Augmented Technology for Education”. This paper analyses teaching approaches and learner experience during two consecutive course years in order to formulate the findings and conclusions valuable for future application in the field of education sciences and potentially more broadly across the disciplines.

Index terms—virtual reality, education sciences, learning, immersive technology, higher education

I. INTRODUCTION

Technology has been a leading voice in sculpting the core identity of current and future education, permitting and adapting even more new ways for educators and learners to engage and to connect, interact and monitor, as well as to immerse in learning experiences. Over the past two decades the increasing international tendency of immersive technology (XR) and specifically virtual reality (VR) and augmented reality (AR) being integrated in higher education programmes has enabled educators across the globe to deliver opportunities for the most natural way of interacting with the learning object. This has also engaged learners in a variety of simulated 3-D environments and experiences, as well as ensuring their safety and motivation.

XR has transformed the human-computer interface and has humanised it further than any previous technology before its time. Immersive experiences, either reality or fantasy based, allow us to interact with content and other people in the most natural way through first person experience – a way that previously could only have been possible in science fiction. The emergence of immersive learning environments or 3-dimensional (3D) learning environments (3D VLEs) [1], presents a unique opportunity for Higher Education to cross beyond content, disciplinary boundaries and historically set-environments – classroom or desktop instead focusing on the experience of learning.

Considering the immense potential of immersive learning, educators nowadays are looking to integrate this technology as an additional dimension across the disciplines, learning modes and education levels [2]. These efforts to integrate and harness the potential of immersive technology for learning purposes have been impressive; however the same cannot be claimed about the efforts to educate Higher Education graduates including in the field of education sciences, on what the integration of XR in the learning process means for learning including instructional approaches and design strategies. As Kapp highlighted: “It will be important to know how to apply the correct pedagogy, how to choose the right software and hardware, and how to apply the right instructional strategy to ensure learning” [3]. This rhetoric aptly describes the truth of the situation – that the general body of expertise in this field can be characterised as highly fragmented, although, there have been efforts to systematise the general pedagogic principles of learning in VR [4]. In practice this manifest as a tension created by the skill gap, where the two fields – education and immersive technology have merged in the practical, economic and theoretical reality, yet the experts in the field of immersive learning are most often educated in one, or other, of the two fields. Thus, people, who in their professional responsibilities, need to integrate and utilise technology in learning, are most often either educators, instructors or education researchers who often lack deeper knowledge of VR technological aspects, or are the technology experts, who ultimately are not educators or education researchers.

The idea behind this immersive technology learning course “Virtual and Augmented Technology for Education” was to fuse the best research available in the fields of cognitive pedagogy, Technology Enhanced Learning, XR for learning and instructional design in order to enable education sciences graduates to traverse both fields (education and immersive technology) and to help in bridging this skill and knowledge gap.

II. TEACHING AND LEARNING IMMERSIVE TECHNOLOGY IN EDUCATION SCIENCES

A. Rationale for the Course

Learning about XR technology and in fact in XR has been implemented in Higher Education around the globe in various fields using various structural models and pedagogic approaches. For instance, University of Oxford, Norwegian University of Science and Technology, Oral Roberts University,
Syracuse University, Columbia University followed by many more, including colleges and universities of applied sciences across all continents of the globe who employ XR in their study programmes. However, the list is rather shorter for XR focused programmes in education sciences, it includes: University of Central Florida, Stanford University and University of Saskatchewan. The postgraduate course “Virtual and Augmented Reality Technology for Education” explored in this study was introduced as an elective course in 2021 which is part of a completely new (Master of Science) programme in education sciences “Technology Innovations and Design for Education” at the University of Latvia (Riga, Latvia). The course was taught for two consecutive years during the Spring semester of 2021 and 2022, in very different circumstances due to the COVID-19 lockdown in 2021.

The aim of the course was to promote the students’ understanding of how learning occurs in the immersive virtual environment and the preconditions for the relevant mode of learning, how people perceive new information through learning experiences in a virtual environment and how to adapt learning content to virtual reality technologies. In this course, students are enabled to develop an understanding of pedagogy and cognitive psychology theories and to acquire practical skills in integrating and developing VR learning content. Upon completion of this course, the students are expected to have increased their academic competence for understanding immersive technology affordances and potential, related pedagogical theories, as well as developed innovative and conceptual thinking, analytical and practical skills in applying XR technologies for educational purposes. The students are expected to have developed an ability to identify the regularities and critical aspects of the virtual reality learning process, based on the analysis of relevant theories, good practices and technology aspects. The students are expected to be able to make reasoned and theoretically sound decisions in the process of developing new VR educational content and proposing innovative education solutions.

The initial course design envisaged a challenging yet necessary balance between research-based and hands-on immersive technology laboratory and experience-based approach. A dedicated immersive technology laboratory was developed with technology infrastructure ranging from the most popular standalone headsets (HMDs) to the latest models of HMDs with quality eye-tracking features, 3-D projectors and 360 cameras, data gathering and analytics tools including facial and cognitive analytics, as well as a variety of XR content creation tools.

B. Approaches

The main mode of the course delivery by design is hybrid research-based approach – using the full potential of in person and hands-on learning: theory and research based modules were delivered online, while the hands-on immersive technology experience was gained in person at the laboratory. The hybrid approach was implemented in 2022, however, because of social distancing limitations during the lockdown in 2021, various necessary amendments had to be made to the initial course design to deliver the course entirely remotely. Several pedagogic and instructional solutions were employed to achieve the best results in these restrictive times.

The course implementation relied heavily on the Constructivist [5] and Connectivist [6] approaches to learning, deliberately fostering the understanding of its potential in students. Immersive virtual learning fits the Constructivist learning design [2], as it stresses that the chosen instructional learning design has to provide macro and micro support to assist the learners in constructing their knowledge and engaging them for meaningful learning. The macro support tools include related cases, information resources, cognitive tools, conversation, and collaboration tools, and social or contextual support. While a micro strategy should make use of multimedia and principles such as the spatial continuity principle, coherence principle, modality principle, and redundancy principle to strengthen the learning process.

Expert groups and networks were a great way to ignite student motivation and passion for knowledge hunting. In 2021 it was a true challenge to deliver opportunities for practical experience and networking opportunities for students. This challenge was addressed by involving students in virtual meetings and conferences with national and international partners and colleagues in the field of immersive learning. One of the most notable opportunities was the 7th International Conference of the Immersive Learning Research Network (iLRN2021) which took place in May 2021. The conference enabled participants to engage via VR HMDs or a desktop computer connecting people across the globe by use of a virtual campus and realistic avatars. This experience allowed for students to be, not only part of the event and to network with students around the world, but also enabled a rare opportunity to be ‘together’ in one environment and create a sense of true presence and connectedness. However, in 2022 practical in person learning, including: getting acquainted with the variety of hardware, available content, software, group projects, discussions and expert guest-speaker meetings, set an intensive pace.

In addition, learning in context, including from successful start-ups and case-studies for immersive technology applications in academia was a crucial part of the employed learning approach. Asynchronous accessibility to course content was enabled by employing a flipped classroom approach when it came to introducing new topic and utilising a variety of digital tools and resources, compiling all directions for involvement in the LMS. This combination of flipped-classroom approach with research-based learning, allowed more contact time to be spent on in-depth analysis, collaborative and practical work resulting in high fluidity across learning environments, and learner-driven learning.

C. Course Structure

The course structure (see Fig. 1) was devised as a progression from concept introduction, then to research and case-study analysis to immersive learning experience and solution analysis, and all the way to mapping out immersive learning experience instructional design and experimenting with content creation platforms.
A qualitative analysis focusing on the students' experience during both course years – 2021, 2022 was undertaken. For the purposes of this study a total of 125 anonymous student reflections were analysed using content analysis method to summarise recurring and highlight unique topical issues stated in student responses. Data collection in 2021 (course taught during the lockdown) consisted of two student survey exercises: 1) an anonymous monthly survey completed by students after each month (total of 4 months) of the course implementation (36 reflections); and 2) a comprehensive survey of each student participating in the course about the experience, course implementation, impact and professional benefits of the taught course. Data collection in 2022 (course taught in person / hybrid) also consisted of two student survey exercises: 1) a comprehensive survey completed by all (16) students at the beginning of the course, 2) an anonymous monthly survey of each student participating in the course about the experience, course implementation, impact and professional benefits of the taught course (64 reflections).

The anonymous monthly survey was structured in blocks aimed at gathering reflections about student experience and ranged from: the content, structure and overall coherence of the programme, resources, infrastructure, the learning process (approaches, implementation) and educator performance. While, the comprehensive survey consisted of ten questions: 1) Name/Surname; 2) Gender and age; 3) Previously acquired education (qualifications, degree and sector) and experience: industry, duration. (e.g.: secondary education, 5 years); 4) Do you have any previous experience with immersive technologies (AR, VR, MR)?; 5) Do you have previous experience with immersive technologies in education?; 6) How do you generally assess the usefulness and relevance of the course for today's labour market and educational developments? (1 – Not useful up to 5 – very useful); 7) How do you evaluate the overall course structure? Would you recommend any changes? If yes, please write your recommendations.; 8) What are the main benefits of the expertise developed within the course in your professional growth? Please give specific examples, projects, skills, success/achievement; 9) What is your opinion about this course being / potentially being taught entirely remotely?; 10) What are your main findings from this course, which you had applied to your professional activities, please describe?

The sample consisted of 25 students aged 22-45, male (N4), female (N14). Although 11 students had stated prior experience with XR technologies, only two had experience for more than one year. Also, when asked about experience with XR applications for learning only one student from the entire sample had experience for more than 3 years, while 24 students confirmed to either had only used XR for entertainment (9) or a solid “No” (15). A prior degree in education was not a compulsory admission criterion, thus students came from a variety of professional backgrounds: communications and art, entrepreneurship, computer sciences, history, design, languages, music, philosophy, and education. 18 of the students already worked in the field of education – either an education institution or a company providing educational solutions.

### III. METHODOLOGY

This inquiry presents findings based on the learners’ perspectives by analysing the gathered feedback during both course years 2021/2022 and cross-analysing it with the scientific literature.

#### A. Findings from the Anonymous Surveys

Findings from the anonymous surveys are structured in four categories: instructional approach (see Table 1); resources and infrastructure (see Table 2); hands-on experience (see Table 3) and impact of the course (see Table 4).

1) Student feedback on instructional approach chosen for the course emphasised the importance of building a strong theoretical foundation before practical work, also the chosen flipped-classroom approach was viewed differently by students (at the beginning of the course).

<table>
<thead>
<tr>
<th>TABLE 1. ANONYMOUS STUDENT REFLECTIONS – INSTRUCTIONAL APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Great importance is given to reading the scientific literature in order to develop a fundamental understanding of terms, pedagogical theories and the importance of the use of technology in education. During independent studies we read and obtain information, then discuss our findings with the lecturer and the group in lectures.</td>
</tr>
<tr>
<td>2. The lecturer places great emphasis on reading and analysing scientific literature, offering articles and books by various authors, as well as inviting you to search and create your own literature.</td>
</tr>
<tr>
<td>3. Currently, a great deal of emphasis is placed on developing a basic understanding of terms, pedagogical theories and the importance of the use of technology in education.</td>
</tr>
<tr>
<td>4. During independent studies we read and obtain information, discuss with the lecturer in online classes and solve practical work. The flipped-classroom approach is very good, as much more can be learned and a deeper understanding of the topic is formed.</td>
</tr>
<tr>
<td>5. I believe if we hadn't utilised the flipped-classroom approach, we would have mastered the topics sooner.</td>
</tr>
</tbody>
</table>
2) Resources and infrastructure: feedback in this category mostly overlapped highlighting two main comments:

<table>
<thead>
<tr>
<th>TABLE II. ANONYMOUS STUDENT REFLECTIONS – CATEGORY RESOURCES AND INFRASTRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The technical base of teaching materials is diverse, well-thought-through, corresponds to the relevant topic.</td>
</tr>
<tr>
<td>2. Informative and methodological resource base is at a high level. The materials and practical works of the lectures are very well prepared and during the lectures, the lecturer perfectly complements them with in-depth analysis, which makes the material easier to understand and understand.</td>
</tr>
<tr>
<td>3. Hands-on experience: students highlighted several aspects, such as synergy between theory and practice as well as case-study exploration and participation and networking at the conference.</td>
</tr>
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<table>
<thead>
<tr>
<th>TABLE III. ANONYMOUS STUDENT REFLECTIONS – HANDS-ON EXPERIENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Practical exercises are based on the theoretical basis previously studied in independent studies.</td>
</tr>
<tr>
<td>2. In April there was more diversity in the content of the course. We welcomed a guest lecture from an expert/entrepreneur in the field of XR. Each student presented their research on VR and learned about interesting learning solutions from course members.</td>
</tr>
<tr>
<td>3. It is valuable to get a personal account of the best-practice examples in the technology sector.</td>
</tr>
<tr>
<td>4. Students are involved in the study process. There is an opportunity to express your opinion, facilitate discussions. Guidelines for the writing a scientific article are provided.</td>
</tr>
<tr>
<td>5. In April we worked more practically in this course, testing out different virtual reality learning experiences for use in education, evaluating and analysing them. Also, the visit of the guest lecturer on the development of the trauma simulator was interesting and valuable. To practically test and analyse different XR learning experiences is a necessary process, because only by practical application is it possible to gain a deeper understanding of the essence of XR potential and applications.</td>
</tr>
<tr>
<td>6. In May we attended an immersive learning conference together and started discussing the topic of our final assignment and possible solutions.</td>
</tr>
</tbody>
</table>

4) Reflection on impact of the course: student feedback in this category was overlapping and highlighted two main comments, however also sparse, as it was potentially too early (during the final weeks of the course) to be able to evaluate its impact. Thus, these remarks mirror student experience and understanding of the potential impact rather than the actual impact the course had on their professional lives. In order to gain a better understanding of the overall impact the course had on students’ professional lives, comprehensive surveys were carried out upon completion of the course.

<table>
<thead>
<tr>
<th>TABLE IV. ANONYMOUS STUDENT REFLECTIONS – CATEGORY IMPACT OF THE COURSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. An interesting and very valuable course, during which we studied the theoretical foundations, discussed and explored through practice the various possibilities afforded by immersive technology.</td>
</tr>
<tr>
<td>2. The practical exercises completed during the course helped to understand how complex and multifaceted the process of designing an immersive learning experience truly is.</td>
</tr>
</tbody>
</table>

B. Findings from the Comprehensive Survey

Findings from the comprehensive student survey are structured in two main categories: 1) overall course structure, 2) main personal and professional benefits from the course.

1) Overall course structure from student perspective: students noted that this course was useful and relevant for today's labour market and educational developments. Students in general considered the course structure to be good, where the level of expertise and knowledge gained depended on individual work. This course gives an idea of how immersive technologies are being used in the education sector, as well as ideas on how they could be used in their practical activities in the learning process. The recommendation would be to more clearly define the achievable outcome in each lecture. Understanding the benefits of XR applications and potential in education was strengthened including how learning experience can be applied in different areas of education, such as maths, languages, art, sport, computing, robotics and social sciences. However, a common challenge is still scarce availability of immersive technology in education institutions.

2) Main personal and professional benefits from the course: according to the surveyed students, several benefits of the course have been highlighted such as: opportunity to learn technical aspects of immersive technologies and main pedagogical strategies of implementing learning in VR and AR, as well as the opportunity to analyse and discuss the immersive technologies in the context of education, preparation and presentation of scientific publications, understanding of learning theories in the context of immersive technologies, analysis of XR learning experiences and motivation to link professional activity to XR in the future. Students acknowledge that they gained a deeper understanding of XR’s role in the learning process after finishing the course. Students also reported that they have shared knowledge about the potential and innovative solutions of XR technology in the particular fields they are working in at the moment, for instance art and culture. Based on this student survey, the course developers succeeded in achieving the main goals. Students emphasised the understanding of pedagogy theories, which describe virtual reality as a mode of learning and gained theoretical and practical skills in analysing and developing XR educational experiences in different sectors and how to use XR in the learning process.
V. CONCLUSIONS

Findings were cross-analysed with the evidence from current research in the fields of technology-enhanced learning and immersive learning in order to formulate conclusions for future cross-disciplinary application.

Between 2020 and 2022, the COVID-19 pandemic has challenged and redefined learning practices across all levels of education throughout the world [7]. As the analysis of this case study confirms, courses that already practise self-blend and enriched virtual models of learning, have the advantages of transitioning to either remote or in-person learning smoother or almost unnoticeable. The comparison of remote and hybrid approaches in 2021 and 2022 allowed to gain a deeper understanding of the importance both core axis – theory and practice have in the success of such course implementation. Whilst, the theoretical and academic competency can be successfully developed via remote approach. As stated in the students’ responses: “this course can serve as a good example that it is possible to study technology application remotely, because the emphasis was made on different learning theories and XR technology affordances. Augmented and virtual reality applications were used to test and analyse learning experiences.” Majority of the students stated that practical examples are exciting and helpful, as well as help linking course content to the specifics of the education system framework. Moreover, the hybrid approach in 2022 have emphasised the importance of practical experience and devoted time to testing and experimentation was highly valued by students. As stated in the students’ responses: “the ability to engage in hands-on XR technology application exploration without limitations has been highly beneficial. Evidently, the lack of limitless access to technology is not a barrier in understanding them, however the practical experience and possibility to use them is a crucial next step.”

Potential implications for a programme that includes a similar course focusing on immersive technology applications for learning purposes: the persisting gap in terminology across fields of immersive technology, education, instructional design and technology facilitated learning [4] has proven to be a challenge for students coming from different professional backgrounds and thus deserves more attention in future research and education programmes. Additionally, it requires more rigorous monitoring and planning from educator’s side. As in comparison to the remote approach (excluding the practical experience), the hybrid approach highlighted challenges for the educator to closely monitor the pace that students progressed in both parallels – theory and practical skills, especially for a group with diverse prior background. Nevertheless, this approach led to students being highly motivated to learn new skills and experiment, whilst the remote approach provided more structured research-based learning – resulting in better theory acquisition, analytic and academic writing skills.

Both approaches implemented in 2022 and 2021 have shown that creative innovation, permitted by the fluidity of formats and expression of ideas, was pivotal for student engagement and quality results. Thus, the main piece of knowledge that this case analysis has delivered for future education science teaching and course design strategies is that XR technology infrastructure, although highly significant in its efforts to employ and, moreover, teach about its applications, can be temporarily substituted by accessible cloud-based learning solutions and a dynamic instructional strategy. However, the knowledge about the correct pedagogy and instructional strategies cannot, and should not, be substituted or forgotten so as not to fall into the technology-fascination effect trap [8]. The emphasis on instructional design and instructional strategy rather than a clearly pre-defined pedagogic theory approach suggests that educators should be seen as creators and developers of learning strategies, plans and materials. Learning in XR is informed by a fusion of principles from multiple pedagogical perspectives and is best characterised by the fluidity of learning strategies in terms of learning experience design [9]. It is very important to ensure pedagogically correct application and the integration of technology to achieve the set learning objectives.

The urgent need for various remote and blended learning environments, technology has enabled educators to notably, if not completely, transform the learning process and, in fact, to redefine the role of technology by increasing from a support tool to asserting itself in the central role as a method of learning environment and experience delivery [9]. This evolution has affected learning content creation itself, as there has been an increasing need for experts in education technology solutions, instructional designers and educators who are able to traverse the technology enhanced learning terrain to deliver effective learning solutions and experience. Looking at the soaring labour market demand for such experts world-wide, including the recent surge in remote positions, it has become clear that this situation is not unique to either one field, country or continent.

REFERENCES

Learning Spatial Skills Collaboratively in Immersive Virtual Environments: A Systematic Review

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Abstract—In this paper we explore the intersection of three domains: immersive virtual reality (VR), collaborative problem solving, and the development of spatial skills. We conducted a narrative review of literature between 2011 and 2021 looking for articles that included keywords associated with spatial skills, collaboration, and immersive virtual reality in 7 well known databases. Searches resulted in a thorough review of 21 articles. These articles included examples of virtual, physical, and applied spatial, collaborative tasks. Most of the tasks in the research were performance tasks that involved spatial skills of object location and spatial navigation by locating objects in a virtual world. Results of these studies also suggest specific design features that can benefit collaboration among users when engaging in spatial tasks. This study contributes to the literature by synthesizing research on collaboration and spatial skills in virtual reality and distilling suggestions for designers of VR experiences.

Index Terms—spatial skills, collaborative learning, virtual reality, problem solving

I. INTRODUCTION

The technology for immersive virtual reality (VR) has become more affordable and accessible to a wider audience, making VR a feasible tool for educators at all levels. Research has identified two domains where VR can be a useful learning tool: learning spatial skills [1] and in learning collaborative problem solving (CPS) [2]. Spatial skills include a range of cognitive capabilities that individuals use to interact with the environment and objects within that environment, and include mental rotation, object location, spatial orientation, and spatial navigation [1]. Higher levels of spatial skills are associated with achievement in mathematics [3], [4], and success in science, technology, engineering and mathematics (STEM) careers [5]. Furthermore, spatial skills are important for navigating in everyday life [6]. VR is uniquely suited for both developing and measuring spatial skills [1]. The stereoscopic viewpoint in VR prompts users to experience spatial presence, which is the psychological feeling of being present in the virtual world [7]. However, the same rich and immersive virtual environments that can spark spatial understanding can cause extraneous cognitive load [8]. Studies suggest that collaboration between two partners can help mitigate cognitive load through spatially focused dialogue between the partners [9]. Furthermore, CPS are extremely valuable for individuals to learn and refine. We hypothesize that designing collaborative experiences in VR could enable players to develop spatial skills and apply them to specific contexts while simultaneously developing CPS. Prior reviews have noted the usefulness of VR in developing spatial skills [1] and of collaboration in VR [10], but no review has incorporated both spatial skills and collaboration in VR. In this paper, we describe a systematic review of the literature on how spatial skills and collaboration have been developed in VR experiences.

II. RESEARCH QUESTIONS

The following four research questions guide this inquiry:

- What is the current research around collaborative problem solving and spatial skill learning in immersive virtual reality?
- What types of activities are used in these studies to develop or demonstrate spatial skills?
- What types of collaborative activities are included in these studies?
- What are the design implications based on existing studies on VR, spatial skills, and collaboration?

III. METHOD

Virtual reality refers to the “simulation of a real or imagined environment that can be experienced visually in the three dimensions of width, height, and depth and that may additionally provide an interactive experience visually in full real time motion with sound and possibly with tactile and other forms of feedback” [11, pp.53]. Spatial skills are the cognitive skills that individuals use in perception of and interactions with objects within a three-dimensional space [12]. CPS are defined as “the capacity for an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling knowledge, skills, and efforts to reach that solution” [13, pp.13].

In this narrative review, we searched the following databases: Academic Search Complete, Web of Science, Science Direct, Scopus, PubMed and ERIC. We used the following keywords: “Virtual reality” OR “head mounted display” OR “CAVE” OR “immersive*” OR “interactive*” AND (“collaboration” OR “collaborative*” OR “cooperative*” OR

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“team*” OR “group*”) AND (“Spatial*”). We selected these databases because they provide a wide range of literature, which allows for a comprehensive view of the research across multiple fields. We included original studies published between August 2011 and 2021 that were written in English and that incorporated VR, spatial skills, and CPS. We excluded literature reviews, conference abstracts (though full conference papers are included when particularly relevant), chapters and books, theses, and other gray literature. This initial search identified 1,509 records. After duplicates, book chapters, review articles and editorials were excluded, 665 articles remained. The records for these articles were screened by two raters, resulting in 192 eligible articles. Three raters reviewed abstracts for those articles, and excluded 171 studies for a final article set of 21. Each of these articles was read and outlined by one of three researchers, and a second researcher reviewed the notes and article side by side.

IV. RESULTS

Research Question 1: What is the current research around collaborative problem solving and spatial skill learning in immersive virtual reality?

We found three types of studies that examined spatial skills and collaborative problem solving skills: studies that examined spatially-oriented applications of VR, studies that examined virtual factors to support collaborative activities, and studies that examined physical attributes to support collaborative activities. These three types of studies contributed to the virtual collaboration literature by either improving participants’ collaborative abilities or enhancing their spatial skills. Our entire set of studies is organized and summarized in Table I.

Research Question 2: What types of activities are used in these studies to develop or demonstrate spatial skills?

The perception of three dimensions in virtual reality makes VR an excellent environment for both developing and studying spatial skills [1]. Researchers have identified many different types of spatial skills [14]. We identified four types of spatial activities in this set of articles: locating objects in the virtual world, solving puzzles, navigating and wayfinding, and understanding spatial objects [14], [15].

A recent review of spatial skills and virtual reality identified four types of spatial skills: mental rotation, the ability to rotate objects and view them from different perspectives; spatial orientation, the ability to travel in a specific direction relative to a target; object location, the ability to remember where an object is located in three dimensional space; and spatial navigation, the ability to envision and follow a route between two locations [1], [11]. The types of activities, the spatial skills utilized in each type, and study references are included in Table II.

Eleven studies had participants locate objects within a virtual world, which can activate object location and spatial navigation skills. Studies that drew upon both object location and spatial navigation skills included navigating through a virtual mall to find specific objects [15], placing recycling bins on a virtual campus [16], reviewing information about

<table>
<thead>
<tr>
<th>References</th>
<th>Summary of Results</th>
</tr>
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<tbody>
<tr>
<td>[30]</td>
<td>The virtual city Urban Rama allows users to navigate to points of interest without changing perspectives.</td>
</tr>
<tr>
<td>[32]</td>
<td>Participants learned organic chemistry better by building organic molecules in a virtual environment.</td>
</tr>
<tr>
<td>[29]</td>
<td>Integrating a pointer into a real-time video produced a better sense of connection in remote collaboration than an annotated snapshot.</td>
</tr>
<tr>
<td>[15]</td>
<td>The results exhibited difference in navigation behavior and spatial memory caused by three user behavior patterns: cooperative (COO), competitive (COM) and single (SIN) in the HMD VR environment.</td>
</tr>
<tr>
<td>[22]</td>
<td>Immersive VR is effective in teaching the consequences of climate change (e.g. ocean acidification).</td>
</tr>
<tr>
<td>[33]</td>
<td>The use of modern interactive systems DG@VR (Descriptive Geometry at Virtual Reality) in the teaching process contributes to the virtualization and development of students’ spatial visualization abilities in geometry.</td>
</tr>
<tr>
<td>[17]</td>
<td>3D and VR groups had better overall spatial memory development than the 2D group, and there was a general positive correlation between visual attention and their spatial memory development.</td>
</tr>
</tbody>
</table>

TABLE I. SUMMARY OF RESULTS

<table>
<thead>
<tr>
<th>References</th>
<th>Summary of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>[19]</td>
<td>Making avatars “show through” helps maintain a socially convenient distance between avatars and requires less movement than if these techniques were not applied.</td>
</tr>
<tr>
<td>[24]</td>
<td>The addition of a visual landmark has a positive impact on collaboration on male users, in particular for action descriptions when constructing a common frame of reference.</td>
</tr>
<tr>
<td>[28]</td>
<td>The use of point-cloud avatars that have high movement fidelity lowers error rates and task completion when compared to avatars with high visual fidelity.</td>
</tr>
<tr>
<td>[25]</td>
<td>When comparing no cues, annotation on a snapshot, and a pointer, pointers appear to be the most favored strategy for communication between collaborators.</td>
</tr>
<tr>
<td>[20]</td>
<td>When collaborating in a virtual task, collaborators will apply the rule of least collaborative effort; they may increase their own cognitive load to decrease their partner’s mental effort.</td>
</tr>
<tr>
<td>[16]</td>
<td>Higher levels of immersiveness had higher scores of presence when engaging in the activity of placing recycling bins on a virtual campus.</td>
</tr>
<tr>
<td>[26]</td>
<td>Collaboration times were significantly longer when participants stood at different locations and collaboration times increased with greater perceived depth discrepancy between the two viewing locations.</td>
</tr>
<tr>
<td>[21]</td>
<td>Fixed landmarks and lateralized landmarks positively influence how male operators collaborate, but have no effect on female operators.</td>
</tr>
<tr>
<td>[31]</td>
<td>The adjustment conditions led to significant improvements in joint two-user travel, which is evidenced by more efficient travel sequences and lower task loads imposed on the navigator and the passenger.</td>
</tr>
<tr>
<td>[27]</td>
<td>Visiospatial puzzle solving tasks in virtual reality can be used to evaluate the effectiveness of pair performance.</td>
</tr>
<tr>
<td>[18]</td>
<td>Spatial auditory cues help users find objects and participants preferred having visual cues (hands and head), and felt a better spatial awareness and social experience.</td>
</tr>
<tr>
<td>[34]</td>
<td>Results indicated significantly higher learning gains after using a CAVE to collaboratively explore the brain compared to a textbook condition.</td>
</tr>
<tr>
<td>[23]</td>
<td>The tangible user interface is the more effective than a physical tabletop space (coisTable) in collaboration.</td>
</tr>
</tbody>
</table>
a building and then visiting the actual building to identify differences placed by the researchers [17], and having an expert guide a user through a virtual office to find hidden LEGO[T](18). Some studies focused on object location skills, where the participant was in a fixed position in the virtual environment. Activities included being asked to identify and recall virtual car engine parts [19] being asked to identify a particular water bottle either using different types of landmarks [20] or by having their partner rotate to see the water bottle [21], or being asked to count species of animals in a virtual ocean [22]. In Huang et al.'s study [23], five individuals collaborated on planning and constructing a building on a shared table with both physical and virtual attributes.

In four of the studies, participants solved puzzles, which can activate both mental rotation and object location spatial skills. Participants worked together to copy the structure of a set of yellow tetramino blocks using white tetramino blocks [24], to solve a tangram puzzle where one partner instructed the other on how to put together the pieces [25], to match an object to a test object by adjusting the depth of the object [26], and to solve spatial configuration puzzles built with three dimensional blocks [27]. In the study by Gamelin et al. [28] a player guided a partner to a specific location in the virtual world to select a virtual cube and then used gestures such as pointing to identify a three row pattern in a grid in another part of the world.

Participants drew upon both spatial orientation and spatial navigation skills by engaging in virtual navigation and way finding in three studies. In two studies participants explored a virtual city [29], [30]. For example, in Chen et al. [30], participants were virtually placed in a New York City neighborhood and asked to identify their location, then to navigate through the neighborhood and comment on their perceptions of density in the environment. In Weissker [31], participants had to coordinate a change in orientation after a short jump when starting side by side or one in front of the other.

In three studies, participants gained understanding of spatial objects and orientations. Participants learned organic chemistry by building organic molecules in a virtual environment [32], gained a better understanding of geometry through viewing geometric figures in VR [33], and learned neuroanatomy by exploring the structures and connections in a virtual brain [34].

Research Question 3: What types of collaborative activities are included in these studies?

To classify collaborative activities that were implemented in these papers, we employed McGrath's [35] task circumplex, which organizes tasks on a two-dimensional scale, one axis being conflict–cooperation and the other axis conceptual–behavioral. McGrath divided group tasks into eight tasks: planning tasks (e.g., generate plans), creativity tasks (e.g., generate ideas), intellective tasks (e.g., solve problems with correct answers), decision-making tasks (e.g., dealing with tasks without a single right answer), cognitive conflict tasks (e.g., resolving conflicts of viewpoint), mixed-motive tasks (e.g., resolving conflicts of interest), competitive tasks (e.g., competing for victory), performance tasks (e.g., physical tasks). We found five types of collaborative activities, and most of them were performance tasks. According to McGrath’s [35] group task circumplex, we listed the types of tasks and their positions in the circumplex, as well as study references in Table III.

TABLE III. TYPES OF COLLABORATIVE ACTIVITIES

<table>
<thead>
<tr>
<th>Types of Collaborative activities</th>
<th>Number of Studies</th>
<th>Positions in Circumplex</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Task</td>
<td>13</td>
<td>Moderate cooperation, highly conceptual</td>
<td>[15],[18]–[21], [24]–[30]</td>
</tr>
<tr>
<td>Creativity Task</td>
<td>3</td>
<td>High cooperation, moderately conceptual</td>
<td>[22],[32],[33]</td>
</tr>
<tr>
<td>Planning Task</td>
<td>2</td>
<td>High cooperation, moderately conceptual</td>
<td>[16],[17]</td>
</tr>
<tr>
<td>Decision-making Task</td>
<td>2</td>
<td>Moderate conflict, highly conceptual</td>
<td>[23],[31]</td>
</tr>
<tr>
<td>Intellective Task</td>
<td>1</td>
<td>Moderate cooperation, highly conceptual</td>
<td>[34]</td>
</tr>
</tbody>
</table>

Since communication in collaborative virtual environments lacks visual cues such as gaze and facial expressions, designers and programmers must include cues to establish a common frame of reference (COFOR) for successful collaboration. This set of studies included different assistive clues including spatial cues such as audio and visual cues, landmarks and avatars, various perspective-taking techniques, and interventions within the physical environment.

When navigating and finding specific targets in virtual environments Yang et al.[18] and Chen et al.[30] found that participants preferred having visual cues such as landmarks, building shapes, and named streets. Chellali et al.[24] found that the use of a visual landmark improved the ability for partners to communicate with each other because they were better able to describe their actions in the virtual environment. Kim, Lee, Sakata and Billinghurst [25] found that, when deciding between an annotation on a snapshot and a pointer, pointers integrated into a live video create a better sense of connectedness in remote collaboration. Gamelin [28] found that the use of point-cloud avatars can significantly

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TABLE II. TYPES OF SPATIAL ACTIVITIES

<table>
<thead>
<tr>
<th>Types of spatial activities</th>
<th>Number of Studies</th>
<th>Spatial Skill Utilized</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locating objects</td>
<td>11</td>
<td>object location, spatial navigation</td>
<td>[15],[23],[29]</td>
</tr>
<tr>
<td>Solving puzzles</td>
<td>4</td>
<td>mental rotation, object location</td>
<td>[24]–[27]</td>
</tr>
<tr>
<td>Navigation and orientation</td>
<td>3</td>
<td>spatial orientation, spatial navigation</td>
<td>[28],[30],[31]</td>
</tr>
<tr>
<td>Understanding spatial objects</td>
<td>3</td>
<td>mental rotation, object location</td>
<td>[32]–[34]</td>
</tr>
</tbody>
</table>
lower error rates and task completion times in immersive collaborative virtual environments compared to high-fidelity pre-constructed and animated virtual avatars. However, some studies also found unfavorable results of these spatial cues for certain groups of people or under some circumstances. Pouliquen-Lardy et al. [21] found that the relative position of the addressee to the target influenced the level of mental demand on the partner who was directing the addressee to the target. Markowitz [22] found that participants didn’t use the lateral cues on a stable lateral visual landmark, but instead used the point of view of the addressee to minimize the collaborative effort on a task, even if they increased their own mental effort.

Another obstacle in collaborative communication in virtual environments is the distortions in collaborative spatial judgments from different perspectives of participants. Pollock et al. [26] found that collaboration times were significantly longer when participants stood at different locations compared to when participants were collocated, and collaboration time was also increased with greater perceived depth discrepancy between the two viewing locations. Weissker et al. [31] found that joint-user travel and cognitive load could be improved by allowing users to adjust their spatial formation while jumping, a technique they call the Multi Ray Jumping Technique. Chen et al. [30] built an intuitive navigation interface called Urban Rama that allowed users to navigate to points of interest in a virtual city without changing perspectives.

In learning about brain structures in neuroanatomy, De Back et al. [34] found a significant effect in higher learning gains for the CAVE compared to the textbook condition, which they attributed to immersive, collaborative, and active learning. When engaging in a building inspection task, Shi et al. [17] found that 3D and VR groups had better overall spatial memory development than the 2D group during the task, and there was a general positive correlation between visual attention and their spatial memory development. Apart from group performance, Oprean et al. [16] also discovered that immersive capabilities improve feelings of presence in the remote locations and perceptions of being in the remote location increase feelings of team membership.

Research Question 4: What are the design implications based on existing studies on VR, spatial skills, and collaboration? We gathered the following recommendations for practitioners to consider in designing virtual reality environments for collaborative learning with spatial skills. The design recommendations are summarized in Table IV.

V. DISCUSSION

In this study, we found research in all three of our dimensions of interest: immersive virtual reality, collaboration, and spatial skill development (RQ1). The spatial activities fell into four categories: locating objects, solving puzzles, navigation and orientation, and understanding spatial objects (RQ2). We found that most of the collaborative activities were performance tasks, however, we also found studies that included creativity, planning, decision-making, and intellective tasks (RQ3). We distilled a set of recommendations based on this research (RQ4). Our final set of 21 articles included some educational applications and some laboratory studies; in the future we will focus on either educational applications or lab studies. Many of the lab experiments did not have an immediate connection to domain knowledge, however, still provided valuable information about features of the virtual world can support spatial collaboration are useful for moving forward. These studies also measured a variety of outcomes; having a suggested standardized set of measures for different types of spatial skills and also ways to measure collaborative skills will help future research efforts. Most of the studies we found used adult audiences, future research could also investigate additional age groups and educational contexts.

VI. CONCLUSION

This study found three types of studies that included both spatial skills and collaborative problem solving: applications of collaborative spatial skills, virtual tools in collaborative spatial skills, and physical tools in collaborative spatial skills. The fewest studies investigated physical tools in collaborative spatial skills. The largest number of studies used virtual tools in supporting collaborative spatial skills. The applications demonstrate a wide range of activities that have been developed and studied in VR, from developing mental rotation skills by examining virtual molecules or geometric models in VR to developing spatial navigation by exploring virtual buildings, cities, and even virtual human brains. There is room for future research and development of more applications of spatial skills in collaborative virtual activities. These studies also demonstrated a variety of collaborative tasks, with the most

<table>
<thead>
<tr>
<th>Virtual Features</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangible User Interfaces</td>
<td>Avoid blocking the screen areas; Enable off-screen operations and data sharing; Provide more types of tangible widgets. [23]</td>
</tr>
<tr>
<td>Point-cloud avatars</td>
<td>Design avatars with high motion fidelity; visual realism is less important [28]</td>
</tr>
<tr>
<td>Spatial auditory cues</td>
<td>Use spatial auditory cues to help with navigation, object search, and spatial awareness. Augmenting avatar hands with a head and shoulders improves social presence, spatial awareness, and system usability. [18]</td>
</tr>
<tr>
<td>Visual cues</td>
<td>Use pointers rather than annotation to communicate between partners. [25] Use players’ positions and shared knowledge of the virtual environment to generate exocentric visual cues. [20] Create visual landmarks that allow location of objects around them (lateralized), are fixed to avoid direction changing, are easy to identify and name, and are visible to all users. [24] Face the users towards the target in the virtual world to optimize remote communication. [21] Use landmarks, building shapes, and named streets to help users navigate and identify objects in virtual environments. [18] and [30]</td>
</tr>
<tr>
<td>Perspective-taking techniques</td>
<td>Use joint navigation for individual navigation for discussions, guided tours, presentation, and storytelling, use individual navigation when speed is required. [31]</td>
</tr>
</tbody>
</table>
common being moderately cooperative and highly behavioral performance tasks. Future design and research could explore ways of broadening the types of collaborative activities to include high cooperation and high conceptual tasks such as planning, decision-making, and even co-creating in virtual environments.

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Skill Systems as Expansion in Serious Games for Game-Based Learning

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Abstract—The ROP-Skill System - Model (Random Or Point – Skill System) is developed for higher education with Serious Games in universities. Through this game, we seek to excite students about opportunities in modeling relational databases and employing next-generation science standards so that the game can be tested in universities. We translate the model and implement the ROP-Skill System into a serious escape game for relational databases in Unity.

Index terms—serious games, game based learning, escape room, skill tree, skill system, higher education, Unity, ROP-Skill System - Model

I. INTRODUCTION

In the age of digitalization for higher education and the pandemic situation, Serious Games are used as interesting interactive exercises. In terms of knowledge, diversity, and group dynamics, digital games allow universities to introduce complex subjects in new formats tailored to provide motivation for different educational levels. But the development and extension of content in Serious Games takes time, money and staff. One possibility is the usage of a Skill System for lecturers to expand the content. A skill gives the player new properties in gameplay, such as magic and make the playing more interesting because of more solutions for one problem. The story of the game is unchanged, but the skills of the player are different and more powerful. In the educational context for serious games ROP-Skill System – Model is one of skill systems for education and use the Self-Determination Theory (SDT) components for different types of motivation. The skill system model based on a decision tree with two different strategies called „Random or Point“ to extend the learning content in a Serious Game. In this article we implement the skill system in a Serious Escape Game as a 3D Asset in Unity and discuss the theory, functionality, and benefits. The research goal of the work is to design a Skill System Asset to extend the content of the game in a short period of time and to evaluate the effectiveness of increasing students’ interests in databases. We plan to develop a prototype and investigate the influence on the motivation of heterogeneous groups of students with different previous knowledge.

II. EDUCATIONAL THEORY & METHODS

A. Educational Theory

The ROP-Skill System uses the Self-Determination Theory (SDT) which refers to the flow experience [2], [8], [14] and the Cognitive Evaluation Theory (CET) [5], [18]. The flow theory by Csikszentmihalyi [3] and the extension of Kiili et al. [8] with the playability shows the high potential of educational games. The flow experience can be defined as a complete state of engagement. One argument is that students with higher self-determined motivation are more rapid to reach the flow experience and to be deeply engaged in their task [9].

The Cognitive Evaluation Theory [11] is based on different types of motivation. “The concept of intrinsic motivation (IM) refers to behaviors performed out of interest and enjoyment. In contrast, extrinsic motivation (EM) pertains to behaviors carried out to attain contingent outcomes” [17].

The SDT categorized different types of motivations into three categories (Table I) [11]:

<table>
<thead>
<tr>
<th>Intrinsic Motivation</th>
<th>Extrinsic Motivation</th>
<th>Amotivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic regulation</td>
<td>Integrated regulation</td>
<td>Identified regulation</td>
</tr>
<tr>
<td>Identified regulation</td>
<td>Intergroup regulation</td>
<td>External regulation</td>
</tr>
<tr>
<td>Intergroup regulation</td>
<td>Non regulation</td>
<td></td>
</tr>
</tbody>
</table>

Table I: Self-Determination in a Context of Regulation Type and Autonomy [12]

In this context Ryan & Deci, found that “motivation concerns energy, direction, persistence and equifinality-all aspects of activation and intention” [13].

In education, the students need competence and connection with other people (e.g. peers, teachers) to feel self-determined. The control in the learning task and their activities within the task shows that the degree of autonomy corresponds with the students feeling in the classroom [10]. If autonomy is partly allowed for students, the students feel more competent, open-minded, and creative [7]. The result shows that students’ perceptions of autonomy can be influenced by the teacher with the ’autonomy supportive’. The SDT could be extended by the Academic Motivation Scale (AMS) [15], [16] and shows a relation between STD and academic achievement. In the AMS the ROP-Skill System show a very high level of autonomy. The concept of the model uses the self-determined motivation and a step by step learning in each skill [1].
B. Implementation

The implementation of the ROP Skill System used the linear water fall model of Winston W. Royce [22]. In this case the serious game is developed in Unity with C#, so the ROP-Skill System is implemented and tested in Unity too.

III. SQLLy

SQLity is a new Serious Escape Game, which is used as an interactive material for the elective courses “Data Knowledge Management” and “Introduction to Business Information Systems” since 2020. As a part of a new teaching concept, the Serious Game is based on the content of “Data Knowledge Management” with the focus on relational databases. The goal of our early game design was to answer the questions: how effective is the serious game to learning new soft skills for databases and what kind of benefits exist in indifference to other blended learning concepts if you work with heterogeneous groups of students. We implement three degrees of difficulty (modes): easy, normal, and hard.

In SQLity, the player takes on the role of Cosima, a new IT student at the university who was kidnapped by the hacker Hans after a party. Hans as the main antagonist is pursuing the goal of restructuring the whole world with the help of SQL. His goal is to find more followers and he tests suitable students with the help of escape rooms in an old hotel.

In 35 levels the player solves a series of Escape Room puzzles to find a way out of the hotel. In the end, Cosima meets Hans and after a fight, all technology is switched off. Hans flees and Cosima finally leaves the hotel.

IV. ROP-Skill System – Model

The ROP (Random Or Points) Skill System - model uses two different strategies for skilling and the principles of a decision tree [6].

A. Points Strategy

In the game, the player collects points with each solved task. All points are shown in the middle of the display and can be used to learn new skills (Fig. 2). In this context, the skill classes are adapted to the content of elective courses. Compared to other games, at the beginning of a new game the player usually chooses one character class from several e.g. magician, and can never change it during the same game. In this skill system, the player plays with all classes named skill classes at the same time and can set his abilities in all classes according to his own individual game strategy. The model is designed for a duration of one semester, and limited the available skill classes of the main topics from the teacher’s perspective to three. If the player collected enough points, the skilling in a corresponding skill class is possible. But the collectable points are limited and the player cannot skill all skill classes completely. So, the player has to decide the allocation of his limited points to the skills and he is motivated to try new strategies and play again.

B. Random Strategy

The “Random” skill mode is only activated automatically for certain events:

- The player completed a bonus level
- The player collects a special item or used it

The ROP-Skill system differentiate between game levels and bonus levels and activate or deactivate the random mode (Fig. 3). Each bonus level can be completed with each class of the corresponding level, because the bonus levels contain all elements of the corresponding classes. The other case is the special items. If a particular item belonging to a class is equipped or used, more points can be collected or the probability of a random skill increases.
If the random mode is activated, the sphere in the middle changes from points to random and the selection pointer rotates like a wheel of fortune, which can be started and stopped with enter. If the player press stop, the selection pointer stopped slowly in a random skill class [23]. If a skill class has been random selected, the system skill automatically a new skill in dependence of three degrees of difficulty (modes).

Mode 1 (Easy): The menu pointer rotates slowly till stop and a class is selected by the player’s strengths. So the system uses the skill tree of the class with the most skills and add a new one. If the class is empty, one of the trees at level 1 is randomly skilled.

Mode 2 (Normal): The menu pointer rotates with medium speed. After stop a class is selected and automatically skilled in a random skill tree.

Mode 3 (Hard): The menu pointer rotates quickly and a class is selected by the player weakens, i.e., only one skill point is added to the skill tree that has not been skilled before.

At the end of the random skill, the ball in the middle changes back from random to points. This also happens if a class is selected for the random skill that is already completed so that the random skill fails and the ball changes from random to points again.

V. ROP-SKILL SYSTEM AS A UNITY – FRAMEWORK FOR SERIOUS GAMES ABOUT DATABASES

After each level, the player has the opportunity to learn new skills through the ROP-Skill System before the new escape room level starts. Skills are helpful for the player to protect himself from enemies, to strengthen his own defenses or to heal himself.

A. Skill System Classes

For SQLity, the ROP – Skill System reduced main topics to three classes: trigger, recursive query, and stored procedure. Each class represents one main topics of the lecture of “Data Knowledge Management”. In each class the player could skill in defensive or offensive. The defensive option helps the player to protect or heal himself, with the offensive skills the player can use it to attack Hans or other enemies.

Skill class 1 (Recursive Query): The first skill class „Recursive Query“ skilled the snack machine. Snack machines are 3D in-game objects that store and identify items. If a player finds an unknown item, he uses the snack machine for automatic identification or storage, similar to a box. In addition, other items can be unlocked with a skill. If the player found a snack machine e.g. in the room of Level 2, he can use the skill to activate new health items, armor, or weapons. This is regulated by the opportunities defensive or offensive. The first defensive skill tree called „Hack & Health“ activate the higher healing items and the second skill tree „Hack & Steel“ activate different types of armor. The option offensive has only one skill tree called „Tools“, so the player can activate useful tools e.g. a flashlight, or a virus card for hacking monsters or the PC of Hans.

Skill class 2 (Stored Procedures): The class „Stored Procedures“ is a really powerful class and makes a lot of fun. The option defensive has two skill trees named „Day of Revenge“ and „Trickster“. "Day of Revenge", manipulate the ball sorting machine and the player can flood Hans' command center with balls by the ventilation shaft. The skill tree „Trickster“ has skills to hack the robots, e.g. they run away if the player is in the room or they think the player is one of them. The offensive option has only one skill tree called „Be my Tool!“. The abilities of this skill tree allow the player to use enemies as team members to attack other enemies.

Skill class 3 (Trigger): The class “Trigger” is the skill class which uses trigger platforms as traps. If an enemy walks over such a platform in the game, he can be changed, destroyed or sleep for minutes with the help of a skill. The option defensive has two skill trees named „Sneak“ and „Prick“. The first skill tree „Sneak“ manipulate the platform for Level 01 monsters and the „Prick“ – skill tree manipulated Level 02 monster. The offensive option stops the enemies or tricked them. The offensive skill tree called „Be my Tool!“ destroyed them or changed them to attack other enemies.

B. Data Format

As the first recommendation, the blueprint of the Serious Game “SQLity” have to include the considerations of all planned gaming implementations such as start menu, tablet menu or save game directory. This is necessary to minimize the redundancies in effort and resource allocation since SQLity components must be modular and scalable. To expand the serious game with the ROP-Skill System, a uniform exchange format was necessary to save the game status and skills. It was also important that the data format was suitable for AR- and VR-Prototypes, because our used Game Engine Unity allows both and the skill system should be also used in other games and prototypes. In summary, the data exchange format must be the following requirements: platform independent, extendable for all SQLity modules, extendable for AR- and VR-modelling approaches, humanoid centric, good performance and low overhead. Naturally, the platform independence, the security and expandability of XML was the major reasons for the selection. XML was originally designed for different domains with the XML schema technology and can distinguish between different skill classes and save game directory [21], [20].

C. ROP-Skill System in Unity

Fig. 4 shows the ROP-Skill System as a 3D model in Unity after the implementation. In this example the player collects four points for the class “Trigger”.

Fig. 3. ROP-Skill System – Model in “Random-Modes” [23].
In “Trigger” are the two options defensive and offensive for the player usable as buttons. If the player chooses defensive, the information of the skill trees “Sneak” and “Prick” appear (Fig. 5). All texts could be changed by the lecturer.

In this example “Sneak” is chosen (Fig. 6) and the player can skill Level 01 with five points, but the collected points are not enough.

If the player has five points and skill Level 01 of Sneak, the new skill is marked in a bright green and the number of points is reduced. If the Random-Strategy is activated, the ball in the middle switch from “Points” to “Random”. The player can start the skill mode with the “Start” - button (Fig. 7).

The pointer rotate like a wheel of fortune and the player can stop it with the “Stop” – button or Enter (Fig. 8). After the automatically skilling, the sphere rotates back to points. The collected points are not reduced, and the current number of points is displayed.

VI. STUDY

This is a comparative study that evaluates the user satisfaction and motivation. The study aims to recruit approximately 120 participants to secure statistically valid results and our participants will be split in two groups each using the prototype: Group A: Students with the master’s degree (20) and Group B: Students with the bachelor’s degree (100)

The planned study is preceded by follows the interaction of the students with the prototype ROP-Skill System which is implemented in SQLity. The questionnaire is completely anonymous. The author used Moodle to share the survey link to each class and used Lime survey as survey software. Statistical analysis focused on the descriptive analysis [16], because of the small first class, which represents the group, who are currently pursuing their master’s degree. The findings of both classes from bachelor and master students were compared and consensus reached on the main themes present in the data.

VII. RESULTS

The current version of “SQLity” with the ROP-Skill System has been pre-tested for quality assurance in January 2022 in a block seminar with a small group of students. The group had 10
male and 4 female students. On a Likert scale of 6 (Strongly Disagree) to 1 (Strongly Agree) for motivation to visit the block seminar again, the students' average was 2.00, the recommendation of SQLity with the ROP-Skill System for other students was 1.85, and the skill to solve SQL-Problems was 2.38. The same Likert scale was used for the other parameters like game performance 1.79, usability of the menu 1.71, and task logic 1.79. We typically have a large number of individual students visiting our university but due to shutting down and/or dramatically reducing campus density, this has not been an option. Now, in person UX testing with appropriate social distancing measures is possible and we think that the pandemic numbers will decrease in summer like the last year. Our study has been started and will finish in May 2022.

VIII. CONCLUSION AND FUTURE WORK

The ROP-Skill System was designed for the lecturers in universities to optimize Serious Escape Games and recap the content of one semester in a few sessions. The using of two different methods for skilling makes the game more difficult, but also interesting and the modes of difficulty change the skill system to create new challenges. In the educational context, the ROP-Skill System shows significant advantages to expand the content of Serious Games and represents a particularly promising field of research and development. We suggest the implementation with XML as the data storage and transport file format and a separate camera. After our implementation and the pretesting with good results, we start the main study to evaluate the ROP-Skill System.

ACKNOWLEDGMENT

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Synchronous Multi-User Cross-Platform Virtual Reality for School Teachers

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Abstract—Motivated by a desire to apply Computer Science and Virtual Reality (VR) technology due to the need for improving secondary school education in Malawi, this paper presents a prototype of a synchronous multi-user cross-platform real-time 3D VR application. This tool can be used by VR application developers in assessing the feasibility of using VR technologies for secondary school teaching in Malawi. The prototype VR application illustrates the capabilities of the proposed development tools, as well as how the proposed technologies can be utilized in a design and implementation that accounts for the context of Malawi, where access to electricity and internet services are a challenge for many.

Index terms—virtual reality, education, technology

I. INTRODUCTION

A variety of domains and fields are aided by Computer Science and its associated technologies, in order to develop [1], and technology has had influences in significant development in the education sector [2]. As a result, this paper discusses a study in which a prototype VR application for education was developed in relation to the need for improving secondary school education in Malawi by applying VR technology.

II. RESEARCH PROBLEM AND SIGNIFICANCE

In the Malawi Growth and Development Strategy (MGDS) III document, the Malawi Government [3] stated that one of its desired outcomes in relation to development is “improved quality of secondary school education” [3]. Considering the benefits of VR in education, such as increased student motivation [4], the use of real-time interactive 3D environments simulated using VR technology, as a tool for teaching, can be considered as a possible solution to enhancing the secondary school curriculum in Malawi. However, documented evidence regarding the use of real-time interactive 3D environments simulated using VR technologies for education in Malawi was not found. In the field of Software Engineering, a feasibility study is an activity which is carried out to determine if it is feasible to utilise and/or develop a particular system [5]. Therefore, considering the apparent lack of information relating to any tools and VR technologies that can be used to assist VR application developers in carrying out a feasibility study relating to real-time 3D and VR technologies within the context of Malawi, this paper proposes tools and VR technologies that can be developed and utilised to aid VR application developers in the process of assessing the feasibility of employing real-time interactive 3D environments simulated using VR technologies, for secondary school teaching within the context of Malawi.

This paper adds onto the knowledge base of research focusing on VR in education by discussing the potential benefits of utilizing multiple VR devices and platforms in education because the VR application discussed in this paper consists of cross-platform utilization of VR devices, thereby contrasting how a lot of research into VR in education often compares different VR platforms and devices with the aim of recommending a suitable platform as opposed to highlighting how different VR platforms can complement each other.

III. RELATED WORK

VR is considered to have the potential to significantly change teaching and learning [6]. VR can be defined in several ways [7], such as the simulation of an environment or the simulation of an experience [7], [8]. According to Makransky and Lilleholt [7], VR platforms can be categorized as “Cave Automatic Virtual Environment (CAVE), Head Mounted Displays (HMD) and desktop VR” [7]. CAVE VR platforms consist of images projected onto multiple screens setup to surround the user [9], [10]; HMD VR platforms are comprised of a wearable device or headset, in which images are projected onto displays situated in front of the user’s eyes [11], and desktop VR platforms provide a VR experience through a traditional computing device such as a desktop computer or a laptop [12], using a standard display device such as a computer monitor [8], [11], [12].

Some benefits of applying VR to education are increased student motivation [4], [13]; and the possibility of experiential learning [14], [15]. Southgate, et al. [16] utilized the Oculus Rift HMD VR device, which high school students used to collaborate in a multi-user three-dimensional environment via a computer game titled Minecraft [16]. Southgate, et al. identified a number of challenges regarding the use of VR within this context [16]. For instance, Southgate, et al. [16] noted that due to the hardware used, the activity could not be conducted in the classroom and a separate room was needed. Another challenge was access to Wi-Fi internet, with Southgate, et al. [16] noting that the computer game used needed a connection to the internet for the multi-user functionality. Mas, et al. [17] developed a collaborative VR application called Indy for industrial training purposes [17]. This
V. Methodology

The study discussed in this paper adopts a case study approach, which consists of investigating a circumstance which has very little known about within a specific context [23]. In this case the circumstance is the utilisation of VR technologies within the context of secondary school teaching in Malawi. This study also employs methods from Software Engineering, a discipline in computing with a focus on “software production” [5]; Human Computer Interaction (HCI), which has a “focus on the design and usability of computing systems” [24]; and Interaction Design, which focuses on “designing interactive products” [24] with the aim of aiding “how people communicate and interact” [24] as they go about their daily and professional lives [24].

A. Data Collection

When designing an “interactive product” [24], it is crucial to account for how, where and by whom the product will be used [24]. Teachers are well placed to provide significant insights into the applications of technology to education [25], however, they are rarely involved in the design process of learning based software [25]. Therefore, involving teachers in the development process of software designed for educational purposes is important [25]. The study discussed in this paper proposes that VR application developers take a “user centered design” [24] approach, where intended users are involved in the development and design of the interactive product [24]. Working with the school educators in Malawi during a feasibility study underscores the importance of involving teachers in the design and development of software for educational purposes [25]. Gaining good knowledge and understanding of potential users within the context in which they belong to and operate in, can result in effective user experiences for “interactive products” [24]. VR application developers can utilise questionnaires as a tool to gain insight into the use of VR technology by secondary school educators in Malawi. Questionnaires can be used to collect data in relation to perceptions and views that research participants have in relation to the subject matter [24]. A questionnaire was developed as part of the study discussed in this paper, which was designed to be used to assess the extent of knowledge: experience; and interest in digital and VR technologies amongst secondary school educators in Malawi.

Considering that the study discussed in this paper was carried out in England during the COVID-19 pandemic, travel to Malawi was a challenge. Therefore, the questionnaire was designed to be administered remotely. The questionnaire was intended to be administered as a Microsoft Word document, enabling participants to complete it offline. This is a similar approach to the one taken by Gondwe [26], who had initially administered an online questionnaire via Google Forms to student teacher trainees in Malawi. However, at the request of the research participants, Gondwe had to then administer the questionnaire as a Microsoft Word document via WhatsApp, for offline completion due to concerns from the research participants regarding the cost of internet services [26].

A trial run to identify any potential problems with questionnaire, as well as to assess the potential viability of the chosen approach, before it was to be applied for primary data collection in Malawi, was initiated with school educators from England as research participants, which included teacher trainees; university lecturers involved in teaching teacher trainees/students; and secondary school teachers. To take part, individuals must initiate contact with the researcher, upon coming across a request for research participants, which was disseminated through various departments and individuals within the University of Hull in England. This effectively consisted of elements of convenience sampling and snowball sampling approaches [27].

B. The Prototype VR Application

In Software Engineering terms, a prototype is “an initial version of a software system” [5], which can be used to investigate a problem and potential solutions to that problem [5]. In Software Engineering, requirements are informed by the needs of the intended users of a system [5], and requirements engineering is a process in which the aim is to develop and maintain a “system requirements document” [5], of which a feasibility study is the initial process of requirements engineering [5]. To adequately involve secondary school educators in the development process of VR applications for use in Malawi, the study discussed in this paper proposes the development and use of VR application prototypes as a tool for the communication of ideas between VR application developers and the secondary school educators when carrying out a
feasibility study in Malawi. Prototypes can also be used to assess the “technical feasibility of a suggested design and its production” [24]. Therefore, regarding VR technologies and systems, of which there is seemingly no evidence relating to usage in school education in Malawi, a prototype would be useful for carrying a feasibility study.

Off the shelf software applications can be used for VR in education, just as the Minecraft game was used by Southgate, et al. [16]. However, the study discussed in this paper proposes that VR application developers develop prototypes for use specifically in carrying out a feasibility study in Malawi, to account for and showcase how the proposed VR technologies could potentially be used within the context of Malawi. Pankomera and Van Greunen [20] note that the application of ICT in a developing nation like Malawi should take into account the context of the specific country as opposed to simply replicating approaches that might have been taken in a more developed country [20]. Sharp, et al. [24] also note that accounting for context, including issues such as “cultural differences” [24] is important when designing interactive products, since what might have been proven to work for a particular group may not be suitable for a different group [24]. Accessibility and inclusion also need to be considered, where in relation to interactive systems, accessibility consists of ensuring that the “product is accessible by as many people as possible” [24], and inclusiveness refers to “being fair, open, and equal to everyone” [24]. Considering that the most widely used language in Malawi is Chichewa [28], [29]; although the dominant language of instruction in education in Malawi is English [28], the issue of language localization would also need to be considered in relation to accessibility and inclusion, more so because Chichewa is a taught subject in secondary schools in Malawi [21].

The prototype VR application presented in this paper was developed to illustrate a prototype which accounts for the challenges faced in Malawi in relation to the use of Information and Communication Technologies. This study identified key requirements of the prototype from some of these challenges in relation to the context of Malawi as follows:

- It should showcase a design and implementation that does not rely on electricity from the national electricity grid in Malawi.
- It should showcase a design and implementation which considers usage in a classroom environment in the context of Malawi.
- It should showcase a design which does not rely on the internet for network connectivity for multi-user collaborative experiences.
- It should utilise cost-effective tools and technologies.
- It should showcase the potential for developing accessible and inclusive features.

The Unreal Engine 4 game engine was used to develop the prototype VR application, because it provides a project template known as the Collab Viewer [30], which provides implementation for functionality that enables multiple users to interact within the same 3D environment via a network, using desktop VR and HMD VR devices [30]. This prototype was built on top of this template to accelerating the development process. In addition, the Unreal Engine is free to use for non-commercial products and provides access to all of the source code [31], making it ideal for prototyping.

The prototype application was designed and developed to support HMD devices, exemplified by utilising the Oculus Quest, a standalone HMD device which does not need to be connected to any other device to be used [32], as shown in Fig. 1. Desktop VR devices are also supported, exemplified by utilising Windows computers as shown in Fig. 2, and Android mobile devices as shown in Fig. 3. Supporting different devices opens up the possibility of enabling users who might otherwise have challenges using a specific device, to still use the application with alternate devices [24]. Therefore, the design and implementation presented in this prototype showcases the potential for designing and implementing accessible and inclusive features using the proposed technologies. Furthermore, the Unreal Engine provides language localization tools as part of the engine [33], making the Unreal Engine an ideal development tool for developing VR applications that need to support multiple languages.

Reliance on the internet or an existing network infrastructure for collaborative experiences is avoided by enabling multi-user functionality through a local area network setup on a router, with users on different devices interacting together via this local network. This also minimizes cost while also accounting for the fact that classrooms are social environments [16].

Functionality in which users can interact with the 3D environment by contributing to the construction of a house like structure, as shown in Fig. 1, and Fig. 2, was implemented using the Easy Building System v10 Unreal Engine 4 asset [34], which was available for free from the Unreal Engine marketplace [35]. This showcases not only some capabilities of the proposed development tools, but it also highlights some of content that is ready, and in this case, freely available within the eco-system of the proposed set of development tools, which can further accelerate and ease the development process for VR application developers.

![Fig. 1. View from an HMD VR user on the Oculus Quest.](image-url)
The prototype VR application presented in this paper was designed and implemented to support different types of devices, specifically portable and mobile devices such as Android phones and tablets, as well as standalone HMD devices, all of which do not need a constant connection to an electricity outlet to be used. This showcases how the issue of not needing to rely on the national power grid for electricity can be addressed. Furthermore, the standalone nature of an HMD device like the Oculus Quest also addresses the issue of cost since it does not need to be tethered to other devices, while ensuring that we can take advantage of the immersive features of the device.

V. CONCLUSION AND FURTHER DEVELOPMENT

Due to the apparent lack of documented evidence regarding the utilisation of real-time 3D environments simulated using VR technologies for education in Malawi, this paper proposed tools and VR technologies that can be used and developed by VR application developers to aid in the process of assessing the feasibility of utilising real-time interactive 3D environments simulated using VR technologies for secondary school teaching in the context of Malawi. This paper presented a VR application prototype that can be used as tool for communicating ideas between VR application developers and school educators in Malawi, within the context of Malawi. Furthermore, this paper proposed the use of the Unreal Engine, a tool that can be used to accelerate and ease the development of a prototype networked VR application supporting multiple devices. In future, the prototype will be iterated on, with the aim of developing a functional VR prototype application that can be used as a tool to carry out a feasibility study of employing real-time 3D environments simulated using VR technologies, for secondary school teaching in Malawi.

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Simulated Gaze Tracking using Computer Vision for Virtual Reality

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Abstract—As Virtual Reality (VR) is becoming more viable for creating immersive learning environments, a promising area of study is in monitoring and assessing learner’s engagement. Several related works in this area have used gaze tracking. Unfortunately, gaze tracking in VR is currently limited by hardware availability. This paper presents an approach for engagement monitoring that does not require the traditional costs of more sophisticated hardware setup. A simple combination of video processing techniques was used to show which contents capture the user’s attention, similar to the information current gaze trackers provide. However, success with this method was only evident with a sample video; refinements are still needed to cater to unpredictable changes in field of view. After fine-tuning the process, this approach may potentially benefit instructional VR content developers in determining which content grabs their learners’ attention effectively.

Index Terms—Virtual reality, immersive learning environment, gaze tracking, eye tracking, computer vision

I. INTRODUCTION

Virtual Reality (VR) allows transformation of learning experience from being limited in printed textbooks and classrooms to much more engaging and immersive environments regardless of distance [1]. With the development of supportive accessories such as motion controllers, learners can more easily participate in hands-on tasks for practicing and deepening their understanding towards lecture content [2]. However, one challenge in VR, as it is in typical digital instruction platforms, is creating content that will generate learner engagement.

A technology that has been used to analyze learner engagement with content is gaze tracking, a biometric technique that can monitor and follow a person’s eye movement in real-time. In VR, recent improvements on gaze tracking focus on improving hardware capability, such as tracking modules or attachable lenses serving as add-ons for VR headsets. Unfortunately, VR in education is commonly associated with high cost as current technology is primarily based on hardware and computational compatibility [3].

Reducing hardware dependencies is a viable solution towards equality in VR-supported education, and one of the viable approaches is through analysis of dynamic data gathered from VR usage. Gaze tracking is one area where this could be possible. This research is an attempt to contribute to the field of engagement assessment in VR. A different approach using only usage data without the need of any additional hardware requirements is proposed to partially replace current costly gaze tracking techniques with a simpler and more affordable approach. This does not only lower hardware dependency in VR technology but also opens a new research direction for learner engagement assessment.

II. RELATED WORKS

A. Gaze Tracking Apparatuses

Gaze tracking is the process of measuring where one is looking at with their eyes. This can be done through various means, the most popular being through tracking eye movements. With the emergence of head-mounted devices, head tracking has also become a possibility. Emerging VR technologies use both eye and head tracking for gaze tracking.

There are various gaze tracking algorithms that are hardware-dependent; one of the most common is using infrared light to track eye movement through reflection. Microsoft’s Kinect is a motion sensing device which features a near-infrared laser projector, three-dimensional (3D) depth sensors and an RGB camera. Kinect can reconstruct a 3D pattern in a wide range of ambient light conditions by projecting infrared light into the surrounding environment then capturing the reflection with depth sensors and the camera [4]. Another prominent product is Tobii’s Eye Tracker which uses the same approach of infrared light capture and calculating the relative position between user’s head and eyes. Needless to say, these hardware advancements are not available in cheaper VR headsets such as Google Cardboard [5] and its various do-it-yourself replicates.

There are also efforts in designing a software-based module without additional complicated eye-tracker hardware [6]. One work proposes an eye-tracking Intelligent Software Module, which overlays a coordinate grid onto the eyes and detects the position of the pupil within such grid. Through a mathematical apparatus, it is possible to determine which region on the screen the user is gazing at. This approach can derive a visual route and a heat map of the user’s accumulated eye movement without the need of infrared-light eye-trackers compared to other dominant instruments in the market. While this approach does not depend on infrared capable hardware, a dedicated camera directed at the pupils is still necessary.
As currently there are not many VR headsets that provide additional cameras for pupil tracking, a different software module with a different mathematical apparatus, which does not need any additional hardware is developed in this research. Also, in contrast to other approaches dedicated to tracking eye movement, the focus is on the contents and features that are concentrated by the users. This is to acquire data for content assessment, which is a pivotal task in educational planning.

### B. Immersive Learning Environments

Immersive Learning Environments (ILEs) are integrated learning situations which combine traditional instructional strategy and methodology with interactive software and tools, such as game-based and simulation-based learning, as well as virtual 3D environments. Compared to traditional environments, ILEs feature far more capacity of providing learner-centered approach, greatly enhancing the effectiveness in consolidating relationship between instructional goals and learner’s perception [7].

As current ILE designs focus on achieving higher learning efficiency for learners, the assessment of lecture’s content quality is imperative to the development of future ILE models. Analyzing learner’s concentration on different features throughout the lecture is an important task in lecture assessment, which is one of the goals of developing an accessible gaze tracking method.

### III. Conceptualizing the Pseudo Gaze Tracker

To test the validity of this gaze-tracking simulation, the following video recordings were used:

- **Toy Video**: a simple video recorded with a panning motion on a clean background with well-delineated objects.
- **VR Screencast**: a video recorded from a screencast of a novel VR user.
- **Mozilla’s Sample WebXR Video**: a snippet of the video used for Mozilla WebXR showcase [8].

The objective is to determine potential regions of the 360° screen where a learner might concentrate on while watching a video or changing their viewpoint while using a VR headset. The intensity of learner’s focus in each region of the screen during the time interval is also measured. These focus areas are visualized using heat maps.

After heuristically checking a few recordings, three primary types of VR recordings were identified for further investigation:

- **Type 1**: Recordings with steadily changing background due to user’s viewpoint movement. As the viewpoint changes throughout the video, it is possible to gather all features into a panoramic visualization. Changes in features are negligible due to user’s consistent viewpoint movement.
- **Type 2**: Recordings with little to no background changes. A panoramic image cannot be constructed in this case, as changes in features pose significant noise which are undesirable to gather all features into a panoramic image.
- **Type 3**: Records featuring both types of animation mentioned above. This is the most common type experienced in VR environments.

For Type 1, a workflow (see Fig. 1) consisting of five steps is proposed:

1. Capture frames with a given frames per second rate ($\frac{1}{fpsRate}$) from the original video.
2. Conduct saliency detection to locate salient features that might attract user’s attention in each frame. This includes reducing noise in each frame prior to feature detection and selecting regions of interest after feature detection.
3. Conduct panorama stitching to join all frames into a single image.
4. Match salient features between each frame and the panoramic image.
5. Plot a heat map showing appearance frequency of salient regions.

For Type 2, the workflow is similar to the approach for Type 1 recording, excluding panoramic joining and feature matching steps. Processing for Type 3 involves multiple Type 1 and Type 2 sub-sessions together. In this case, both workflows are applied and the results from both workflows are assessed.

### IV. Pseudo Gaze Tracker Construction

#### A. Frame Construction

Given a predetermined $fpsRate$, the input video is read using OpenCV and screenshots are taken every $\frac{1}{fpsRate}$ seconds. This will be referred to as “original frames.”

#### B. Panorama Stitching (Type 1 Only)

As this apparatus primarily works with separated frames captured from the video, it is necessary to obtain a panoramic image to display an overview perspective experience by the user. OpenCV’s High-level Stitching API (Stitcher class) was used to conduct this panorama stitching process.

#### C. Saliency Detection

1. **Frame pre-processing**: For each frame, in order to capture the salient features, it is necessary to minimize visual interference factors that might detrimentally affect the saliency detection process. These factors include inconsistent backgrounds, light patterns, or encoding differences, among others. To mitigate environmental noise, the Image Threshold with Otsu’s Binarization [9] was applied to achieve an optimal global threshold for an image histogram. This allows easy separation of the background and other objects in an image.

2. **Algorithmic saliency detection**: In each frame, several noticeable regions closest to the center of each frame are detected using OpenCV’s Saliency API - cv.saliency. As the frames are static and only the salient regions - not specific objects - are needed, the fine-grained technique was used with OpenCV’s Fine-grained Saliency Detector along with a thresholding technique to make it easier to extract the Rectangular Regions of Interests (ROI) within the image. Fig. 2 shows an original frame and its saliency map before thresholding is applied.
3) **Selection of most significant ROIs:** To determine the most noticeable regions, a function to the significance of each region is needed. To do this, contours surrounding salient regions are detected to determine a bounding box. The assumption is that a bounding box is worth being noticed if it is close to the frame’s center and it is big enough. Thus, the significance of a bounding box is directly proportional to its size and inversely proportional to its distance from frame’s center. The following function is heuristically defined to calculate each bounding box’s significance:

$$\text{Significance}(S, D) = \frac{S^a}{D^b}$$

In which:
- $S$: Bounding box’s area.
- $D$: Distance from bounding box’s center to frame’s center.
- $a$: Area weighting ratio. This is currently set to 2.0.
- $b$: Distance weighting ratio. This is currently set to 3.0.

To further limit the range of bounding boxes detected, two more conditions in bounding box selection process regarding size and dimensions are added:
- The bounding box’s height and width shall not be bigger than half of frame’s height and width, respectively.
- The size of a bounding box shall not be especially small, unless it belongs to an animation (motion saliency).

If a bounding box falls into either of above two conditions, its significance is set to 0. Fig. 3 shows a resulting frame from thresholding with significant bounding boxes.

**D. Feature Matching Between Frames and Panoramic Image (Type 1 Only)**

Salient features are scattered across multiple frames. To acquire an accumulated distribution of eye concentration, feature matching with the salient features as template is conducted to get their coordinates on the panoramic image. Hence, the longer a feature stays within the user’s field of vision, the more attention it is accorded to. These coordinates will later be used to visualize user’s eye concentration.

**E. Heat Map Visualization**

After conducting saliency detection, bounding box selection, and panoramic image mapping, the coordinates of most significant features for each frame are extracted. The accumulated data of these coordinates are plotted into a heat map showing appearance frequency of salient features within the panoramic image for Type 1 recordings or a base frame for Type 2 recordings.
V. RESULTS AND DISCUSSION

A. Toy Video (Type 1)

Fig. 4 shows the result of stitching processes on the toy video. For each frame, the five most significant salient features are taken, assuming that the user can only maintain concentration on a maximum of five features at a time. While this is again a heuristic decision, this was based on graphics research recommendation of limiting features in a visualization to just a couple of categories [10]. This recording was specifically created to test the proposed approach; hence, the expected result is known beforehand. From qualitative inspection, the proposed approach was able to achieve its goal of deriving a pseudo gaze tracking result in the form of a heat map of salient features.

![Fig. 4. Result of Type 1 video and its heat map accumulation.](image)

B. VR Screencast (Type 2)

The toy video was specifically recorded to develop the proposed approach. To have a more realistic assessment of how the approach will perform in actual situations, the final configurations from the toy video analysis was used in an actual VR screencast recording. As the recording’s length is considerable (30 seconds), \(fpsRate = 5\) was set.

![Fig. 5. Result of heat map accumulation of Type 2 video using Workflow 2.](image)

C. Mozilla’s Sample WebXR Video (Type 3)

This VR showcase features both Type 1 and Type 2 sub-sessions. Workflow 1 returns a runtime error during the panorama stitching process, which indicates panorama stitching process is inapplicable as expected. Meanwhile, Workflow 2 returns a heat map similar to the second test case.

![Fig. 6. Result of Type 3 sample video using Workflow 2.](image)

As this type involves both Type 1 and Type 2 sub-sessions, it is optimal to apply both workflows into corresponding sub-sessions separately.

VI. CONCLUSION

Table I shows the results summary for each recording and workflow tested. The proposed approach works well in deriving a heat map showing intensity of salient regions on-screen throughout a given video. From this, the possible distribution of video observer’s eye movement can be determined as it closely relates to distribution of salient features.

<table>
<thead>
<tr>
<th>Video and Workflow Results Summary</th>
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<tr>
<td><strong>Toy Video</strong></td>
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<td><strong>VR Screencast</strong></td>
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<td><strong>Web Sample</strong></td>
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Different workflows showed different performances. Workflow 1 shows all features in a panoramic image, which is ideal for assessing video contents with heat map. However, panorama stitching process is considerably vulnerable to cases with inconsistent background changes, thus Workflow 1 cannot be applied widely. On the other hand, result from Workflow 2 lacks panoramic perspective, making it possible to map two different features, with different panoramic coordinates, into same coordinate on a 2D heat map. This renders Workflow 2 inappropriate for gaze tracking in VR environments.

VII. LIMITATIONS AND FUTURE WORK

A. Limitations

Currently there are three primary limitations that can potentially be improved in future works. First limitation is the difficulty in generating panoramic, 360° images for representation of the VR environment. Real VR recordings include inconsistent rotations in user’s viewpoint, object and feature changes, and motion blur effect, among others. These are outside of normal panorama stitching algorithms, and thus make panorama building from VR recordings challenging. A possible solution is to generate a panoramic image of the entire content space once through controlled operation. Thus, the panoramic stitching will no longer be needed for every recording as a master panoramic image is already available.

The second limitation is the accuracy of significance function. This function is empirically derived after a set of test runs on different experimental records. Although it detected the most important salient regions, more work will be needed in developing a new function or enabling the researcher using this approach to select different functions and parameters (e.g., values for a and b, number of features to be detected, minimum bounding box size). This is similar to how hyperparameters such as kernel functions are set in machine learning algorithms.

The final limitation is the workflows’ performance. As most of the process focus on image processing under pixel scale, the time required for a recording exponentially increases with the recording’s length and resolution. For example, a 45-second, 1920px × 1080px resolution record takes approximately 10 minutes with Google Colaboratory’s NVIDIA Tesla K80 GPU to completely undergo the workflow. This is most likely unacceptable since it is a relatively short recording with a resolution that is not unusually high. It is imperative to enhance performance efficiency of the workflow in order to make the process adaptable to recordings with longer lengths and higher resolutions.

B. Future Work

For panorama generation, a possible approach is to derive a polar coordinate for construction of panoramic view. This will resolve cases with inconsistent viewpoint changes. A popular apparatus is to implement gyroscopic data acquired from VR headset’s sensors (for instance, Oculus Rift features Accelerometer, Magnetometer and Gyroscope sensors [11]).

Still, algorithmic approaches will be prioritized to not involve additional hardware components.

Algorithmic approaches also include analyzing several candidate significance functions through test runs validating the accuracy of different weighting ratio sets on different test recordings. The possibility of using other functions (e.g., logarithmic functions) may also be explored. Stronger image processing techniques within and outside OpenCV’s libraries will be explored to achieve higher overall performance.

After obtaining acceptable results in mentioned limitations, the approach will be integrated into VR applications and remodeled from post-processing technique to real-time analyzing software add-on. The final goal is to match the performance of VR real-time eye tracking modules currently in use.

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A Virtual Learning Model for Virtual Reality and Literature

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Abstract—This paper posits a learning model for virtual reality and literature and articulates concatenated stages by which participants experience Adaptability, Transitionality, Fusion, Enhancement, and Knowledge Transference. This paper concludes that learning in virtual reality (VR) replicates experiential learning in the physical world.

Index terms—Virtual reality (VR), literature, learning model, English, experiential learning, virtual world, adaptability, transitionality, fusion, enhancement, knowledge transference

I. INTRODUCTION

This study answers two questions 1. what does learn look like in VR, and 2. how does VR learning apply to the literature classroom. After identifying a loosely designed model of what learning looks like in VR, which I shall refer to as the VR Learning Model, I then move on to another related question, how do we know if VR enhances the learning of literature? When thinking this through or identifying virtual reality’s “learning outcomes” and its application to learning and literature, a few things need to be understood. First, one must understand, or at least accept, a complex concept simply, which is to see a virtual experience as a real experience. While the reality of a virtual world can be questioned and debated, that avatars, worlds, events, etc., in VR, are perfectly real [1]. In a virtual world, the brain is still receiving input regardless of it being virtual fiction.

This study argues that not only is virtual world information copied into the brain just like physical world information, but it is also used and applied to the learning process in the same way.

II. METHODS

A. Selected Methodology

The qualitative approach used in my research is grounded theory [8]. I used this approach because my research fits the criteria for grounded theory in that there is a paucity of data regarding the effectiveness of VR as a tool to teach literature. Grounded theory “focuses on a process or an action that has distinct steps or phases that occur over time” [2]. Anselm Strauss and Juliet Corbin [8], as cited by Creswell and Poth [2], explain that “investigators seek to systematically develop a theory that explains process, action, or interaction on a topic” [2].

The grounded theory requires collecting data such as interviews, relevant documents, and researcher observations. This data is then carefully analyzed. One important process in grounded theory is the “zigzag” approach which is an Exploring Virtual Reality iterative approach that entails gathering data and analyzing data, gathering more data, analyzing that data, etc. This research, therefore, intends to explain the relationship between VR and literature [4].

An iterative data collection and analysis to develop a theoretical explanation of the VR learning process by watching and interviewing participants using VR to enhance their understanding of literature. My grounded theory approach aims to potentially develop a framework of the process that explains the phases in which students reach experiential learning and enhance their appreciation for literature. Analysis of the data I hope will reveal the participants’ common experiences that will be thematically categorized to better understand future applications of VR in the literature classroom and develop a deeper understanding of the impact VR has on providing cultural context as it relates to literary analysis.

B. Study Participants

Thirteen students from a literature undergrad and graduate course were selected for this study. The sample included observations and interviews of thirteen literature students in undergrad and graduate-level English courses at a Central Valley CSU.

C. VR Experience Descriptions

Three VR experiences were used "The Price of Freedom," [10] "The Book of Distance," [9] and "The Key" [11] to understand VR’s potential to enhance the understanding, comprehension, and appreciation of literature as measured through observation, reading a poem, and short answer questions, and viva voce interviews. Participants who experienced "The Price of Freedom" focused on the poem "MKULTRA" by the poet Fesharki. The poem and the VR experience both focused on the MKULtra events. In which the CIA used LSD to try to control and program human subjects.

"The Price of Freedom" [10] is a 15–30-minute animated virtual reality experience that involves the user in an Avatar setting in which they are asked to carry out an assassination. The game involves various critical thinking and manipulation of VR objects.

Participants who experienced "The Book of Distance" [9] focused on the anonymous poem written in the Japanese internment camps, "That Damned Fence." The poem and the
VR experience focused on the Japanese internment camps. "The Book of Distance" is a 30-minute animated virtual experience that is both the first and second perspective of a young man leaving Japan for America hoping for a better life. The experience also uses archival documents and photos to bring the event to life.

Participants who experienced "The Key" [11] focused on Sir Herbert’s poem “Refugee.” The VR experience is a 15-min interactive short film/narrative in a first-person perspective with many interactive moments. The poem and the VR experience both focus on journeying into the unknown, the plight of a refugee, facing challenges, and making difficult decisions.

D. Data Collection Process

For this study, students from English literature classes were invited to apply to participate. Students were selected based on their lack of VR experience, as well as other factors. Participant selection also ensured equitable representation in terms of gender. Data was collected by means of observation, short answer questionnaires, as well as face-to-face interviews. Since data collection and analysis is an interrelated processes in grounded theory, the analysis began immediately along with observation [8]. Analysis began at the start of the study and was used to create and direct additional interview questions that followed the VR experience and observation [8]. Some of the research questions were based on selected VR experiences and a related poem; the questions were framed open-endedly to allow free expression, discovery, new ideas, and the potential for themes to emerge organically.

Participants were observed while playing through the VR experiences. Some interview questions were added or eliminated if found irrelevant or necessary based on the early analysis during the observation [8]. Immediately after completing the experience, participants were asked to read the selected poem and answer reading response questions pertaining to the poems. All interviews were recorded via Zoom with the participants' permission and transcribed verbatim.

E. Data Analysis Process

The basic principle of grounded theory data analysis will guide this study [4]. Deep, thorough, and meticulous analysis will be conducted for all interviews to ensure that no important idea or discovery would be overlooked or misinterpreted. Open-coding, Axial coding, and Selective coding will be used to analyze the data collected [8]. After transcribing each interview and reading them over multiple times, similarities will be noted during the Axial coding that is apparent in all the interviews and participant responses. The research process itself will guide understanding the emerging themes [8].

I began by using in-vivo coding, citing, and highlighting the participant’s own language. For each participant, I noted what emerged as a matter of particular importance for each sentence or paragraph and assigned a code word. Next, I created a list of all the code words from each participant and highlighted common, re-occurring languages that appeared in all participants. For example, if the following statements all carry a similar expression for the code word confusion: “hidden,” “didn’t make sense,” “finding out,” “figuring out.” I then grouped the codes into emerging ideas and concepts from my long list of codes.

The grouped concepts were divided into reoccurring themes and formed categories [8]. The major concepts that emerged were grouped into related categories with the same phenomenon. These categories serve as the cornerstones of my developing theory [8]. The most relevant themes that emerged were integrated to form a theoretical framework. This framework aims to explain the central theme of the data as well as account for variation in each participant.

III. Data Analysis

A. Open Coding

Coding in this study includes the process of open coding, axial coding, selective coding, and thematic matching. The reorganizing of codes and determining significant categories continued throughout the data-analysis process and throughout the memoing and writing process until the researcher felt confident and satisfied that the data was fully accounted for, including the emerging theory. A list of in vivo codes and phrases emerged through the iterative, open coding process. A total of seven preliminary categories were developed via the repetition of code words and phrases in the interviews for all three VR experiences.

B. Axial Coding

Although the primary purpose of open coding is to categorize all data collected and not to determine relationships between categories, it was evident throughout the open-coding process that some of these emerging preliminary themes were closely related, and these relationships and the core categories became more well-defined throughout the axial coding process. According to Glaser, "The analyst starts by coding each incident in his data into as many categories of analysis as possible, as categories emerge or as data emerge that fit an existing category" [3].

Additionally, some of the preliminary categories merged during the axial coding process. In contrast, some categories developed new subcategories, resulting in five core categories that emerged from the data collected from all 13 participants: 1. Knowledge Transference, 2. Adaptability, 3. Transitionality, 4. Fusion and 5. Enhancement. The preliminary category “Reality World-Shifting” became a subcategory of Adaptability. The preliminary category “First-Person Shift” became the category Transference. Additionally, the preliminary categories “Shared Experience” became Fusion, and “Realization” became epiphany.

Both epiphany and empathy/sympathy merged as two subcategories of Fusion before becoming the core-category Enhancement.

A total of five core categories were generated during the selective-coding process via the open and axial coding results. The five core categories include the four subcategories and themes that merged with the core codes.
C. Selective Coding

1) Knowledge Transference

To begin with, I define Knowledge Transference as gained or old knowledge or information transferred from one world to another for learning, enhancing, and filling knowledge gaps. This transference of knowledge can come from either the physical world and be brought into the VR world or vice versa. Another essential point to note is that Knowledge Transference stands alone. It does not need any other element added for it to happen within the emerged learning model. By that, for example, I mean that Adaptability does not need to occur for Knowledge Transference to happen. Examples of Knowledge Transference frequently appeared in the data.

Additionally, there seem to be various levels of Knowledge Transference. There are “low-levels” of transference, such as bringing in or applying knowledge technology to adapt to VR. For example, as one participant stated, “I play some video games, so it’s kind of like the controller kind of transfers over, but it was still somewhat familiar…” This participant was able to apply prior game knowledge to help adapt to the VR experience. The participant’s own language, regarding controller, transferring over, is what gave me the category name “transference.” An example of a “higher” Knowledge Transference was manifested when one of the participants used VR knowledge to better understand historical events, such as WWII.

One participant noted during the interview after the VR experience Book of Distance,

“As a player, you were really presented with this very small box, you know, it’s funny because it actually reminded me of my grandfather, who is a World War two veteran, and he was captured by the Germans, and they kept him in like a small box, so kind of may be associated with that.”

The participant applied their VR experience to meaningfully reflect on the experience of being in the Japanese internment camps and the experience of being in the Nazi concentration camps in WWII. The participant also makes a personal connection regarding their grandfather, who was captured and forced to live in a small box.

2) Adaptability

Each participant at some point discussed the idea of Adaptability, and the majority of the participants asserted that adjusting to VR was relatively easy and intuitive. Adaptability became one of the core codes. I define Adaptability as any discussion on VR interactability, movement, physical space, controls, and any other discussion regarding adapting to or adjusting to the VR world. Participant observations that speak specifically to Adaptability include, “I did kind of struggle to adapt was... it felt like having to learn the controls...” another student reported on adapting to VR movement “Just controls, like, what’s interacted with what’s not, what hand gestures trigger the remotes...”

Another theme that began to surface was the idea of what I call “world-shifting.” For example, some participants commented on the fictional world and compared it to the real world “...animation world like you know it is not, it is cartoony compared to realistic” and “It made you feel like you were somewhere else. You weren’t in the real world. You were somewhere else... it’s obviously virtual reality... it makes you feel like you’re somewhere else. You know you’re not in this real world where you can hear it the way like you see things like it’s like it feels real while you’re in there.” Initially, I thought this would be a code on its own since several participants were noting the shift from the “real-world” to the VR world.

However, after further analysis, I decided that “world-shifting” would best merge with Adaptability since it also expresses “adapting” to VR and the VR Worlds. More importantly, it became apparent that participants needed to successfully adjust to the VR experience in order to make positive progress into the other categories that emerged from the data.

3) Transitionality

The third significant core category that emerged is Transitionality. I define this as the transition from being a bystander, watcher, or player to becoming an active participant—the move from watching to being a part of the experience.

Like Knowledge Transference, Transitionality stands alone. It does not need any other element added for it to happen. For example, Adaptability or Knowledge Transference does not need to occur for Transitionality to take place.

Some examples of Transitionality are straightforward. For example, one participant describes the transition by stating, “It felt real as if I was actually standing there going through the experience.” Another said, “It’s just like, it’s like, although it’s her story like it’s also my story.” The participant is expressing a move from being a “watcher” or bystander to becoming the character in the story. Another example is a participant who identifies experiencing a very active role as the narrator, stating, “I was playing for the character and what was going on.”

Other quotes, however, have more depth, for example, “Once I was in the world. Then when I started acting out things that they did, or when I started picking up rocks and putting them in the wheelbarrow and that sort of thing, it took down that detachment barrier that existed between someone else’s story and my story. And it was sort of like I took on the heaviness of that situation, the heaviness with this experience.” The participant describes “acting out” tasks the other characters were doing and “taking on the heaviness” and essentially is providing a descriptive example of transitioning from being a “bystander” to becoming an active participant in the VR world.

4) Fusion

The fourth core category, and one of the more significant categories, to emerge is Fusion. Fusion is character bonding. The participant’s knowledge base fuses or binds with the “narrator’s” and becomes shared knowledge. What the game/experience/narrator knows becomes a shared
understanding of the player—thereby allowing for a kind of player binding or Fusion to occur. Unlike Knowledge Transfer and Transitionality that act alone, there must be some form of Transitionality to have Fusion. There cannot be Fusion if there is no Transitionality.

5) Negative Subcategories

Additionally, one unique theme is the subcategory “negative transitionality.” One participant had a relatively negative experience of Transitionality. The participant struggled to adapt. Negative Transitionality is “The inability to accept the artificial world.” However, and interestingly, the negative Transitionality did not affect the participant from experiencing Fusion and Enhancement. The participant also had Fusion moments and later had Enhancement moments during the interview as the participant answered the questions.

IV. RESULTS

David Sousa, an international consultant in educational neuroscience, [7] and virtual reality philosophy from neural science and philosophy professor David Chalmers [1]. As stated previously, these theories serve only as a helpful lens and tool for a more in-depth understanding of themes and categories that materialized in my study.

In his analysis of the “reality” of VR, Chalmers discusses Descartes’s idea that the brain receives sensory input, processes it, sends the information through the pineal gland to the nonphysical mind. The mind thinks, reasons, and makes decisions, sends the signal back to the brain through the pineal gland, and the brain carries out its activities [1]. In my data analysis, I identified this as “Knowledge Transfer,” which is the VR input, storing the information, using it, and applying it outside in the physical world. Every virtual experience the participant has had is copied into the biological brain no differently than an experience in the physical world [1]. Not only is virtual world information copied into the brain just like physical world information, but it is also used and applied to the learning process in the same way.

To better understand how virtual experience is transferred into learning, we need to discuss how we learn more generally. David Sousa posits that when applying information, “the brain calls selected areas of the brain to play depending on what an individual is doing at the moment” [7]. Sousa explains how the brain deals with information from our environment, and it is stored as immediate, working, or long-term based on how the learner is attached to the meaning of the information and learning [7]. He also emphasizes that the brain continues to be altered by each experience and interaction that we have with the information we are processing. Revisiting the information only strengthens the neural connection and increases the depth of learning [7]. Moreover, past experiences always influence new learning, and this idea leads right into Knowledge Transfer which is the most critical category that emerged in the data.

Sousa also discusses “the power of transfer,” which he refers to as the process that allows inventiveness to unfold. Transfer is the “ability to learn in one situation and then use that learning, possibly in a modified or generalized form, in other situations” [7]. This idea of transfer allows me to interpret tangible results of my data and show that the learning in VR did indeed enhance reading comprehension and appreciation of the literature. Prior to my knowledge of Sousa’s theory on transfer, I categorized this as Knowledge Transfer and identified “low” and “high” levels of Knowledge Transfer. “Low” knowledge transfer appeared in the form of more simple indicators that I have mentioned earlier, such as applying previous gaming knowledge to adapt to the use of VR.

“I play some video games, so it kind of like, the controller kind of transfers over...”

“High” Knowledge Transfer would be similar to Sousa’s transfer of learning and identifying if the participant has applied the new learning via the VR experience into the physical world, and more specifically, the selected reading. This “high” Knowledge Transfer was visible in their interview when discussing what they learned in VR and when applying their gained knowledge to the reading they were provided with and in their reading response questions.

Sousa states that the learner’s current environment often provokes the transfer process. Most of the time, the transference of long-term storage is not under the conscious control of the learner, and past learning always influences the acquisition of new knowledge [7]. While my VR learning model has several phases and is similar to Kolb’s Experiential learning model, Knowledge Transfer is at the core of my VR Learning Model [6].

The data shows that participants all expressed that adapting to the virtual world was essential and was the earliest indicator of Knowledge Transfer being applied. Transitionality occurred as the participants began to merge themselves into the environment as active participants rather than bystanders or watchers. Fusion with the character and the virtual world led to Enhancement. Enhancement (what is learned or gained from the virtual reality experience) is established by the brain as either an immediate, short-term, or long-term memory and is stored to be used in the future as the brain sees fit. Ultimately, however, it is through knowledge transfer that we can see how this learned knowledge is applied in both the readings in a literature class as well as in larger situations.

All participants showed some level of Enhancement from the VR experience. While the majority of participants’ Enhancement resulted in greater depth in the reading response and interview, I feel confident that the virtual reality experience added an extra layer of enrichment to all participants (to varying degrees), even those who displayed low levels of Enhancement. Furthermore, just because some participants demonstrated a “low” level of Enhancement in terms of literature does not mean that their knowledge was not enhanced in other respects. Knowledge transfer in this study applies to the literature, but it also has implications of Knowledge Transfers beyond the focused study. Meaning that just because its impact is less visible in this study is not to say that the brain will not use it in “new learning in future situations” [7].
V. CONCLUSIONS

In brief, then, my theory of VR learning as it applies to the understanding and appreciation of literature is that participants go through four main stages of learning. See table 3. These stages are not necessarily sequential and are recursive. The first stage is Adaptability. In this stage, participants learn to adapt to the virtual world or environment.

The second stage is transitionality. In this stage, participants transition from being third-person bystanders into being active participants. The third stage is Fusion. In this stage, participants bind with or fuse with the character or world and develop a shared experience or knowledge, becoming first-person protagonists. The fourth stage is Enhancement. In this stage, participants identify with the avatar and develop feelings of empathy and sympathy and may experience an epiphany.

While the first three stages take place within the virtual world, Enhancement connects the virtual world and the physical world. That is, the Enhancement in this study applies to the degree to which their virtual experience enhances their ability to understand and appreciate the relevant literature, but Enhancement would also apply to phenomena beyond literature as well.

Connecting and even determining each of these four stages is Knowledge Transference. In fact, Knowledge Transference occurs strictly within the brain. Parts of the four stages are not sequential because they connect with Knowledge Transference. Even if a participant doesn’t realize one stage, for example, Fusion, they can realize the other stages because the back and forth is between Knowledge Transference. For example, in the graph (fig. 1) should be visualized in three dimensions the gray area which is labeled Knowledge Transference which in some respects corresponds to the gray matter of the brain, and the blue corresponds to the VR goggles, except for the Enhancement stage which would apply with the goggles on or off.

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Work-in-Progress—Virtual Reality Integration into Geography Education: A Case Study of Physical Geography

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Abstract—This paper is about the creation, deployment, and refinement of a smartphone-based virtual reality geographic environment for an entry-level geography course. The topics covered will be the development of the virtual reality prototype, the problems and solutions in implementation, the results of its deployment, and future development of this line of study.

Index terms—virtual reality, vr, Unity, gis, Blender, remote

I. INTRODUCTION

Virtual Reality is a blossoming field of potential applications for education. The continual development and refinement of the technology has led to wider availability and reduced costs. Harnessing this technology for geographic education is a utility that is still being actively researched. In the pursuit of these potential applications, a virtual reality prototype was created, and a case study conducted around “GEOGRAPHY 101 - Earth’s Physical Environment” course at San Diego State University. The course goes over Earth systems, environmental composition, ecosystems, and physical features. It also lightly covers mapping and imagery. While many different types of classroom aids are used in geography courses, the most common are videos and physical models. Creating virtual environments around the topics of discussion in geography courses could serve to better the learning experience and generate a positive impact on the students’ perception on the subject of geography as a whole. In addition, creating virtual versions of classroom aids would help reduce costs and allow distribution of materials over the internet. After this (1) introduction, this paper will discuss the following topics regarding Virtual Reality implementation: (2) Development and creation of a smartphone based virtual reality environment, (3) refinement of the environment (4) its deployment, and (5) the results and potential future studies that could be conducted.

II. DEVELOPMENT AND CREATION

A. Software and Tools

The programs utilized for this project were the modeling and animation program Blender, a plugin for Blender called BlenderGIS, Unity game engine, and a web scraping program called RenderDoc. The hardware used were Pixel 3a smartphones and Google Cardboard-like devices. Google Forms was used as a survey platform for participants, with an Entry and Exit survey being administered at the beginning and end of the study respectively.

B. Selection of the concepts presented

The environments were created by first determining key concepts that could use reinforcement or be supported with a virtual reality component. Due to the variety of potential topics that are covered in Geography 101, identified concepts were weighed against the complexity of developing environments for that concept, with concepts that would require substantial development such as global climates and air pressure cycles being put aside due to the sheer complexity of making an interactive environment for a topic of that magnitude, in additional to the overall amount of geographic data that would be needed to gathered for a singular topic. The concepts that were included in the virtual reality application consisted of: Map literacy, Glacial Landforms, and Imagery types.

C. Development of the environments

The actual steps of development were relatively simple once the workflow was established. A concept would be paired to a real life location. Data for that location would be gathered, the data could be something as detailed as a laser dot model or as rough as a web-scraped Google Maps model. This would be used in Blender to create a rough landscape model. Unity was used to add the information boxes, refine the user interactions and experience The most commonly used dataset was the one generated by the National Aeronautics and Space Administration Shuttle Radar Topography Mission (NASA SRTM). After the environments were finalized, the conceptual information was added using Unity engine.

III. REFINEMENT OF THE ENVIRONMENTS

The environments ranged from something as urban as the San Diego State University campus to something as remote as the Matterhorn in the European Alps. Due to this variability in environments, it was decided that instead of having a directly interactive virtual reality environment in the method of immersive, realistic simulations which would require the creation and implementation of a more advanced locomotion and user-action interpretation [1], the project would focus on
simplicity of interaction elements, and letting the quality of the environments serve as an element that related lecture information can directly reference instead of just presenting information in a relatively traditional and standard format of text, video and imagery but with no relation to its presence within a virtual space. For the larger environments, depending on the complexity of the modeled terrain, image quality could be pushed to sub-meter spatial resolution, however for a useable virtual reality experience one needs to develop not just for fidelity but for responsiveness as well. Increased framerates and refresh rates have been shown to be key factors in determining if a user wants to interact in virtual reality past the initial exposure to it [2]. For smaller environments, instead of increasing image fidelity, the free processing power that was not used on increasing framerates went to increased model complexity. This served to increase user immersion in the smaller environments where the limited scope of an environment would lead to increased attention to detail by the end user. Due to the limited processing capabilities of the hardware utilized, details outside of the basic geographic landscape and major landforms were removed from the environments, leading to a sterile feeling environment that does not really aim for immersion, but instead positions the user as exploring a 3D model of the environment. Overall development time spent getting the workflow setup and then learning how to develop in Unity for iOS and Android devices took a bit over two months, however the timetable for the environmental creations took around 3 weeks total. The process and product were continually refined as the project continued, so the total time commitment values are fuzzy. It is important to note that due to difficulties with both development of the Unity program and getting the proper licensing for distribution on the Apple application store, iOS testing was not pursued.

IV. DEPLOYMENT OF THE PROTOTYPE

Entry surveys were sent out to participants via Google Forms on the 11th of October 2021 with the goal of establishing a baseline set of parameters. The virtual reality prototype was deployed on October 18th, 2021, and was released alongside the exit survey. Participants were allowed to complete their assigned study method at their own time and pace over the course of the next week after their group assignments. Instructions were sent out to students on how to create anonymous amazon accounts and wish lists. Participants submitted anonymous Amazon Wishlist registries with hidden addresses in order to receive the Google Cardboard-like devices which would allow participants to conduct remote testing, and if needed participants also checked out or were sent a rental Android smartphone to run the virtual reality prototype. Instructions and training were available to all participants regarding how to assemble their cardboard headset, in both written documentation format, in-person sessions, or via video tutorials. In addition, every student who was issued a loaner phone went through a basic orientation process on how to navigate the device, what to do for troubleshooting, and how to install it into the headset provided by the study. Of the initial 38 participants that indicated interest during the recruitment phase, only 26 completed all phases of the study and submitted an Exit Survey. 13 of these participants were assigned to a control group that did not utilize the virtual reality prototype and instead were allowed to use a prepared common study document in addition to other traditional methods such as PowerPoint presentations, internet searches, and video explanations. The other 13 were provided the virtual reality prototype and the headset, and were instructed to take the exit survey after they had finished using the prototype at their own pace to allow some level of remote learning independence.

V. RESULTS, LIMITATIONS AND FUTURE STUDIES

A. Results

The overall trend that was found was that the use of smartphone-based virtual reality as an alternative to a remote lecture was not effective as a replacement to traditional methods, however it does show promise as a tool used to change attitudes and to highlight very specific concepts. The topics that did well in virtual reality revolved around concepts where context was important and presenting a specific set of informational setup was needed. Topics that could have an abundance of information available when looking up the subject online could lead one to the wrong conclusion due to semantics or the differences in contextual setup.

![Fig. 1. Results of the 12 question quiz between the two study groups.](image)

There were three main conclusions drawn from this study. The first is that utilizing low-cost smartphone-based virtual reality is good at representing singular geographic topics (specific land formations, individual map types), but with enough preparation time this could possibly be expanded to include a wider range of topics or even a full simulation. The second is that virtual reality by itself as a standalone lecture replacement has a negligible impact on knowledge comprehension of geographic topics overall. The knowledge scores and the improvements between groups suggest that traditional methods are much more efficient in most scenarios, with virtual reality outperforming traditional only in very specific contexts. Lastly, smartphone-based virtual reality might not be used as an efficient alternative to other methods of study, but can potentially be used to great effect as a supplement to traditional lecture methods, focusing on singular topics and allowing development resources to be focused on that topic will definitely make an experience that should last in the students’ memories. There were some sections where the use of virtual reality was more effective than traditional methods, but those sections were limited in scope, and more tests would be needed to solidify if this is a recurring trend or a one-off occurrence for this study. It should be noted that while the end determination was that virtual reality was not a good replacement for traditional lecture materials, many participants viewed their use and experience with the technology as positive, and there was a marked change in stances and attitudes towards
usage of virtual reality technologies in education. As an academic alternative, the virtual reality prototype was unsuccessful, however as an attitude changing device it was very successful in convincing people of the potential that virtual reality has in academia. The main conclusion arrived at for the study was that virtual reality using the development and planning methods in the study and deployment on smartphones would be a good academic aid for specific concepts given the correct setup, but not a good academic alternative to traditional forms of study in general. Attitude change was nearly universal, with the few dissenting voices raising concerns about nausea or cost of accessibility in low resource availability areas of the world.

Participant feedback noted how initially attention grabbing the environment was, and how because they were able to go at their own pace, and explore however they desired within the environment, they felt engaged with the prototype. Several of the participants noted that graphical fidelity on some environments were lacking, and that on other environments the framerate was unstable, sometimes leading to nausea or disorientation due to the lowered framerates. Several suggestions were provided on how to change the interface the users interact with, and how to differently present some of the information within the prototype to have the experience feel natural. Overall feedback suggested other topics that virtual reality deployments similar to the one used in this study could cover, and that the experience was mostly positive and changed their stances towards using virtual reality in education.

B. Limitations

While virtual reality presents a unique perspective for presenting various topics in geography, the amount of work required to justify its use as an alternative for remote learning instead of traditional methods of study is exorbitantly high. There were some major limitations that were encountered in the course of creating this study. The limited graphical power of smartphones not only denied the route of making a graphically immersive high detail environment, but in certain situations required standard model complexity to be able to fit the scope of a desired landscape. The amount of time dedicated to the development of the virtual reality environments and the cost of the research and data gathering for locations where geographical data was insufficient limited what concepts and locations were able to be chosen for the virtual reality prototype. Another hurdle was the dependence on user familiarity and competency. While tutorials and examples were provided, a non-insignificant amount of participants had difficulty understanding different aspects of their participation, from application installation, to building the cardboard virtual reality headset. There is also an expected level of technological familiarity and competency that comes with the use of smartphones and while this worry may diminish as smartphone adoption rates rise, it is still an issue if this type of virtual reality deployment is used in areas with low technological literacy. One of the largest hurdles of this study was getting participants and conducting recruitment due to lockdown procedures making testing and distribution difficult, and to the general lack of available students during this time period. The last major hurdle was figuring out new methods and styles of education. Traditional methods are proven and have centuries of refinement to become incredibly efficient. Most of the teaching resources used today are formatted for traditional methods, and having to adapt or generate new content for a new delivery system is very resource intensive.

C. Future Studies

If this study were to be run again, gathering a larger sample group, making sure that one can develop for the operating system that everyone has, and narrowing the focus of the study to specific concepts within a specific subject would be the core changes made on a subsequent run. If we look at the novel topic of the deployment method in this study in the long-term perspective, it is very likely that dedicated virtual reality devices will replace versatile tools like smartphones. Increasing availability and affordability [3] of virtual reality technology will allow developers to create virtual products with greater fidelity and complexity. While being able to utilize technology that students already have is a great cost-saving measure, the limitations were significant and difference in quality between smartphone use and dedicate virtual reality devices will only continue to grow. While at this time, smartphone-based virtual reality may not be a direct alternative for traditional lecture methods, future research can instead focus on how smartphone-based virtual reality can support traditional methods instead of attempting to replace it. More case studies need to be conducted regarding implementation of virtual reality as a tool in a plethora of topics, because the wider the technology spreads, the greater the userbase becomes, meaning more lessons can be learned about virtual reality implementation within the educational space. Smartphones were utilized here because of the need to have pre-distributed or easily distributed hardware during quarantine times, however if dedicated hardware could have been utilized, the planned but unimplemented capabilities of the prototype would have been explored, and the main draw of virtual reality to create a space completely controlled by its designer would have been utilized to its fullest. Research outside of smartphone-based virtual reality is just as important, and studies could be conducted that can compare the benefits of various virtual reality implements and their optimized use cases [4]. Virtual Reality has the potential to become a commonly used form of education. Finding ways to translate the centuries worth of teaching methodology and developing new ones unique to the virtual space is a topic that needs to be addressed.

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Abstract—The concept of merging gamification and mixed reality (MR) can create a motivational combination for better student performance and learning outcomes. Therefore, this work-in-progress study aims to design a methodology that can create an educational application to improve student engagement, motivation, and their learning outcomes with the advantage of MR technology features. This study presents a gamified MR application approach using an enhanced attention, relevance, confidence, and satisfaction (ARCS) model with gamification called “ARCS +G” to combine instructional designs with motivational designs. Furthermore, it enables educators and developers to design and develop engaging applications for their audiences.

Index Terms—mixed reality (MR), education, gamification, ARCS, ARCS+G, motivation, head-mounted display (HMD)

I. INTRODUCTION

The combination of gamification and mixed reality (MR) can create a motivational tool to improve the performance and learning outcomes of students. Gamification in learning is a valuable strategy for driving engagement and motivation in terms of learning by incorporating game components, mechanics, and dynamics into the learning process [1]. In addition, MR is a very interesting area in the field of educational games. In MR, the user can interact with different virtual environments. The users are more entertained when they have a strong sense of audiovisual simulation [2]. Understanding the characteristics of gamification can help educators and developers in designing meaningful MR applications for their students. This paper aims to design an enhanced educational MR application with gamification elements, components, mechanics, and dynamics to increase motivation and engagement of students. The application will use an enhanced attention, relevance, confidence, and satisfaction (ARCS) model with gamification called “ARCS+G” which was developed by Hamza et al. [1]. Moreover, motivation to learn is an essential factor in education [3], and the incorporating the concept of gamification in the educational system can improve the students’ motivation to learn [4].

II. BACKGROUND

MR refers to the combination of both the virtual world and the real world that creates a new visualization environment in which digital and physical objects interact and coexist. MR technology allows the integration of virtual data and the physical environment, which allows users to interact with both the virtual content and the physical content, thus enhancing their experience [5]. MR is an innovative technology that gains increasing popularity in various fields, especially the education sector. In the learning environment, MR integrates real digital settings to create a flexible and rich picture for learners’ conceptual and mental representation by facilitating the coexistence of digital and physical objects that instantly respond to the learners’ experience [5]. MR can be implemented as an interactive and real-time multimedia technology to facilitate the development of an improved learning environment where the learners can include virtual contents within the real-world setting. Moreover, it provides learners with a more intuitive and realistic way of utilizing and interacting with location-specific and contextual information by linking the digital and physical worlds. Users can visualize, move, and manipulate virtual reality (VR) objects while including them alongside physical objects. Although MR is not a new technology, the continual development and technological innovations in virtual reality make the subject attractive to many scholars. The latest technological innovations in MR, such as head-mounted displays (HMD), provide users with the ability to experience objects in a more immersive way. MR technology is gaining momentum in the education sector at a relatively fast rate as it has become a potential tool for learning and teaching. An MR environment positively influences the attention of learners’ attention and provides them with a more engaging and fun learning experience compared with traditional learning methods. Various studies have addressed the application of MR technology to the education field, reflecting increased scholarly attention.
A. ARCS Model for Motivation

One of the most widely used educational frameworks in evaluating the student’s motivation to learn is John Keller’s ARCS model [7] - [9]. His model is based on Vroom’s expectancy-value theory, which asserts that motivation to learn is comprised of the degree to which the learner becomes engaged in the learning experience through elements of attention, relevance, confidence, and satisfaction [10]. Many scholars have employed the ARCS model into the development of educational materials for learning. In addition, studies have demonstrated that incorporating the ARCS paradigm into an educational design can effectively increase student motivation [1]. The ARCS model categories are described as below:

- Attention refers to how students respond to instructional inputs.
- Relevance is focused on helping students make connections between past learning experiences and the instructions presented.
- Confidence refers to the importance of developing desirable expectations for the students’ performance on the learning activity.
- Satisfaction will be obtained at the end of the learning process when students are permitted to apply new gained knowledge or skills.

B. Gamification

Gamification is the process of integrating elements of game design into non-game contexts to increase user engagement [11] and improve user motivation, participation, and productivity [4]. In the education sector, gamification is a simple game that encourages beneficial engagement between learners and instructors. Developers, who are sometimes also lecturers, can customize and adjust the gamification according to their needs [12]. More specifically, gamification can be defined as the technique of introducing game dynamics and mechanics into classroom learning, e-learning, or blended learning to stimulate participation and engagement when used in a learning context [1]. The use of gamification in learning has been shown to improve student engagement, which can have a positive effect on learning outcomes [13]. The gamification model that is integrated into several educational applications and processes may feature badges, leaderboards, progress bars and meters, points, and other prizes that may be earned by and be given to students. To influence student behavior, educational gamification utilizes game-like rules, player experiences, and cultural roles. [14] Using points, achievements, and badges, users can progress in a gamified application to achieve defined goals [12].

C. ARCS+G

The ARCS+G model is an enhancement of the ARCS model that includes gamification of learning, which was proposed by Hamza et al.. It will be adopted to integrate game design elements with the ARCS model into the design of MR applications based on the game dynamics, such as achievement, reward, status, competition, self-expression, and altruism. The important features between the ARCS model and gamification will be used to position these elements in the ARCS model categories. However, the gamification paradigm employed in this model does not include all the characteristics; only the most fundamental characteristics of human desire and gameplay are considered [1].

III. DESIGN PROCESS

The design process of the application will be established based on the steps of the ARCS motivational design process shown in Fig. 1. The application of MR design in each step of the ARCS motivational design will be explained below.
4) Analyze existing materials and conditions: At this step, existing materials are analyzed, and the condition where the learning will take place in MR to help find areas that need to be improved and integrate the most appropriate game elements to the application.

5) List objectives and assessments: A gamification strategy is employed to satisfy the motivational dynamics. The design objectives and assessments will be based on the game elements. MR environments allow the spatial placement of these goals so this ability should be incorporated at this stage.

B. Design

6) List potential tactics: Possible tactics that might help accomplish the motivational objectives can be one of the gamification components, mechanics, and dynamics. MR features could be used to achieve the gamification components. MR supports collaborative learning, which can make the competition between students more enthusiastic. Also, MR allows remote students to interact with in-class students and allows for spatially aware design reviews in which students can see and annotate 3D models in real time.

7) Select and/or design tactics: Using the enhanced ARCS+G model, game elements can be implemented with confidence, including rewards, status, competition, and satisfaction, which in turn includes achievement, self-expression, and altruism. MR opens a new world of opportunities to visualize these elements for the user and their peers.

8) Integrate with instruction: Here, a gamified MR application is designed and developed to combine the instructional and motivational components. MR allows for instructions to be presented by an avatar or other embodied 3D representation sharing the environment with the student as a co-learner.

C. Develop

9) Select and develop materials: MR applications can be developed using a variety of game development engines such as Unity, Unreal, etc. For MR, there are different tools that can be utilized to deploy MR application such as VR and AR HMDs. Also, there are a wide range of platforms in which the MR application can be embedded in a variety of computer-based learning platforms such as e-learning system (Moodle, Blackboard, Brightspace, etc.), homework, and tutorial system as well as in the virtual world system [13].

D. Evaluate (Pilot)

10) Evaluate and revise: Using the Instructional Materials Motivation Survey (IMMS) to evaluate the participants’ motivation after the MR experiment session, the motivational effects can be observed and obtained through the recording feature in HMD devices.

IV. DISCUSSION AND CONCLUSION

This was the first step in applying ARCS+G to MR educational applications. This approach was limited as it reports on the adjustments needed rather than proposing a completely new methodology. This was conducted when multiple prototypes have been developed under this approach. Experiments were conducted and lessons were learned from their creation. It was not possible to create such a methodology. The contributions of this brief paper are in outlining the differences to the ARCS+G model when used in MR in terms of its motivational design. Through this approach, educators and developers can customize the environment to meet their own unique learning needs. This motivational design model may assist educators and developers in designing and developing MR-related applications or any other similar technology for their students. MR with gamification needs further empirical testing to determine its effectiveness. Therefore, we look forward to designing and developing a gamified MR application that will be used by university students to test the effectiveness of gamified MR in education. This application will be entertaining, motivating, and engaging for students.

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Work-in-Progress—Computer Vision Methods to Examine Neurodiverse Gaze Patterns in 360-Video

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Abstract—Computer vision (CV) is a subset of artificial intelligence (AI) that focuses on enabling computers to detect and understand objects from visual stimuli and multimedia. With advances in computational power and open-source libraries, more educators and instructional designers are seeking to capitalize on the perceived benefits of CV. This work-in-progress paper reports the CV approach our research team has developed to explore the usage patterns of neurodiverse learners within a 360-degree spherical video-based virtual reality system.

Index terms—computer vision, SVVR, artificial intelligence, 360-video, autism

I. BACKGROUND & RELATED WORK

Research on the use of artificial intelligence (AI) in education has been ongoing for over 30 years [1]. In this time, researchers have explored widely the potential of AI to facilitate the teaching and learning process and to simulate human intelligence, with the goal of facilitating inferences, judgments, and/or predictions in educational settings [2]. Recent computational advancements have led to a renewed interest in using AI technologies in learning contexts, a growing number of studies are underway to explore the tremendous potential of this technology [3]. Among AI approaches, computer vision (CV) has emerged as a particularly relevant technology for assisting instructors in evaluating student engagement and evaluating instructional materials. CV is a subset of AI, deriving meaningful information from visual input such as images and videos and, in some cases, acting based on its interpretations [4]. With CV having gained substantial attention in numerous industries, including automotive, health care, energy, and manufacturing [5], the expectation that this technology might abet disruptive innovations in educational and learning contexts is growing.

A. Examples of Computer Vision in Education Research

CV has been examined across a range of educational and learning contexts. In one example, researchers examined student engagement within classroom recordings [6]. Findings suggest that CV can be used to recognize individual behaviors with ‘reasonable accuracy’ and as a way of quantifying in-class behaviors. CV is also being widely considered to detect and assess live learner and instructor interactions as a way of providing actionable feedback [7]. Researchers have examined how learners attend to objects and interact with instructional videos [8] and how CV can aid in the improvement and development of instructional materials [9]. However, the majority of extant CV and education research has been applied with neurotypical learners. Research exploring how CV methods and processes might be applied for neurodiverse learners is limited, despite evidence that this approach has vast potential for supporting neurodiverse groups [10].

In addition to this, most of the research tends to follow what is known as a medical model, which focuses on early detection and diagnosis of neurodiverse characteristics [10]. For example, CV methods have been deployed to analyze attention and psychological factors encoded in eye movements and to develop emotional classifiers [11] of individuals to help in diagnosis of autism [12]. However, a more social-ecological perspective for incorporating CV might consider how researchers could leverage this technology to better understand how learners attend to and engage in technology-mediated learning environments and multimedia [13]. Whereas most prior research in this area has utilized eye tracking to make inferences about how neurodiverse learners attend to objects of importance [15], advancements in CV provide new opportunities to examine this area.

II. VIRTUOSO-SVVR

The research presented within this work-in-progress paper reports the approach one team of researchers has developed to implement CV as a way of examining usage patterns of neurodiverse learners within a 360-degree spherical video-based virtual reality (SVVR) system called Virtuoso-SVVR [16].
Virtuoso is a virtual reality intervention that was designed for and in collaboration with autistic adults enrolled in a day program called Impact Innovation. Impact Innovation provides support and services for over 20 autistic adults in a year-round program with an emphasis on promoting vocational and social opportunities. The target goals of Virtuoso were situated around providing a formalized training routine for public transportation, as this is often cited as being one of the greatest barriers to community integration for individuals with disabilities [18]. Virtuoso uses a stage-wise instructional scaffolding technique that progresses from simple to complex across a spectrum of low-tech to high-tech tools [20]. This stage-wise approach includes (1) skill introduction, (2) 360-degree video modeling of the skill, (3) rehearsal of the skill within a fully immersive VR scenario, and (4) real-world practice of the skill. The work presented in this manuscript focuses only on the second stage of our approach (360-degree video modeling of the skill). In this stage, learners are presented with a series of 360-degree videos that present the task of using public transportation bus into 4 discrete subskills that were determined through task analysis, namely (1) checking the schedule, (2) walking to the shuttle stop, (3) checking a mobile application, and (4) getting on the shuttle (https://www.youtube.com/watch?v=5oiKnsiybeM). Virtuoso-SVVR functions across a range of devices, including Google Cardboard and Oculus Rift head-mounted displays.

III. METHODS

This work took place within the context of a structured usage test for Virtuoso that was completed in June of 2019. Participants consisted of autistic associates from a day program (n=6) and neurotypical (NT) staff members from the same program (n=6). All participants completed assent and consent procedures prior to taking part in the study. All ASD participants were male with an average age of 26.6 years. Neurotypical participants were both male (n=3) and female (n=3) with an average age of 22.6 years. The researchers sought to address the following research questions: (RQ1) How can computer vision algorithms detect variation in usage patterns of autistic and neurotypical users of a SVVR system? (RQ2) What usage patterns emerge as users watch videos within a SVVR system?, and (RQ3) How do usage patterns compare and differ between neurotypical and autistic users of a SVVR system?

A. Data Collection and Preparation

Open Broadcaster Software (https://obsproject.com/) was used to capture screen recordings while participants used the Virtuoso-SVVR system. All recordings were captured at the same resolution. The output of this process was four recordings for each participant with one video for each of the discrete tasks (i.e., checking the schedule, walking to the shuttle, application, and getting on the shuttle), for a total of 48 videos. One neurotypical participant’s video output was corrupted. A Python script was developed to detect objects in the video recordings. The script was built around TensorFlow (https://www.tensorflow.org/), an open-source software library for machine learning. Image AI 2.0.3 was also used, which is a CV Python library (http://www.imageai.org/). Our script segmented SVVR videos into individual image stills at 30 frames per second and provided a detected object classifier and probability based on pre-trained YOLOv3 (https://viso.ai) neural network weights. Frame number, object class, confidence value, and bounding box coordinates were written to a CSV file for each video. CSV files were reviewed, classifications with a confidence score of 80 and above were saved, and classes were reviewed for accuracy [21].

IV. ONGOING ANALYSES

Preliminary analyses are currently underway using sequential pattern mining and entropy methods. Sequential pattern mining will help identify explicit meaningful patterns, while entropy analysis measures the complexity and uncertainty of these behaviors. Markov Chain modeling will determine the global network structure of behaviors. These analysis techniques were chosen as they are all related to uncovering statistically relevant patterns within data examples. Since our research goals are to explore variations in how learners attend to objects within 360-degree videos, these three techniques provide us with preliminary insight to iterate on and inform next steps.

Sequential pattern mining is one of the commonly used learning analytics methods to discover frequent patterns from input sequences [22]. It can be used to understand students’ learning behaviors in learning environments [23]. It takes several sequences as input and calculates statistically relevant patterns. Its output is several patterns and their support values. The support value, which lies between 0 and 1, indicates the possibility of the pattern occurring in the given data set. The higher the support value is, the more frequently the pattern occurs, allowing discovery of meaningful patterns and comparison between the two groups of participants.

Entropy, or information density, measures how much content an event carries, or the uncertainty in a series of numbers [24]. The value of entropy lies between 0 and 1. The higher the value is, the more information the unit carries, and the higher level of uncertainty it is. Entropy analysis has been used to measure the complexity of learning behaviors presented in solving ill-structured problems [25]. We are conducting the entropy analysis to understand the uncertainty on behavior sequences between the two groups of participants (Fig. 1).

![Example preliminary entropy analysis](Fig. 1)
Markov Chains are stochastic models describing a sequence of events where the probability of a state depends on the previous state [26]. Markov Chains use network structures to condense the data. Markov Chains present a global representation of the data where each state is an item, and each item is taken into consideration. We are implementing this method to determine the sequence of focal objects in the intervention.

V. CONCLUSION

This work-in-progress paper presents a novel approach to utilizing CV as a way of assessing how neurodiverse learners attend to objects within a spherical video-based virtual reality system. Work is ongoing with an emphasis on developing analysis techniques to bring to light gaze patterns that might inform directions for future research and applied design decisions. Findings from this work can inform the design of multimedia experiences for learners across the spectrum. Limitations in the approach concerning the misidentification of objects is an area for future research.

VI. REFERENCES


Abstract—Recent research has produced mixed results regarding the effectiveness of learning in VR. It has been suggested that the rich multisensory input in VR may induce cognitive overload that impedes the learning process. Cognitive load is typically measured by administering questionnaires. Although questionnaires are easily used, they imply the need to interrupt students during learning or to assess cognitive load in retrospect. In this work-in-progress paper, we argue that VR motion tracking data has the potential to provide unobtrusive, yet valid measures of cognitive load. We report preliminary results from a user study that aims at predicting cognitive load using the tracking data of a VR headset and two hand controllers. Using a recurrent neural network, we were able to distinguish between different levels of cognitive load with an accuracy of more than 88 percent. Based on this finding, we reflect on future research directions and practical considerations.

Index Terms—virtual reality, cognitive load, motion tracking, N-back task, learning analytics, neural networks

I. INTRODUCTION

Students typically report higher levels of enjoyment and learning satisfaction in virtual reality (VR) compared to classroom education or learning with desktop applications [1]–[4]. At the same time, it is noteworthy that the benefit of VR is highly debated. Several studies associated VR with poorer learning outcomes compared to other modes of instruction [5]–[8] and it has been suggested that VR can induce cognitive overload that hinders learning. This argument is interesting since it contradicts the traditional view that VR enables naturalistic behavior using a 3D interface [9].

In fact, previous research has identified various sources of cognitive load in VR learning environments [10]. This entails traditional sources of cognitive load (task complexity, instructions) but also factors that are more specific to learning in VR, such as the level of immersion [11] and interaction techniques [6]. Consequently, several studies have investigated means to reduce cognitive load, for example pre-training [12], segmenting, and generative learning strategies [3], [7], [13].

All the above findings highlight the importance of assessing the students’ cognitive load in VR learning environments. In this work-in-progress paper, we reflect on the interdependence between cognitive load and the human motor system and how it can be exploited to derive an alternative measure of cognitive load. We argue that VR motion tracking data could overcome the shortcomings of cognitive load questionnaires. Supporting this view, we report the preliminary findings of a study that aims at predicting cognitive load using the tracking data of a VR headset and two hand controllers.

II. MEASURES OF COGNITIVE LOAD

A large variety of questionnaires have been developed that enable convenient, reliable and valid measures of cognitive load, see [10] for an overview. Besides their obvious advantages, the administration of questionnaires requires researchers or educators to interrupt students while learning or to use and interpret the questionnaires as retrospective measures. Second, it is noteworthy that the most questionnaires were typically not developed and validated for the use in immersive learning. In contrast to questionnaires, physiological parameters (e.g. EEG, pupil dilation, galvanic skin response, etc.) offer non-obtrusive measures of cognitive load [14]–[17]. However, they require costly or cumbersome equipment that might not readily be used in an educational context [18].

III. COGNITIVE LOAD AND THE MOTOR SYSTEM

In light of the pitfalls of traditional measures, it is fortunate that VR offers new opportunities to assess the cognitive load of learners. We argue that this opportunity comes in the form of the motion tracking capability that has become a standard feature for most consumer VR headsets.

In fact, there is a large body of evidence showing interference of cognitive and motor tasks [19]. For example, it was repeatedly found that performing a cognitive task has effects on postural control [20]–[22], gait parameters [23]–[25], and arm movements [26], [27]. These findings demonstrate that motor and cognitive tasks compete for limited processing resources [19], [25]. According to this view, the human motor system is indicative of different levels of cognitive load. We argue that this idea could be transferred to an educational context, where subtle movements of the body could be used to act as on-line measures of cognitive load.

IV. USER STUDY

We have set out to conduct a user study in order to explore the usefulness of VR motion tracking data to measure cognitive load. In the following, we present the preliminary
results of 7 participants (2 females, mean age = 39.7, all right-handed). The study adopts the methods and materials shared by previous studies [15], [16]. The task represents a virtual variant of a classical N-back task, which is described below. The differences between our study and the adopted research methods were the type of VR headsets (Oculus Quest vs. HTC Vive) and the sensors that were used for the discrimination of cognitive load (VR motion tracking in the present study vs. EEG or fNIRS in previous research).

A. Procedure

Wearing Oculus Quest VR headsets, the participants were placed in a virtual spaceship environment. They were instructed to react to sequences of colored balls (red, blue, purple, green, or yellow) that appeared on a virtual podium in front of them. Each ball remained on the podium for four seconds. Within this time window, participants had to take the correct action according to the following rule: if the current ball was the same color as the ball presented N trials before, the participants were instructed to pick up the ball and place it in a receptacle in the shape of a treasure chest. All other balls (i.e., non-targets) had to be placed in a vase-shaped receptacle opposite to the treasure chest.

The experiment started with a practice block, in which the participants could familiarize themselves with the VR environment and the task. Participants practiced the 1-back task until they completed a full sequence of twenty balls without making a mistake. Afterwards, three experimental blocks were presented. Each block was characterized by a specific instruction (0-back vs. 1-back vs. 2-back), which was then followed by four sequences of twenty balls. The order of the blocks was randomly determined for each participant.

In contrast to the other blocks, the 0-back block did not require the participants to memorize previously seen colors. In this task, the participants were merely asked to treat all red colored balls as targets and all other colors as non-targets.

The whole experiment had a duration of approximately 18-20 minutes, depending on the number of required practice runs. Fig. 1 shows exemplary sequences of the 0-back, 1-back, and 2-back task.

B. Analysis & Results

As predictors of the N-back level, we use the changes in the position (x, y, z) and rotation (yaw, pitch, roll) of the participants’ head and hands as measured by the VR headset and two hand controllers, resulting in a total of 18 features. These features are recorded every 100ms during each trial. The collected data is balanced, therefore the accuracy of a baseline classifier that always predicts one class (i.e. N-back level) would be around 33%. Since it is suitable to capture temporal dependencies in sequential data, we use a recurrent neural network with long-short term memory [28] to predict the N-back level. Having split the data into 60% train, 20% validation, and 20% test set, we evaluated the proposed model on the test set and obtained an accuracy of 88%.

V. Discussion

We set out to argue that VR motion tracking data provides an alternative to established measures of cognitive load. Having started with data collection, we found preliminary evidence that positional and rotational data gathered from a consumer headset and two hand controllers were able to distinguish between the different levels of the N-back task with high accuracy. This is in line with the close connection between cognition and the motor system [19]. Varying the difficulty of a task has small, however measurable effects on various motion parameters [20]–[24], [26], [27].

Using VR motion tracking data as an indicator of cognitive load opens up many possibilities. Educators could use real-time measurements of cognitive load to identify poor instructional design. For example, if a large proportion of students showed signs of high cognitive load, educators could take
appropriate countermeasures such as pre-training or segmentation [3, 7, 12, 13]. Importantly, educators could monitor and adapt learning content for each student individually, which avoids cognitive overload for weaker students or counteracts the expertise-reversal effect for stronger students [29].

Despite the promising preliminary results, we have identified a few possible pitfalls that deserve more attention. First, some of the postulated areas of application rely on the ability of motion tracking data to distinguish between different types of cognitive load. In this study, we only varied intrinsic cognitive load, i.e. the mental effort induced by the task itself. Therefore, future studies should investigate whether motion tracking data can also be used to measure extraneous cognitive load, i.e. unnecessary load caused by poor instructional design, visual complexity or interaction techniques.

Second, it has yet to be shown whether the potential of motion tracking data also generalizes to other tasks. For example, it is conceivable that motion tracking is less useful in tasks that require the user to perform more complex movements. These movements may introduce noise that impairs the ability of a machine learning algorithm to discriminate between different levels of cognitive load.

VI. CONCLUSION

VR motion tracking data combines the convenience of questionnaires with the ability to provide unobtrusive, real-time measures of cognitive load. In that regard, it is a strong candidate to supplement or even substitute existing subjective or physiological measures of cognitive load. Although it requires more investigation, we found preliminary evidence that motion tracking can play an integral part in the design and adoption of VR in education.

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Work-in-progress—Gamifying the process of Learning Sign Language in VR

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Abstract—This study recognizes the need for providing a tool to facilitate learning British Sign Language (BSL). Virtual reality coupled with gamification holds exciting prospects to accommodate this need. This paper presents a work-in-progress study that focuses on evaluating the impact of combining scaffolded instruction with gamification to design a 3D interactive game to support learning the BSL alphabet. The paper outlines the project motivations, its aims and objectives, the proposed research methodology, and the expected contributions to knowledge.

Index terms—immersive learning, adult learning, serious games, game-based learning, video learning, British Sign Language.

I. INTRODUCTION AND PROBLEM STATEMENT

The need and the benefits of learning a sign language are growing in popularity. People not only learn sign language as a response to their hearing impairment, or to communicate with their deaf family member/s, a growing proportion of hearing people want to be able to communicate with those of the deaf community [1]. The American Sign Language (ASL) is among the five most-used languages in the United States behind Spanish, Italian, German, and French, and has become one of the most popular language classes in colleges and universities. Many schools in the UK teach at least the British Sign Language (BSL) alphabet and there is an ongoing debate in the parliament for BSL to be a part of the national curriculum. Learning a sign language is as hard as learning any other foreign language, especially past the age of optimal language learning (around the onset of puberty) [2].

Learning a visual language like BSL could be well supported by the use of highly visual resources, such as video, or a rich graphical environment. VR could hold the key to this as it offers exciting prospects to support learning by enabling memorable and immersive experiences. There is enough evidence of research agreeing that VR supports high motivation, makes content more engaging, allows greater control over one’s environment, and facilitates repetition and self-pacing. All those have broader cognitive effects on the perception that seem to make learning stick. However, VR does not automatically engage students. VR educational resources need to be designed based on a framework that allows organizing activities and assessments aligned to learning objectives. In addition, learners need to be supported throughout the entire learning process [3]. Scaffolded instruction is an approach where support is offered to help learners develop new skills through modeling a task, giving advice, and/or providing coaching. Support is gradually removed as students develop new skills and autonomous learning strategies [4].

To further motivate and engage learners and stretch knowledge retention VR can be coupled with gamification [5]. The main goal of gamification is to engage learners and help them enhance certain abilities by introducing objectives that give learning a purpose and support behavior change. Although it is agreed that gamification can promote engagement and contribute to the construction of knowledge, scientific studies have shown adverse outcomes related to the impact of gamification in learning. The way game elements are used for gamification produces different effects, burdening the process of determining which elements or collection of these elements can promote engagement and learning for the targeted group of users, completing specific actions [6]. In addition, the way game elements are integrated into the learning resource is determined by the way users access the learning resource. In the case of designing an educational resource for learning BSL, how users learn and practice signing depends on the device the learning resource is being accessed. Depending on how the learning resource is accessed, desktop, mobile, or VR, determines what technology can be used for learning and practicing signing BSL (hand tracking, wearables).

The rest of this paper presents the research questions driving this study and the proposed methodology to address those research questions. It continues by describing the research instruments that have been created to support the study and concludes by discussing expected contributions to knowledge and future work.

II. RESEARCH QUESTIONS

The goal of this work in progress project is to effectively measure the impact of combining scaffolded instruction with gamification while experimenting with different design decisions to create a VR interactive game to facilitate learning.
the BSL alphabet. The research questions addressed by this research project are the following:

- **RQ1**: Gamified VR is more effective for learning compared to video?
- **RQ2**: People learn more effectively BSL signs in immersive or non-immersive (desktop) VR?
- **RQ3**: Chunking BSL signs assist memorability?
- **RQ4**: The visual complexity of the design of the space in VR distracts learners and affects learning?
- **RQ5**: Can mnemonics help in retaining more information in VR?
- **RQ6**: Signing with or without controllers affects learning and user satisfaction?
- **RQ7**: How can we understand and measure objectively learner behavior and learning in VR?

### III. RESEARCH METHODOLOGY

A rigorous methodology is used to study the research questions and address the project aims consists of the following stages:

- **a)** it builds a VR interactive game for learning the BSL alphabet combining scaffolded instruction [1], experimenting with different design decisions to facilitate learning in different learning stages, learn, practice, assess (discussed in Section IV).
- **b)** it builds a VR interactive game for learning BSL signs integrating analytics in every learning stage of the game to understand user and learning behavior.
- **c)** the experimental apparatus of this study follows Mayer’s Media Comparison Experiments [7] to test/compare if participants achieve better learning while using a video-based educational resource versus a VR interactive game immersive and non-immersive (desktop) addressing RQ1 and RQ2.
- **d)** it uses analytics and biometric data, specifically, eye-tracking, to understand the user and learning behavior addressing RQ7.
- **e)** immersive user satisfaction is evaluated using the User Experience Questionnaire (UEQ) [8] which measures usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation), and immersion based on the Immersive Experience Questionnaire (IEQ) [9].

The following sections elaborate on the creation of the research instruments to support the study.

### IV. PROTOTYPE DESCRIPTION – VR INTERACTIVE GAME

Currently, the project is in the stage of developing the research instruments required for this study. These are: (a) a video-based educational resource; (b) a non-immersive interactive game (desktop); and (c) an immersive interactive game (VR game). The video-based educational resource consists of short videos demonstrating the signing of the BSL alphabet that play 3 times each. The players can keep watching the videos as many times as required to learn them. The VR interactive games (non-immersive and immersive) are built to support people to learn the BSL alphabet by coupling video and gamification. Those are extended versions of a game that has been presented elsewhere [10]. This game is being extended and refined based on empirical study results involving 24 participants. The VR interactive games are based on a scaffolded instructional approach to assist learners in the process of learning the BSL alphabet in three levels.

#### A. Level 1 – Learn

In this level, the players explore the environment and discover BSL alphabet signs. Once a letter/sign is found a corresponding video play demonstrating how this is signed. Videos can be played as many times as required for the user to feel confident, they have learned the sign. The initial version of the game contains only 8 signs. The current version of the game is being extended to include all 26 BSL alphabet signs. To maintain the user’s interest and to support memory, three different environments have been created holding 8, 8, and 10 letters respectively to cover all the BSL signs. To address RQ4 those environments differ in terms of visual complexity: (a) environment 1 – holding letters A to H is a very busy; (b) environment 2 – holding letters I to P is very simple; (c) environment 3 – holding letters Q to Z is very simple with embedded mnemonics, those are 3D objects the name of which start with the presented sign (this will help us evaluate RQ5). According to dual coding theory [10] imposing familiar visual images of objects on letter shapes should enhance their memorability. In addition, as players progress to environments 2 and 3, their memory load increases, and extra scaffolding may need to be provided. Mnemonics might provide this extra support.

#### B. Level 2 – Practice

The system/game prompts a letter, and the players practice the formation of the corresponding BSL sign with their hands. To address RQ6 two versions of the VR interactive game will be created:

- **a)** a non-immersive (desktop) experience integrating a computer vision script, in Python, engaging ready-to-use hand recognition machine learning models from the Mediapipe Framework developed by Google. (Fig. 1 (a)) detecting whether the user formed the correct sign based on the proposed in-game letter. The position of the real hands is geometrically projected onto the virtual hands in the game (Fig. 1(b)).

- **b)** an immersive VR experience making use of the Valve Index Controllers that have built-in hand recognition (see Fig. 2). For the Oculus Quest 2 VR device (see Fig. 3), the hand recognition software is built-in and uses onboard cameras to detect the hands without using the controllers. Letters are prompted until they are formed correctly three times each, else the corresponding video is played again offering another practice opportunity to users.

#### C. Level 3 – Assess

Once learners feel confident with their mastery of BSL scaffolding is removed, and they can assess their knowledge by playing a game against a virtual enemy. They keep the enemy away by speaking aloud the letter of the corresponding sign above the enemy’s head.

To address RQ3 and RQ7 certain logs have been integrated into the game to collect precise information related to the number of times users watched a video of a BSL sign, the order
they collected the signs; the total amount they spend in each level; the period they spend training each sign; the number of times they failed forming a sign correctly; the number of times they revised a sign; their final performance. In addition, the iMotion module for VR Eye Tracking is integrated into the VR interactive game to allow understanding of where users look in VR while wearing headsets.

V. THE STUDY

This is a comparative study that evaluates learning and user satisfaction using the three different research instruments discussed in (Section IV). The participants will split into two groups each using: Group A – the video-based learning resource, followed by the non-immersive interactive game (desktop); Group B – the video-based learning resource, followed by the immersive interactive game (VR game).

The study will run in a VR lab. Eye-tracking will be used to objectively and accurately record and analyze visual behavior. Eye-tracking will allow uncovering usability problems without disturbing natural user behavior. Following their interaction with the educational material to learn BSL participants will complete the UEQ [8] and the IEQ [9]. The data will be analyzed using between-subject statistical analysis methods to compare the effectiveness of the video-based learning resource compared to the desktop 3D interactive game and the immersive interactive game.

VI. EXPECTED CONTRIBUTIONS TO KNOWLEDGE

The expected impact of this project on the immersive learning community is outlined below:

- empirical research for the impact on learning and user satisfaction of the VR interactive game (desktop and VR) for learning BSL signs combining scaffolded instruction and gamification.
- research-informed design guidelines for the successful integration of specific design decisions and game mechanics to better support learning, and memory retention.
- evaluate learning and user satisfaction in VR with objective measures.
- the development of a scalable resource for learning the BSL alphabet effectively and pleasantly.

VII. CHALLENGES, DISCUSSION, AND FUTURE WORK

Currently, the project is in the stage of developing the research instruments and planning the study. Recruiting an adequate number of participants to take part in the study to provide statistically valid data is challenging as the expected duration of each session for a player to go through all levels is long. Concluding user behavior and learning by combining the data collected from the game logs and eye-tracking is also challenging as there is no framework to guide this process. The future development of this project will involve extending the VR interactive game to include more languages and more BSL topics. It will also be expanded to be accessed with smartphones, but this may affect the quality of the game and it restricts the ways of interacting with the game to practice the formation of the signs.

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Work-in-progress—Avatar vs Teams: Co-Presence and Visual Behavior in a Videoconference Cooperative Task

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Abstract—The need for effective remote communication solutions is increasing, and videoconferencing tools are the top choice for many. Furthermore, the alternative of using avatars instead of video-based conferencing for enriching the communication process is gaining popularity. This work-in-progress presents an avatar-based remote communication system for studying the exerted sense of co-presence and visual behavior of the user compared to a popular business-oriented communication platform. Users reported a higher sense of co-presence in the avatar condition with an increase in whole visual fixations dedicated to the avatars in comparison to their video feed faces during the cooperative task.

Index terms—Avatar, co-presence, vision, communication

I. INTRODUCTION

In recent years, the average user is getting more used to using videoconferencing tools for a myriad of activities including online education, socializing, working, and even health-sensitive situations [1]. Hence the necessity for robust remote communication systems is skyrocketing as a consequence. There is an important amount of literature exploring the media effect of visual and behavioral realism in avatars on the perceived quality of communication in an immersive virtual environment (VE) utilizing Virtual Reality (VR) head-mounted displays (MHD) [2], [3]. However, the amount of work focusing on the direct comparison of humanoid avatars represented in conventional 2D monitors contrasted with popular video-based conferencing tools is surprisingly lacking. Furthermore, some people feel uncomfortable sharing their private house environment via webcam with others, exposing themselves to potential family members’ interruptions or pets suddenly jumping inside the camera’s field of view (FOV). To make matters worse, there is evidence that “increases in videoconferencing use during the COVID-19 pandemic were associated with greater appearance dissatisfaction, especially facial dissatisfaction,” [4] with people becoming overly conscious about their camera feed for the wrong reasons, breaking the communication engagement and sense of co-presence due to unnecessary distractors as a result. Considering all the reasons above, we implement an avatar-based conferencing tool for exploring the exerted sense of co-presence and visual behavior during a cooperative task. We present our experimental approach and initial findings in this work.

II. METHOD

A. Experiment Setup

We designed and implemented our experimental system to allow the controlled evaluation of interpersonal communication behavior during an active cooperative conversational task under two conditions: (1) CG-based Humanoid Avatar; (2) Video-based conference call. The experiment was performed in our office spaces, with the subject and the experimenter sitting at adjacent working desks facing a PC monitor equipped with a standard webcam, wearing closed-back headphones and standard PC microphones. The subject monitor was also equipped with Tobii Pro X3-120 screen-based eye tracker.

All the elements were powered by a machine equipped with NVIDIA RTX 3070 GPU, Intel Core i7 10700K CPU, and 32 GB of RAM. For the Avatar condition, we implemented a virtual environment emulating an office space rendered with the Unity game engine (Unity 2021.1.16f1). The sessions of the experimenter and the subject were connected via Unity MLAPI, the newer available multiplayer and networking solution from Unity at the moment of writing this paper. The VE consists of a start screen, where the user selects to be either the Host or Join the session by inputting the IP address of the Host machine. The subject then joins the session and proceeds to listen to the explanation of the task to perform before starting the experiment. After confirmation of the subject’s understanding, the task starts.

The avatars were created with Ready Player Me online service [5] and imported in Unity with their SDK, using a picture voluntarily provided by the subject as the model base. The avatars use lip-syncs, moving their lips in accordance with the microphone vocal soundwave input. The avatars can rotate on their pivot, turning to look at the user in direction of the screen, looking at the other avatar, or looking at the shared slide containing the task items. The subject avatar’s orientation is
determined by the eye fixation locations of the subject, while the experimenter’s avatar orientation is set to move according to the scripted discussion content, looking deliberately in each direction in response to the subject’s avatar and the focus point of the discussion.

The Teams condition consisted of the same task performed with the same system configuration to guarantee consistency. The study has a within-subjects design, with each subject randomly experiencing one or the other configuration in sequence, followed by a co-presence questionnaire applied right after each condition.

B. Task

The task selected for the evaluation is an adapted version of the Desert Survival Item cooperative exercise, commonly used for testing interpersonal communication, social presence, and cooperation in co-located communication environments [3][6]. The subject is presented with a situation of emergency, finding himself in an air crash together with the experimenter, having only 5 minutes to rank from most important to least important the presented items to rescue from the airplane to maximize their probability to survive and being rescued. The user is required to explain the reason for each choice, while the experimenter comments based on a script with the predetermined pros and cons for each item. After 5 minutes have passed, the desert task ends and the user proceeds to answer the questionnaire. This process is done twice (i.e., once for each condition). The items presented in the avatar and Teams condition are randomized from a pool of 14 items, displaying 7 in each condition. The workflow of a session with the avatar condition can be seen in Fig. 1, while the equivalent Teams session can be observed in Fig. 2.

C. Participants

For the experiment, we gathered 11 volunteers from our offices (F = 2, M = 9), with ages ranging from 56 to 25 (M = 36.00, SD = 9.86). All the subjects were frequent users of Microsoft Teams in their daily work. They voluntarily signed an agreement for using their images and photos before participating in the experiment.

III. METRICS

We focused on measuring two types of metrics, focusing on the exerted subjective level of co-presence and the quantitative measure of whole fixations.

A. Measuring Co-presence

Co-presence refers to the perceived sensation of being together in the same space, which may lead to better mental and emotional mutual understanding between interlocutors [3]. [7]. For measuring the perceived sense of co-presence, we applied the 34-item version of the Networked Minds Social Presence Inventory [8]. The questionnaire was administered post-test to the subjects immediately after each experimental condition without time limitation for its completion.

B. Measuring Whole Fixations

For determining the visual behavior of the users, we decided to focus on the stricter criteria of “whole fixations” output instead of total fixations within an Area of Interest (AOI). Whole fixations must be preceded by a saccade, be succeeded by a saccade, and occur within the AOI and the time of interest (TOI). In this case, the TOI refers to the 5 minutes allotted to the task, while there was three AOI in each condition: (1) The slide containing the items for the survival items task; (2) the face of the avatar of the subject or the subject’s face in the video feed depending on the condition; (3) the face of the avatar of the experimenter or the experimenter’s face in the video feed depending on the condition. The fixation data were obtained and analyzed using Tobii Pro Lab software.

Fig. 3. Co-presence mean score graph: Avatar condition (left) versus Teams condition (right).
IV. RESULTS AND DISCUSSION

A. Co-presence

We computed the total cumulative mean values of the Networked Minds Social Presence Inventory for each participant, obtaining the total mean of each condition. The Avatar condition showed a higher sense of co-presence (M = 153.09, SD = 21.83, scale range = 34 - 238), while the Teams condition resulted in a lower perceived sense of co-presence (M = 141.73, SD = 21.34, scale range = 34 - 238). Considering the within-subjects design, we performed a paired sample t-test with assumed normality based on histogram inspection, Kurtosis, and Skewness, resulting in a significant difference with 95% of confidence (t (10) = 2.92, p = 0.015). The findings suggest that our avatar-based implementation may affect positively the perceived sense of being “there together” when compared to the Teams video conferencing tool. The means of each condition can be seen in Fig. 3.

B. Whole Fixations

We obtained the total amount of whole fixation duration in milliseconds for each AOI (i.e., faces and slides) by exporting the values registered in Tobii Pro Lab. We computed the means for each AOI in both conditions, obtaining a higher duration of whole fixations dedicated to both avatar faces than their video counterparts. Subject avatar (M = 2052.09, SD = 1830.82); experimenter avatar (M = 9704.90, SD = 9509.17); subject Teams (M = 216.72, SD = 305.02); experimenter Teams (M= 5564.45, SD = 10362.49). Regarding the whole time dedicated to the slides in each condition, the time for the Teams condition was superior (M = 114268.27, SD = 66840.47) to the slide in the avatar condition (M = 97844.72, SD = 62730.99). We applied paired samples t-tests for each condition after confirming normality, not finding statistically significant difference on fixations dedicated to the experimenter’s face in both avatar and Teams condition (t (10) = 1.17, p = 0.26) and slide fixations in both avatar and Teams condition (t (10) = 0.93, p = 0.37). In contrast, there was a highly statistically significant difference in fixations dedicated to the subject’s own face in both conditions (t (10) = 3.20, p = 0.009). The whole fixation mean values for each AOI in each condition can be seen in Fig. 4.

These findings may suggest a tendency of the user to feel more inclined to observe his own avatar interactions with the presented world more than his own image in the video version. We should also consider that pivot turning the avatar towards points of attention may draw the subject’s visual fixations to their own avatar on certain occasions, creating a higher level of engagement without being disruptive enough to lower the sense of co-presence, unlike the Teams condition, which despite having fewer fixations on their own faces, still may be detrimental to co-presence levels due to self-image anxiety [4] amongst other reasons. Hence, if we take these findings into consideration, then implementing CG avatars with controlled gaze-dependent movements in a context that requires higher levels of engagement and attention such as online classes or project discussions may be a promising idea to explore further. Is important to highlight the current work limitations. The test should be applied to a larger number of individuals. Also, the amount and type of communication tasks should be more varied, and further quantitative metrics may be added to better provide a clearer image of the avatar’s underlying effects.

V. CONCLUSIONS AND FUTURE WORK

In this initial exploratory work, we introduced an avatar-based communication system for the evaluation of visual behavior and sense of co-presence in a cooperation task. We found both a higher sense of co-presence and a longer duration of whole fixations dedicated to the avatar condition when compared to the Microsoft Teams video conferencing tool. These initial findings serve as a base for advancing our further exploration of effective remote communication alternatives that may allow meaningful gatherings in a virtual space for several activities in our post-COVID reality.

REFERENCES

Work-in-progress—The Effect of Students’ Perceptions on Intention to use Metaverse Learning Environment in Higher Education

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Abstract—The purpose of this work-in-progress study is to identify the predictiveness of perceived ease to use (PEU), perceived usefulness (PU), perceived enjoyment (PE), and frequency of experience (FE) on the intention to use (IU) a metaverse-based learning environment. A total of 226 undergraduate students participated in the metaverse-based learning using V-story (VirBELA) for a one-semester. Multiple regression was used for data analysis. As a result, PU, PE, and PEU predicted IU in the metaverse-based learning environment. This study empirically analyzed the acceptance factors of learners in a metaverse-based learning environment and is meant as basic data for metaverse research in a learning environment.

Index terms—Metaverse, higher education, intention to use

I. INTRODUCTION

The use of metaverse has witnessed a gradual increase in academic activities like conferences and classes [1]. Metaverse refers to an online platform that enables users to move around virtual spaces using their virtual avatars and interact with other users[2], [3]. The metaverse-based learning environment has been studied with ‘Multi-User Virtual Environment (MUVE)’, but the metaverse-based learning environment has also been garnering attention as an innovative distance-learning platform. Students regards the VR based teaching environments positively [16]. It is necessary to identify the factors that predict the intention to use to help learners increase their acceptance of newer technologies in a metaverse-based learning environment.

According to the Technology Acceptance Model (TAM), Perceived Usefulness (PU) and Perceived Ease to Use (PEU) influence the Intention to Use (IU) [4]. PU means the extent to which the work performance of an individual can be improved when using specific information technology. PEU refers to the degree to which certain information technologies are expected to be conveniently used without much mental and physical effort. External variables were affected in the process of accepting new technologies in accordance with the expanded TAM model [5], [6]. For example, the personal characteristics of users, such as Perceived Enjoyment (PE), can affect technical acceptance. Table I shows the definition of variables in this study (PU, IU PEU and PE).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definition</th>
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<tbody>
<tr>
<td>IU (Intention to Use)</td>
<td>The intention to use new information technology again in the future.</td>
</tr>
<tr>
<td>PU (Perceived Usefulness)</td>
<td>The degree to which an individual’s work performance can be improved when using specific information technology.</td>
</tr>
<tr>
<td>PEU (Perceived Ease of Use)</td>
<td>The degree to which certain information technologies are expected to be easily used without much mental and physical effort.</td>
</tr>
<tr>
<td>PE (Perceived Enjoyment)</td>
<td>To perceive a skill as enjoyable in its own use, regardless of achieving a goal when using new technology.</td>
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II. METHOD

A. Participants

A total of 226 undergraduate students (Males=77, Females=149) took the metaverse-based class as the study participants. There were 53 students in the first grade, 35 students in the second grade, 111 students in the third grade, and 27 students in the fourth grade. They were different frequencies level of experience of the participants in the metaverse-based class: 141 people experienced 1-5 times, 59 people 6-10 times, 19 people 11-15 times, and 7 people 16-20 times.

B. The Teaching Lab Program

To encourage metaverse-based classes, Chonnam National University in South Korea ran the ‘teaching lab’ program. This program recruited professors who are interested in and planned to conduct classes using metaverse. The program assistants support the professors and students in the use of the new platform for the lesson and technical services. Eighteen professors and 708 undergraduate students participated in this program. The frequency of part metaverse in the lesson differed from once to 20 times for one semester, depending on the syllabus and course plan. Fig. 1 illustrates a scene from a lesson in the metaverse.
C. Metaverse Platform: VirBELA(V-story)

V-story is the Korean version of the VirBELA platform that is equipped with presentation functions. Desktop screen sharing and uploading pdf and ppt files are possible for the lesson as shown in Figure 1. Moreover, a laser pointer could be used to increase the learners’ attention (Fig. 2).

D. Data Collection and Analysis

The data were collected at the end of the semester after the conclusion of the metaverse-based class course. Google survey forms were used to collect information about the grade, gender, college, number of courses, frequency of use, perceived significance, perceived usability, frequency of use, and intention to use. For data analysis, both reliability analysis and multiple regression analysis were used in SPSS 22.0.

E. Measurements

The questionnaire of IU includes four items. For example, ‘I am willing to take other classes on the metaverse platform’ [14]. PU questionnaire includes three items. For example, ‘I can handle the functions that I want to use in the metaverse’ [15]. PEU questionnaire consists of five items. For instance, ‘I think I can learn more information by learning in metaverse’ [15]. PE questions consist of four items, and the representative one is ‘I found it interesting to teach at metaverse platform’ [14]. All the questionnaires had all five Likert scales. Cronbach’s alpha for the factors ranged from 0.87 to 0.95, respectively (Table II).

III. Results

Table II shows the descriptive statistics and Pearson’s correlation matrices of the variables in the study. All the variables were positively correlated with IU. The correlational coefficients ranged from 0.539 to 0.921, p < .001.

<table>
<thead>
<tr>
<th>IU</th>
<th>PU</th>
<th>PEU</th>
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<tbody>
<tr>
<td>Pearson Correlation</td>
<td>I U</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P U</td>
<td>.921</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>P E U</td>
<td>.609</td>
<td>.699</td>
<td>1.000</td>
</tr>
<tr>
<td>P E</td>
<td>.805</td>
<td>.789</td>
<td>.539</td>
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</table>

Multiple regression was run to predict IU from PU, PEU and PE. These variables predicted in a statistically significantly manner IU, F(3, 225) = 281.08 (p < .001), R² = .865. PU, PEU and PE variables added statistically significantly to the prediction, p < .05. In the regression equation, the coefficients corresponding to independent variables were PU = .863, PE = .235, and PEU = -.073, in order of highest prediction (see Table III).

IV. Discussion

First, perceived usefulness is the significant predictive factor of the intention to use. This result supports the previous research results. In the previous study, perceived usefulness was identified as one of the significant factors to affect user intention [17]. And, perceived usefulness factor drives the users’ actual behavior [16]. To improve the perception of usefulness, students need to perceive metaverse as efficient, helpful, effective and informative to learn. Future studies need to identify which learning design would be effective for learners to perceive the usefulness of metaverse as a learning tools. The metaverse needs to be useful to gain acceptance among students.

Second, positive emotions like perceived enjoyment are important to predict the intention to use. Enjoyment is regarded as one of the key elements to affect the acceptance of new technology [9]. This could be empirically proved by the enjoyment of SNS [10]. Further studies must identify what
factors predict the perceived enjoyment: avatars, attractive visual images/graphics, and interesting game-based rules.

Third, the perceived ease of use negatively predicts the intention to use. This result is contradictory to the findings of previous studies [6]. In the many literature reviews, perceived ease to use is one of the major elements to greatly affect the intention to use [5]-[8]. Metaverse platforms serve various functions, which imply that the functions could be complicated to operate. Unlike the simple video clip of lecture, learners should control many functions: direction to move, verbal communication, text-based communication, and nonverbal communication like gestures. Based on these results, the metaverse operation icon or key should be instinctive to reduce the cognitive load to operate it. Furthermore, technology anxiety could affect negatively the intention to use [7]. System quality is known to have a strong influence on perceived usefulness [11]-[13]. The participants could experience system problems or technological failures such as sudden stoppages in the metaverse system and frequent errors due to internet problems [16].

V. CONCLUSION

This study identifies the positive effect of the perceived ease to use, perceived usefulness, and perceived enjoyment on the intention to use a metaverse-based learning environment. The teaching lab program at C University in South Korea provided the professors and students with experiences to teach and learn in the metaverse platform with technical support services. Based on the concept that the metaverse-based learning environment could be an alternative university model in the future, this might be a great attempt. To improve the intention to use the metaverse as a learning environment, the metaverse should be easy to use, to provide quality services and enjoyment.

REFERENCES

Work-in-progress—Design of LMS for the Shared Campus in Metaverse Learning Environment

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Abstract—This study is a Metaverse education framework in higher education for a shared learning environment at a consortium university. Here is a case of a consortium university in Korea, which has established a shared learning environment that can entail various advantages by forming a consortium between local governments, universities, and companies. In this work in progress, a Metaverse virtual campus was opened to overcome the distance between regions, and an LMS system was used for learning management. Despite the different attributes of the website and Metaverse, suggestions on how to build a new learning system were described by combining mutual advantages.

Keywords—Metaverse, higher education, shared learning environment, Consortium University

I. INTRODUCTION

As the decline in the school-age population, social and environmental changes such as a sharp decrease in university enrollment resources are occurring. According to OECD Education Working Papers [15], each university institution and government reported that they were taking steps such as collaboration between higher education, alliance, and merger due to the decline in student numbers, increased financial pressure, and intensifying competition for reputation, research personnel, and finance. To overcome these problems, the consortium university, which is a way of sharing resources to reduce operating costs such as providing administrative and educational services and improving the quality of educational services, is a representative example of cooperation [7], [16]. However, there are several problems with shared learning environments such as consortium universities. Examples include limiting quality and diversity, building lecture-sharing systems and operating budgets, sharing class materials, certification, and degree awarding to reduce costs [14].

In Korea, local universities have faced a crisis in the aftermath of population decline and the outflow of local talent to the metropolitan area [17]. The Gwangju-Jeonnam Regional Innovation Platform(GJ RIP) was established by the government, local governments, and local universities to overcome this crisis[18]. GJ RIP is a consortium university platform for responding to innovative industrial and social changes and maintaining continuous higher education [18]. GJ RIP’s main goals are open campus operation, narrowing the gap between universities and the convergence of major education operations, LMS(Learning Management System) operation for joint education, and corporate linkage practical education. As a key platform, it operates iU-GJ (innovation University-Gwangju-Jeonnam), an alliance of 15 universities in Gwangju and Jeollanam-do. iU-GJ has opened a virtual campus using Metaverse to overcome the distance between regions and efficiently utilize the human and material resources possessed by each university.

In the opened Metaverse virtual campus, joint education from 15 universities can be conducted. However, there is no system such as LMS that can manage the results of classes or learning processes based on various people’s activity logs. Since the Metaverse system and the website-based LMS system has different properties, there is a need for a connection method that can effectively perform interworking. If this connection method is established, innovative higher education using Metaverse will be possible. Therefore, the aim of this study is to propose a method of connecting LMS and Metaverse virtual campus.

II. THEORETICAL BACKGROUND

A. Metaverse

Metaverse is a platform that can move to the desired place with an avatar capable of autonomous manipulation in virtual three-dimensional space [1], [2]. A virtual 3D space capable of free movement is not merely an avenue to form social relationships using avatars between users but also makes it easy to communicate emotionally [3].

Metaverse has many advantages and it is possible to recognize that it is in the same space as other students, thereby bringing about interest development [4]. Various situations can be created by applying the actual classroom environment [2]. In universities, interactions between learners and educators occur in physical spaces, which are campus spaces. On the other hand, graduate education mediates the connection between educators and learners through web pages without having to move to campus [5]. In the wake of these differences, there have been cases where university remote education has attempted a virtual
Method to reduce physical disconnection [6]. Therefore, a Metaverse capable of implementing a class environment in virtual reality and interacting with students such as actual classes emerges as an alternative in remote education.

The iU-GJ Metaverse Campus was built using VirBela's platform and characterized by 2,500 simultaneous access to one campus. Moreover, it provides a space optimized for learning purposes, and its function remains the same. It provides virtual spaces and functions suitable for purposes such as space setting, campus broadcasting, private meetings or conference functions, various emotional expression functions using avatars, various activities and meetings, lectures, conferences, and expos. The space composition currently operates a joint integrated campus, and the secretariat, auditorium, small auditorium, lecture building, computer room, expo hall, conference room, and technical support center are being jointly used. Additionally, 15 universities will provide separate operating spaces for each university, providing large auditoriums, small auditoriums, lecture halls, and computer rooms. Fig. 1 illustrates the iU-GJ Metaverse Campus.

Chonnam National University, the university in charge of the project, conducted class design in various formats at VirBela in the second semester of 21 years, and real-time synchronous lectures were mainly conducted. In the form of blended or flipped learning, students took classes in the online LMS system in advance, and learners presented or participated in the metaverse, and classes on the concept of cooperative learning were also conducted for interaction between students. In addition, it is possible to maximize the use of space by directly decorating the classroom space and explaining it. For the design of such a learning platform, workshops and seminars are held for about 5 weeks to instructors in advance, and teaching methods suitable for metaverse are individually provided.

Fig. 1. iU-GJ Metaverse campus.

B. Consortium University

By strengthening cooperation with geographically adjacent universities, a consortium university denotes a concept designed to provide better services. As information and communication technology develops and R&D resources increase, it also cooperates with government agencies and companies or forms national or international consortiums [7]. Through the consortium, universities can enjoy several advantages in revitalizing research, attracting students, and using expensive equipment and services [7]. The shared university platform project, which forms a consortium between universities to share educational and research facilities, jointly

open liberal arts major courses, and support employment, is a representative example of Korea [8].

There are two main backgrounds for GIRIP promotion. From the perspective of local governments, it is possible to revive local universities that are in danger of extinction due to a decrease in the school-age population at the local level of Korea and to overcome difficulties so that they can be used as a bridgehead for future regional development growth. Next, from the standpoint of universities, an education system tailored to local industries is established to provide corporate support such as Optimized Human Resources training and technology development to strengthen university competitiveness and overcome the crisis of extinction. Accordingly, 15 universities in Gwangju and Jeollanam-do participated to create an iU-GJ platform with the concept of Consortium University.

C. LMS

Learning Management Systems (LMS) is a web-based platform designed for the management, documentation, monitoring, reporting, and delivery of courses in both higher education and other training systems [9]. It can be used in traditional classroom classes for remote education, and educational content provision and management, student registration, and student assignments can be evaluated [10]. In line with these LMS advantages, iU-GJ websites (LMS) are organized and operated according to the situation of Korea’s remote education.

In the LMS system, subject information, lecture information, user information, course registration information, and learning history information, which are learning elements, are important, and security and maintenance, accessibility, the convenience of managers and learners, and learning management should be easy [13]. As such, various instructional considerations are necessary to use LMS.

As evidenced by the theoretical background, the development of technology has raised expectations for creating shared universities among local universities by opening a higher learning space that transcends time and space as a virtual environment. However, eventually, LMS and Metaverse must be connected for learning and control. Fig. 2 is a diagram of the framework of networking between the iU-GJ Metaverse Campus and the iU-GJ Website (LMS). It is not completed yet.

Fig. 2 shows a school support system such as iU-GJ University Education Innovation Headquarters is required to manage LMS. This is because student information, lecture information, academic schedule, and evaluation information from 15 universities are collected, and LMS must be managed and maintained based on this information. In addition, in the case of instructors, learning history management and evaluation should be possible, and students should be able to apply for and take lectures. When such login information is entered into the LMS system, information is shared with the iU-GJ Metaverse Campus, and the learning, events, and activities of the users can all be recorded.

Specifically, iU-GJ is operating five convergence major joint curriculums for the first time. 1. Future Energy New Industry-IP Convergence Major, 2. Major of Renewable

At least 30 people per program and a total of 150 people registered in the curriculum. Students may participate as enrolled students who have completed at least four semesters at their university. Up to 21 minor credits can be provided. 

Fig. 2. Link configuration among the iU-GJ website (LMS), the iU-GJ Metaverse campus, and iU-GJ University Education Innovation Headquarters.

III. DISCUSSION AND IMPLICATION

iU-GJ began with the concept of overcoming the extinction of local universities and helping young people settle in the region in Korea, where the school-age population is decreasing. It is expected to contribute to the development of the local economy via the collaborative efforts of the Korean government, local governments, universities, and various institutions to foster human resources and supply manpower necessary for local industries.

These cases imply that to build Consortium universities, a platform can only be made possible with the participation of both the government, local governments, as well as local institutions, and not merely a simple alliance between universities. Many regulations and legal constraints, the insignificant participation of universities and institutions, and the lack of content can make it difficult to maintain the shared university platform.

Next, the construction of an LMS system for remote classes forms an essential part of academic management and the construction of a Metaverse-based virtual campus that can overcome the concept of time and space to eventually increase students’ satisfaction with the class [11], [12].

Finally, the establishment of a virtual campus between LMS and Metaverse will yield synergistic benefits by combining each other's strengths. In terms of academic management of shared universities, the combination of iU-GJ virtual campus and LMS is an essential part, and it is difficult to manage large-scale learners as it is yet to be applied. To overcome these limitations and open a truly shared university in the future, it is necessary to encompass both job seekers and adult learners in addition to university learners. To this end, it is necessary to be reborn as an integrated digital learning platform that can check and prove each learner’s class history in a virtual world without time and space constraints.

REFERENCES


Work-in-Progress—The Role of Immersion When Designing Characters for Adapting Textual Narratives into Comic Strips for Online Higher Education: Trials Prototyping Characters

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Abstract—A critical factor in immersive educational narratives is identification by students with the characters. In this work-in-progress analyzes the process of rendering characters from textual narratives into visual form by non-artists (i.e., instructors). We tried to match archetypes with their visual representation through the platforms: Pixton, Powtoon (both 2D) and The Sims4 (3D). The limitations of characterization can impact students’ narrative immersion. As future work we intend to test with the target group and observe the improvements needed to increase identification and sense of immersion in the narrative.

Index terms—characters, textual narratives, narrative immersion, comics, online higher education

I. INTRODUCTION

Textual narratives have been employed in several applied fields of knowledge, for specific purposes and following various approaches, e.g., for patients narrating their healthcare experiences, narrative journalism [1] and indeed e-learning [2]. We adopt the concept of narrative immersion as one of the immersion dimensions reported in recent literature surveys of the field, which describes the feeling of engagement with the story from temporal, spatial, and emotional aspects [3]. This study looks at the process of rendering textual narrative characters in visual form by non-artists (i.e., instructors).

Considering that images and text can work together and give more meaning to the message [4]. Character archetypes were the starting point, with the expectation of increasing the students’ immersion into the narratives of an online course on software engineering, transitioning from basic to advanced programming. The online course, “Software Development Laboratory”, took place in the second semester of the second year of the Informatics Engineering undergraduate programme at Universidade Aberta, Portugal. This work in progress, exposed limitations in 3 current comic book design tools for creating characters with a focus on narrative immersion.

II. BACKGROUND

Narratives have been used in various fields of knowledge applied to context. A narrative is a version of reality driven by its own need and purpose and is not necessarily a true or false story [5]. Feeling part of or inside the story, leads us to the concept of "(...) narrative immersion and its subcategories (temporal, spatial and emotional) are characterized by a degree of mental absorption or intense preoccupation with the story, the diegetic space and the characters inhabiting this space” [3]. To increase narrative immersion, characters with characteristics of the target audience were created in a Health Video Game to prevent childhood obesity [6]. Textual narratives were developed with the OC2RD2 technique [7] to generate narrative immersion [2]. They were applied in an online Higher Education Software Engineering course. Feedback from students mentioned the need for visual formats, such as animations or e-comics. This was one of the underlying motivations that gave rise to this work [2]. The rendering of textual narrative characters in visual form by non-artists, can be done through comics which are a sequential form of storytelling [8]. Scene with four different types of information (Fig. 1) The yellow rectangle in the upper left corner is the narrator's speech to introduce the scene. The character's speech is in text within the balloon; the shape and connection of the balloon to the character defines whether the character is speaking or thinking (e.g., "Right now the crowds are with us!...") and can reflect the nature and emotion of the narrative [8], translating into images the character's voice and thoughts as the scene is read. Although comics are presented in a structure of their own, we adopted the concept of their application to communicate the narrative with plot and characters to increase immersion narrative [3], [6], [9], [10].

Fig. 1. Avengers #16 vol 1, Marvel Comics, 1965.
III. PEDAGOGIC CONTEXT

SimProgramming is a didactic approach for software engineering education that focuses on the transition between beginner and advanced learning content [11]. This didactic approach is based on situated learning for self- and co-regulation of learning and formative assessment, called e-SimProgramming [12], applied in an undergraduate course of a Computer Engineering program in online higher education in Portugal. The course is structured in 6 topics, each lasting two weeks. In the textual narrative SimProgramming is a fictional software development company to create a narrative immersion in the course. The students are interns in the company and the content and activities are presented in each topic as narratives mediated by the characters: Catmming, Ada, Patavinas, Meiabola, Fezada and Boss, in three different scenes/environments. The target audience for the course comprises adult learners (23+ years old) from various parts of the country and beyond, typically working students [2].

IV. METHODS

The methodology applied in these characterization essays was the DSR - Design Science Research [13]. Tests were carried out by interdisciplinary (Computer Science and Multimedia Education) co-creation for the visual characterization of the prototypes of the characters of the introductory topic of the course. The activities developed in the trials match to the nominal sequence of the process, following the steps of defining the objectives to be achieved, the Design & Development of the Artifacts referring to the prototypes of the characters for comic strips and, finally, the demonstration that it matches the visual characterization of the characters.

A. Archetypes of the Characters

Table I. presents the description of the Ada, Boss, Catmming, Fezada, Meiabola and Patavinas archetypes, which were developed by the SCReLProg project team the following platforms were chosen for testing their creation: Pixton and Powtoon (2D) and The Sims (3D). The choice of 2D platforms was based on those with free accounts and a larger number of characters, accessories, and expressions. The differential of the Powtoon platform is that it allows the download of scenes in characters, accessories, and expressions. The visual prototypes of the 2D and 3D character archetypes were developed in seven tests, by an interdisciplinary team. The following features were explored: body shape, face shape, expressions, costumes, hair shape and color, accessories.

V. RESULTS

A. Prototypes of Characters in Pixton

Fig. 2 shows the characters created on the Pixton platform. It was possible to implement 5 of the 6 characters, with characteristics above eighty percent of their archetypes, except for the character Catmming, for not having available characters such as robots or animals. As for the physical characteristics, the chief's gray hair color became gray. The character Meiabola was left with only a mustache, there was an option to insert a beard, as described in the archetype.

B. Prototypes of Characters in Powtoon

The tests on the Powtoon platform (Fig. 3) showed better results compared to the Pixton platform.

The shape of the face and hair also has limitations. It offers blue and green hair color options, which is an advantage over the Pixton, which is more conservative in this regard. The facial and body features, allow eyes to be configured in various shapes and colors.

<table>
<thead>
<tr>
<th>Character</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ada</td>
<td>36 years old. Some Asian features (...). Short and round. Long dark hair with red highlights, hair caught up (sometimes a hair tail, other times a pull with a pencil catch, with a bit of hair loose on her face), Formal clothing: dresses and skirts. Permanent/characteristic object of the character: scarves.</td>
</tr>
<tr>
<td>Catmming</td>
<td>Mascot -&gt; Artificial Intelligence Catmming: A cat (Norwegian forest - technologist) with its tail connected to a laptop floating around like a &quot;Genie of the Lamp&quot;. It would be our Programming Genie.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Character</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meiabola</td>
<td>Age 45. Caucasian. Tall and elegant. Hair gray and short but somewhat clumsy, lumberjack-type beard, clothing: wearing a pullover and classic Bermuda shorts. His permanent/characteristic object is a beret.</td>
</tr>
</tbody>
</table>
C. Prototypes of Characters in The Sims

The Sims platform has many options for avatar creation, such as face and body modeling, accessories and clothing, and different types of makeup and hair. Therefore, with the descriptions of the archetypes it was possible to create several versions of the same character in an intuitive way. Fig. 4 shows from left to right Boss, Patavinas, Ada, Meia Bola and Fezada. It was possible to implement in 5 of the 6 characters, one hundred percent of the respective archetypes (Fig. 4), except for the Catmming character because there are no animals in the game by default, except through expansions like The Sims 4 Cats & Dogs.

Fig. 4. Characters created on The Sims 4 platform.

VI. DISCUSSION AND FINAL THOUGHTS

Character creation is a challenge and requires the definition of archetypes and their respective characterizations. Table II. shows a map of the implementable features on the platforms used. Although the Pixton and Powtoom platforms provide free accounts, characters cannot be characterized in a detailed and faithful way to the archetypes, which can impact the narrative immersion by the characters [3], [6]. The Sims 4 platform, although not a free version, made it possible to implement all the features in Table II. The tests showed that the transposition of textual narratives to visual form affects characterizations of the characters by the limitation of the platforms. This may affect students' identification with the characters and impact narrative immersion. As future work, we plan to test with students the impacts of characters in visual form and what improvements needed to increase identification with this target audience and increase narrative immersion.

<table>
<thead>
<tr>
<th>Features</th>
<th>Pixton</th>
<th>Powtoom</th>
<th>The Sims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Shape and Face Shape</td>
<td>Partially</td>
<td>Partially</td>
<td>Yes</td>
</tr>
<tr>
<td>Expressions</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Costume Design</td>
<td>Partially</td>
<td>Partially</td>
<td>Yes</td>
</tr>
<tr>
<td>Hair Shape</td>
<td>Partially</td>
<td>Partially</td>
<td>Yes</td>
</tr>
<tr>
<td>Accessories</td>
<td>Partially</td>
<td>Partially</td>
<td>Yes</td>
</tr>
<tr>
<td>Characters of Animal</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

TABLE II. FEATURES SUPPORTED ON THE PLATFORMS

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Work-in-Progress—Post-COVID: Adapting Education to a Changing Educational Environment through Immersive Technology

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Abstract—In a Post-COVID world, Hybrid classes remain essential as students face challenges in attending them in person. This creates additional engagement issues. The creation of an easy-to-use platform to enable this mixed-mode classroom is critical for teachers that are frustrated by the difficult management of hybrid classrooms. An aspect is student engagement, which today has no established analytical mechanism to evaluate during classroom sessions. This work-in-progress paper describes a technology that has the ability to obtain real-time analytic data to determine the engagement of all students at all times and helps teachers to know which students are lagging early on.

Index terms—COVID, student engagement, bias-free, immersive technology, artificial intelligence

I. INTRODUCTION

A. What is The Current Problem That We are Facing? What is the Gap in Knowledge that We Need to Address?

When COVID-19 struck, educators were at the core of the integration of education and technology. The lack of these measurable impacts became even more prevalent as instructors and students adapted to an online education that is extremely different from most in-person experiences – one where students often turn cameras off and there are limited ways to gauge students’ engagement. Extensive research in pedagogical techniques to improve and foster student engagement in learning environments exists, but few have measurable impacts on student learning. When one delves into today’s environment in the schoolroom, it becomes even more evident that hybrid classes will become a regular aspect of educational institutions [1]. They facilitate situations where students simply cannot get to a classroom (sick, family issues, no transportation that day, or quarantined) and yet want to learn, but cannot. This calls for a technology that is feature-rich, allowing students to have a digital “hands-on” experience that will allow students to have an educational experience as similar as possible to a real in-person classroom. Due to the positive effects on spatial knowledge representation, contextual learning, experiential learning, collaborative learning, and engagement that 3-D virtual environments provide as opposed to 2-D methods [2], one possible pathway is through the usage of immersive technology (i.e., virtual reality or VR). The intersection of immersive technology and education provides an environment that has the ability to substitute, augment, modify, and redefine educational tasks in a way that was inconceivable before. The features that are available in this environment can often act as a substitute for non-digital materials, but also can be used for the purposes of completely redesigning classrooms, classroom dynamics, and materials. This, according to the SAMR Model, has the ability to enhance the integration of education and technology as blended classrooms become more prevalent [3]. In addition, real-time data collection through immersion technology can be used to conduct novel analyses on student behavior such as engagement and bias behavior.

While there are many anecdotal data from immersive technology (i.e. metaverse or educational gamification) being used in online courses such as medical training [4], there is not a pool of research data that establishes universal engagement parameters. For instance, previous research shows that traditionally unengaged students experience high immersion and presence, with most having a positive attitude while going through an immersive VR game for a school lesson [5]. However, this was only based on self-reported surveys in a classroom with students that are typically more engaged than the average classroom. These constraints cause difficulties when analyzing these results to extrapolate to other students. Running quantitative analyses can give educators more insight into the pedagogic space.

The Commons XR (TCXR) is conducting novel research on both qualitative and quantitative measurements of students in the classroom. Immersive technology aims to provide an
educational environment that is rich with features for both instructors to utilize during instruction and for students to interact with. This gap in research becomes increasingly stark as we move towards a world where virtual and hybrid learning environments become a normative classroom model in the foreseeable future. In this paper, we will show a path on how immersive technology can be used to obtain real-time data for analytics and boost student engagement in in-person, online, and hybrid classrooms.

B. Why is this Gap Worth Addressing? In Other Words, Why is this so Important Now?

Online education has been rapidly evolving in the past couple of years, especially with COVID-19’s ubiquitous presence on the global scale [6]. Even before then, it was estimated that in 2015, more than 6 million students were enrolled in some variation of an online education [7] as opposed to the 1.5 billion children around the globe affected by the school closures [8], let alone post-secondary students. In a world where COVID-19 is still a presence, this virtual classroom model consumes education and will continue to stay [6]. However, teaching in an online environment differs from teaching in-person, with both offering their own unique benefits. Teaching in-person allows for spontaneous interactions between students and teachers and is a way to gauge student engagement. However, online environments allow students to attend classes remotely in addition to giving reticent students a text chat feature for communication. Regardless, in a post-covid world, virtual or hybrid education has left an indelible mark on society [6]. Thus, there should be no need to compromise the benefit of either modality of education.

Immersive technology seeks to provide instructors with an environment where they are presented with a larger variety of mediums of knowledge transfer that allows them to feel ‘present’ with their students. Our research seeks to provide insights into how these different functions can boost student engagement in classrooms.

II. THE RESEARCH APPROACH

The research approach that will be conducted is to utilize an educational metaverse environment (aka, immersion technology or educational gamification) as the alternative platform for partial educational classroom study (not the entire class). This will be used to attack the null hypothesis: There is no difference in assessment grades between leaning in current traditional methods and in an anonymized VR environment. In the current educational experience, it is mostly in these three categories: in-person, fully online, or a form of hybrid learning. Each has its challenges. There are many factors that could contribute to difficulty in learning through different mediums such as implicit bias, low student engagement, and low interaction. Below are some of the features TCXR provides that aim to decrease the load of some of these challenges:

- TCXR’s technology can decrease implicit bias through anonymous features such as the use of genderless avatars [9] that are colored purple [10].
- TCXR’s experience can also increase student interaction through interactable 3D objects. Both VR and interactable 3D objects have been shown to enhance the learning experience in a prior course [11].

- Students in hybrid learning environments are interested in instructor presence, high interaction, and being surrounded by people [12]. TCXR’s immersion platform will provide each student with these attributes and the same experience during the intervention, regardless of if they are in person, online, or hybrid.

TCXR has performed short trials in classrooms collecting both qualitative and quantitative data. TCXR intends to improve on those trials and scale them for multiple classes held in the same course.

III. THE RESEARCH METHOD

The method will have a quantitative and qualitative approach. For the quantitative component, students will take part in a standard class that is regularly assessed (quizzes, tests on a scheduled basis), whether it is in person, online, or hybrid, with an instructor that teaches the same section to multiple classes. We will denote both classes distinctly as Class A and Class B with the properties of the classes containing at least 12 students taught by the same instructor in a semester or quarter-long curriculum. Students in Class A will learn a portion of the section material through TCXR’s platform while students in Class B will continue with their standard curriculum. An added approach for primary and secondary schools would be to continue with the same instructor (fall/spring) for the same students to collect more empirical data. It is never intended for TCXR’s platform to be used for an entire class or course because we can extract sufficient data in a smaller time period for analytics. This allows the instructor to better focus for a specific time period on the sectional material and have sufficient data from the platform to form an assessment. After a period of time where assessments can be created through normal class processes, data from the normal class will be aggregated. A TCXR staff member will be present to ensure the classes run smoothly on the platform in both troubleshooting and user experience. The data derived from TCXR’s platform on a per-class basis will also be aggregated and compared to the assessments from the non TCXR class. These assessments will be analyzed to determine if there are significant differences in their standard method of instruction or through TCXR’s anonymized environment. Standard statistical practices will be conducted, such as regression and ANOVA procedures.

For the qualitative approach, a survey will be conducted at the end of the TCXR platform class use. Students will be asked how they felt the environment changed their ability to learn, their perceived student engagement, their comfort in utilizing the technology, their perception of any reduced bias in the anonymized environment, as well as an open form for students to give any feedback necessary. The instructor will also complete their own survey, detailing the ease of use of the technology and if their pedagogic style was altered for the better. Instructors will be coached on using TCXR equipment beforehand.
IV. INTENDED OUTCOMES

The flexibility of immersive technology in its environment and object creation can serve to increase the stimulus students experience while at the same time can improve hybrid class communication abilities. Furthermore, the anonymity feature can remove some detrimental elements of the classroom (e.g. implicit bias) and therefore improve student engagement and desire to learn. A primary goal of this study is to integrate with a class lesson while being as simple to use as possible in a class environment. TCXR’s student engagement analysis can also help the instructor improve their pedagogy, notably since predicting low-engagement students is significant towards fostering high-quality learning in the classroom [13]. This will be assessed qualitatively by requesting instructor feedback, and quantitatively, by analyzing any upward trends in student grades after TCXR’s experiences. This can also be cross-referenced to both the alternative class being taught at the same time as well as past courses the instructor taught. Using this feedback from instructors, and comparative data from our experiment which is only conducted during specific periods during the course, we can begin to improve upon the accuracy of our engagement metrics and work towards implementing our system in full classrooms.

The overarching intent of this paper is to investigate a method of improving the classroom dynamics to increase student engagement using real-time analytics through immersive technology. Future research can stem from this experiment. One possibility is to focus specifically on the negative factors in the classroom such as implicit bias between students. Another is replicating a study on the efficacy of student engagement strategies in post-pandemic pedagogy [14] but performed with immersive technology. With TCXR’s anonymity feature and student analytics, differences in student behavior can be analyzed with respect to the number of anonymity features TCXR’s instructors choose to implement.

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Abstract—New technologies are becoming an essential part of education. Advances in these technologies are changing traditional learning processes, thus affecting students’ motivation and strongly influencing their learning outcomes. Mixed reality (MR) is one of the emerging technologies that may affect students’ learning motivation, with the potential to improve their performance and enhance learning outcomes. Nevertheless, it remains unclear how MR affects students’ motivation to learn. Thus, the aim of this doctoral colloquium is to propose how research may be conducted to evaluate the efficacy and potential of MR technology for motivating dentistry students in higher education. In this research, we design and develop a gamified educational MR application by combining the (Analysis, Design, Development, Implementation, and Evaluation) ADDIE instructional design framework with the (Attention, Relevance, Confidence, and Satisfaction) ARCS model for motivational design that is integrated with gamification components, called the ARCS+G model. The MR application is to be used by dentistry students at Umm Al-Qura University in a fundamental implantology course to train them on pre-operative planning using dental cone-beam computed tomography (CBCT). In this setting, we will investigate students’ pretest and posttest learning motivation with the Instructional Materials Motivation Survey (IMMS).

Index Terms—ADDIE, ARCS, dentistry education, gamification, HoloLense, implantology, mixed reality (MR) and rapid application development (RAD)

I. INTRODUCTION

With advancement in the development of information technology (IT), educational technologies are changing the way people engage and interact with learning materials [1]. Mixed reality (MR) is an emerging technology that is being driven and included in modern education [2]. The term “mixed reality” comes from Paul Milgram and Fumio Kishino’s 1994 paper [3], "A Taxonomy of Mixed Reality Visual Displays". Although that research did not describe the current version of MR, it did investigate the concept of a virtuality continuum and taxonomic classification applied to displays [2]. Today, MR is a three-dimensional visualization tool that uses a head-mounted display (HMD) to permit real-time interactivity with computer-generated objects overlaid on the real world.

Despite the technological advancements in education, students’ motivation to learn is an important component of the education process and has a significant impact on learning outcomes [4]. However, it remains unclear how the use of MR technology affects students’ motivation to learn [4]. A review of relevant literature found various applications of MR in educational settings, intended to enhance students’ learning achievements [5], [6].

In this study, we propose a non-traditional method that may provide a new way for educators to have a great impact and effectively motivate students to learn. The purpose of the research is to investigate the influence of MR technology on students’ learning motivation versus conventional learning.

In dentistry education, advances in technology are changing the way dentistry is practiced, requiring a shift in the lessons taught to dental students and dentists pursuing professional education after completing their formal university studies [7]. Technological advancements hold exciting potential to change the way dentistry is taught, both as a result of new learning methodologies becoming available and student population. As educators, we are faced with the task of making a fundamental decision. We may either insist on conventional ways as the only way forward, or we can take advantage of the opportunity presented by today’s students’ transforming learning styles and the new capabilities of recent technologies [7].

The goal of this work was to carefully design and develop a framework for MR applications to impact both knowledge acquisition and learner motivation by integrating instructional and motivational design. This MR application could form the basis for developing many further MR applications to improve the teaching and learning process by immersing the student in an experience that keeps them engaged and involves them in procedural learning by allowing them to interact with more realistic 3D objects.

A. Research Aims and Scope

The main aims of this research were to propose how in future studies, we may evaluate the effect of MR on dentistry students’ motivation to learn and assess the differences in their
performance, which could indicate the potential for using MR technology to influence learning outcomes.

B. Research Questions and Objectives

Our ongoing research seeks to answer the following main research question: **How does a mixed-reality implantology application affect dentistry students’ learning motivation in higher education?** The research question can be broken down into the following three sub-questions:

- **RQ1:** How can the ARCS+G model for motivation improve students’ motivation to learn and performance in using an MR application?
- **RQ2:** What is the 3D quality difference that keeps students motivated in the cone-beam computed tomography (CBCT) rendering in MR using HoloLens?
- **RQ3:** What are the differences in dentistry students’ learning outcomes when they use MR versus traditional learning materials?

To answer the research questions, we seek to achieve the following objectives:

- **OB1:** Explore the benefits of using the ARCS+G model of motivation to enhance students’ motivation to learn and improve dentistry students’ performance through using an MR application.
- **OB2:** Explore the 3D object quality difference that helps students stay motivated when applied to dental CBCT image-rendering in MR.
- **OB3:** Compare dentistry students’ learning outcomes when using the MR application versus traditional learning materials.

II. METHODOLOGY

The methodology of research based on the (Analysis, Design, Development, Implementation, Evaluation) ADDIE framework for instructional design was integrated with the ARCS (Attention, Relevance, Confidence, and Satisfaction) model for motivation, in designing and developing an educational MR application tool, to overcome the lack of motivational elements in the former instructional design framework [8], [9]. The methodological framework of the research is shown in Fig. 1. The students will engage in a designed instructional activity combined with gamification components. The activity involves attaining cognitive knowledge of physical structures and procedural knowledge that allows them to manipulate 3D objects in virtual space and explore the dental CBCT image and how the quality of the 3D CBCT object affects student understanding and keeps them motivated.

A. Research Design

The research has an experimental design, which uses descriptive and comparative analysis, and mixed methods enrich the research with both quantitative and qualitative data. The quantitative data from the pretest and posttest will be statistically assessed through coding and processed with the use of the Statistical Package for the Social Sciences (SPSS). The qualitative data will be derived from focus group interviews and video recordings of users’ experiences and interactions, which will be processed and assessed using NVIVO.

B. Research Process

1) **Analysis Phase:** The analysis phase will entail examining the instructional goals, target audience, and required resources [8]. At this stage, the instructional goals of the MR application will be defined, including the competency gaps and desired outcomes. The characteristics of the dentistry students will also be identified. Moreover, the required resources, such as hardware and software, will be identified at this stage, as shown in Fig. 2.

2) **Design Phase:** The design phase addresses learning objectives, assessment tools, activities, content, subject matter analysis, lesson preparation, and media selection.

With the use of the ARCS model for motivation [9], specific and measurable learning objectives of the educational tool will be defined to fulfil the instructional goals. Then, using the enhanced ARCS+G model, game elements can be implemented with confidence, including rewards, status, competition, and satisfaction, which in turn includes achievement, self-expression, and altruism to increase students’ motivation.

3) **Development Phase:** The development phase will involve creating learning resources, validating and revising drafts, and conducting a pilot test [8]. At this stage, an MR educational application will be developed based on the design phase using the Unity engine, due to the infrequent iterations and feedback in the application’s development, a Rapid Application Development (RAD) Framework will be used at this stage which is a method of rapidly developing application that emphasizes frequent iterations and feedback.

4) **Implementation Phase:** Next, we implement the learning solution by preparing the learning space and engaging participants [8]. At this stage, participants will be divided into two groups: experimental and control. The experimental group will be given the MR application and taken through
Fig. 2. Overview of MR system.

an orientation process, while the control group will listen to ordinary lectures. This process is important for distinguishing between the ordinary learning process and the use of an MR model for learning [10].

5) Evaluation Phase: We will then evaluate the learning resources’ quality and how well the students accomplish instructional goals [8]. At this stage, the MR application will be evaluated through data analysis of posttest responses collected using the Instructional Materials Motivation Survey (IMMS). Also, the scores following students’ experiences of learning will be analyzed to evaluate students’ performance and compare their learning outcomes.

C. System Overview

Software To develop this system, we used Unity as the game engine for application development and Vuforia as the software development kit (SDK), with C# as the programming language for developing the key feature of the application. The system includes a custom-built MR application for a single dental implant called (MR Implantology). This system uses the Mixed-Reality Tool Kit (MRTK) [11], which is an open-source development kit for mixed-reality applications. MRTK provides a cross-platform input system, foundational components, and common building blocks for spatial interactions. The application can also use target markers that the Vuforia engine can detect and recognize, which need to be related to the application developed in the Unity program. Once a target marker is detected, the Vuforia engine represents the information stored in its database.

Hardware Our setup was installed on a laptop computer (Lenovo IdeaPad L340 Gaming, Intel Core i7-9750H CPU @ 2.60 GHz, 9th Gen, x64-based processor, 8 GB RAM, NVIDIA GeForce GTX1650) running Windows 10. The aim for the application is to be run in MR head-mounted displays (HMDs) such as Microsoft HoloLens 2. Fig.2 presents an overview of the MR System.

III. Conclusion

The initial prototype and novel concept for the future were work proposed in this paper. This study found a promising research area with potential for MR in implantology education that has not yet been explored in the MR learning applications domain. Future work will validate the integration of gamification into MR learning applications by using different APIs combining motivational design and gamification. Further plans also include the development of Android devices, testing them with dentistry students at Umm Alqura University to validate the proposed framework.

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Doctoral Colloquium—Confronting Death: Lived Experiences from Players of the Serious Game Spiritfarer

Abstract—Serious games are a unique subset of immersive learning environments that combine elements of pedagogical strategies, embedded content, and game elements to provide players with opportunities to engage in playful opportunities that are ‘serious’ in nature. Although serious games have been explored in the literature, little exists to chronicle how commercially available serious games have impacted the learning experiences of gamers. This Doctoral Colloquium paper describes an ongoing study that seeks to explore the lived experiences of those who have played the commercially available serious game Spiritfarer. Research will explore educational impacts, emotional responses, and changes in attitude towards death.

Index terms—serious games, empathy, lived experience, Spiritfarer

I. BACKGROUND & RELATED WORK

Serious games combine elements of pedagogical strategies, embedded content, and game elements to provide players with opportunities to engage in playful opportunities that are ‘serious’ in nature. The unique properties of the medium position it well within a rich typology of immersive learning environments and platforms including simulations, impact games, virtual reality environments, etc. [1]. The applications of serious games have been quite broad, with topics including healthcare [2], war and humanitarian crises [3], environmental issues [4], to name a few.

Serious games have demonstrated effectiveness in palliative care for both providers and their patients [5]. Recent studies have shown promising results in the use of serious games and simulations to develop empathy in healthcare providers towards geriatric patients [6] and those recently diagnosed with terminal illnesses [7]. Patients themselves have also been the beneficiaries and end users of these empathic interventions. Participants in role-playing games on advanced care planning were more likely to discuss end-of-life care with family members and complete advanced directives [8]. Although serious games have been discussed widely in the literature, there is a dearth of empirical research that explores the potential of the medium in broader societal-based educational contexts [9]. This is in part because serious game research is often conducted with games developed for specific contexts rather than exploring serious games that were released for widespread commercial distribution [10]. This work-in-progress paper reports the approach one team of researchers is using to examine a commercially available serious game called Spiritfarer. The research will explore Spiritfarer and its potential to provide meaningful opportunities for learning and to elicit emotional responses from its players.

II. SPIRITFARER: A SERIOUS GAME

Spiritfarer is a commercially available game developed by Thunder Lotus. It was released in 2020 and has been published on PC, Xbox, Playstation, and Nintendo devices. Since release, Thunder Lotus’ Spiritfarer has sold over 1 million copies. Spiritfarer, is a cozy resource management game about the intimacy and tedium of death [11]. Cozy management games are characterized by their relaxing pace, emphasis on relationships and caretaking, undemanding game mechanics.

In Spiritfarer, players assume the role of Stella, who has been charged by Charon with caring for deceased passengers aboard Stella’s ship to ease their passage through the Everdoor, the portal to the afterlife. Before the spirits in her charge can make their final voyage to the Everdoor, Stella must make them comfortable by meeting their needs and resolve their unfinished business by completing quests. Stella is accompanied by her cat, Daffodil, who assists Stella in the resource collection mini-games and can be controlled by a second player. Much of this work includes what we typically associate with resource management games (e.g., farming, fishing, and crafting) to
obtain the supplies required to care for her passengers and make improvements to the ship. As upgrades are completed, the player must periodically reorganize the ship to accommodate the new structures, providing highly customized and personalized experiences during each playthrough.

Fig 1. Screenshots from Spiritfarer: (A) Player is organizing buildings for the boat, (B) Stella taking a spirit to the Everdoor, (C) Stella being given a task by a spirit, and (D) Stella tending to a garden by playing music.

A. Spiritfarer as a Serious Game

In contrast to most resource management games, the emphasis in Spiritfarer is on relationships rather than resource collection [11], and was released at just the right moment to help players process our collective trauma [12]. Players unlock new skills by interacting with the spirits, and ferrying them to the Everdoor rewards players with Obols, which can be exchanged at shrines for powerful abilities. Notably, the player’s gameplay experiences, and ship are instead marked by frequent physical reminders of loss [13]. Although the ship fills with buildings and cabins, it feels progressively emptier as each of the spirits passes through the Everdoor. The player is confronted with the memories of those who have gone each time they use a new skill or pass by an empty cabin. Other buildings can be salvaged for resources, but cabins remain on deck as imprints of the spirits who briefly called them home.

Although Spiritfarer was released as a commercial off-the-shelf (COTS) game, it defies easy categorization and possesses attributes of serious games [14], notably in its treatment of death and grief and its focus on building empathy. Spiritfarer addresses weighty themes for players to unpack, but these themes are counterbalanced against its cozy aesthetic, which has been likened to Hiroshi Yoshida woodblock prints and Hayao Miyazaki films [13]. The distinctive aesthetic and revisionist mythmaking of a kind empowered female character replacing Charon would also qualify Spiritfarer as an art game [15].

In its attention to caretaking and relationship management, the game emphasizes social-emotional learning, specifically in promoting empathy [16]. Developing empathy for others imposes additional affective and cognitive demands on players, so serious games must manage the cognitive load to reallocate processing to building relationships with characters [17]. There are multi-step puzzles to solve in Spiritfarer and visually complex segments such as the “lightning-in-a-bottle” resource collection mini-game, but the game does not prioritize cognitively demanding tasks, nor does it penalize players with fail states. Importantly, in alignment with the nature of a serious game, Spiritfarer provides gameplay opportunities that inject significance, interest, purpose, challenge, and humor into an educational dilemma [18].

Discovering our purpose and accepting our mortality are indeed matters of profound importance as well as the subjects of the video game Spiritfarer (2020) from independent developer Thunder Lotus Games. Spiritfarer poses an opportunity to explore these difficult conversations with a wider fanbase who may or may not be directly confronted with end-of-life decisions.

B. Research Questions

Spiritfarer has been widely commended for its innovative gameplay, narrative, and character development [13], and the investigators hope to discover affective and educational outcomes from players’ experiences. The present study will be guided by the following research questions:

RQ1: What gameplay elements elicit emotions from players of Spiritfarer?
RQ2: What is the nature of players’ emotional responses?
RQ3: How does Spiritfarer impact attitudes toward end-of-life?

II. METHODS

This study will employ Lived Experience Descriptions (LEDs), a phenomenological approach consisting of open-ended survey questions and virtual semi-structured interviews. Many studies examining the lived experiences of gamers have focused on game content rather than the various personal meanings that play holds for gamers, yet this is a rich area for better understanding gamers’ perceptions and motivations [19].

C. Participants and Recruitment

Study participants will be limited to adult gamers (18+) who have previously played Spiritfarer. Our target sample size is 50 (n=50), which is based on prior work [20]. Participants will be recruited through flyers posted at three host universities, each of which has received IRB approval; social media announcements targeting groups and forums dedicated to both Spiritfarer and its developer, Thunder Lotus Games; and a listserv request for participation through the investigators’ professional organization, the Association for Educational Communication and Technology. Participants may select their preferred level of participation, the LED survey and/or virtual interview. Additionally, participants will be encouraged to share details of the study with others for the purpose of snowball sampling. This will likely prove an effective sampling method due to the game’s devoted, connected fanbase [21].

D. Instruments and Data Collection

The two qualitative instruments to be pilot tested in this study are the Lived Experience Description (LED) questionnaire and the semi-structured interview protocol. The LED questionnaire consists of open-ended questions asking participants to describe their experiences playing Spiritfarer, including its most compelling narrative events, gameplay mechanics, and its perceived educational value (e.g., ‘If you were going to recommend Spiritfarer to a friend, what’s a
spoiler-free synopsis you would give?"). The semi-structured interview expounds on these topics with specific questions about the game’s themes and characters as well as if/how it has impacted the participants’ beliefs about grief, loss, and death (e.g., ‘Has Spiritfarer changed your view of grief, loss, or palliative care?’). The interviewer will ask follow-up questions as needed to ensure that participant responses and emotions are fully being captured. The design of these instruments is based on previously published work that examined the potential social and educational impacts of playing Pokémon Go [20]. The LEDs and interviews represent minimal risk to participants in that participants choose what to share in the LED survey and the semi-structured interview protocol allows them to guide the conversation.

1) Data Analysis

Qualitative data from the LED questionnaires and interviews will be analyzed using the whole-part-whole approach [22]. Questionnaires and interview transcripts will first be uploaded to Nvivo qualitative data analysis software and read in their entirety without analysis. Next, the investigators will conduct multiple line readings and annotate each entry with comments, questions, summaries, and reflections. These annotations will be clustered through process, causation, and magnitude codes for further analysis [23], reading both within and across participants’ data. Coded sections will elicit themes and participant narratives, which will be de-identified and then reported through selected quotes, excerpts, and concept maps.

III. DISCUSSION AND FUTURE WORK

The purpose of this study is to gather insights about players’ learning and reflections on the themes presented in Spiritfarer through analyses of their experiences and perspectives. Players’ perspectives on topics such as death, grief, and loss are of particular interest. The investigators also expect that insights from this study will indicate future paths of fruitful research, including the use of serious games with specific populations and professions to enhance skills, dispositions, and empathy. To date, many game-based interventions in palliative care have relied largely on role-playing and card games [5]; therefore, this initial study could potentially expand another avenue of game-based research in palliative care through serious and commercial off-the-shelf (COTS) video games.

REFERENCES

Doctoral Colloquium—ME++ Data Ethics of Biometrics Through Ballet and AR

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Abstract—This Doctoral Colloquium explores data ethics and biometric data through the development of an augmented reality (AR) classical ballet experience. This paper focuses on two areas: (i) The development and use of tool sets for motion capture and video extraction. (ii) On dancers’ understanding and experiences of the ‘body as a data artefact’ for the creation of motion graphic (3D rigged) characters of an AR experience. Questions: (1) Is there a difference in sense of self (identity) between the human and the virtual? (2) How does sharing your personal biometric data make you feel? (3) How can biometric and immersive development tools be used in the computing classroom and dance studios to raise awareness of data ethics?

Index Terms—data ethics, augmented reality, motion capture, ballet, computing education

I. INTRODUCTION

We live in a society where individuals are ‘datafied from birth’ [1] with limited access to understanding what and how their personal data is collected, stored, and potentially used. As part of the pre-university computing curriculum, legislation is taught but falls short of the ethical implications of personal data, both information and biometrics. Through the use of technologies, access to the hidden data of biometrics, and exploration of the children’s code [2] alongside existing curriculum content on e-safety and legislation, students and educators can interrogate those data. Thus, allowing cross-curricular learning along with coding and ethics development. There are many open-access data sets available from the Office of National Statistics (ONS) [3] to IEEE Dataport [4], but they are explicitly limited in terms of dance data. Additionally, the ability for students to generate the data as part of the learning enables a closer relationship to those data.

There is little discussion or examination of data ethics within the pre-university computing curriculum or examinations (UK context) other than topics covering legislation, data types, and storage [5]. In addition, there is limited research on data ethics within the computing curriculum aimed explicitly at pre-university education (Grades 7-13, England). This study aims to address this gap by introducing data ethics through biometrics to visualise and make concrete the intangible sense of data.

This paper focuses on one cohort of this PhD study addressing the specific technological developments of biometric data generation, enabling participants to respond to data ethics questions. It seeks to understand participant perspectives of ME++, the ‘data-self and the real-self’ as performers and educators. If any, what differences are there between performing through an avatar using aggregated personal biometric data and performing as the ‘human-self’? The outcome is to provide opportunities for classroom discussions on data ethics and explore, modify, and utilise biometric data in creative computing activities. The voices of the dance participants humanise the abstract nature of large datasets/spreadsheets. This study developed activities specifically for data ethics exploration, alongside opportunities for enhancing programming and digital design skills within a pre-university computing classroom.

Fig. 1. Dancer wear Emotiv headset with EEG data visualisations.

The title ME++ draws on posthuman ‘boundary blurring’ of the human and the non-human. Data and human-self through the ++ draws out the idea that the I in the digital world is more than just the I of the physical world. It is not a question of ‘better than’ but notions of the digital, the data- self. Our digital data footprints leave traces for others to access and potential misuse. The interdisciplinary nature of computer science, education, and dance enable favourable access to biometric data of others with the interaction of the non-human through programming and dialogue. It is inclusive through web-based tools and
accessibility in the classroom including immersive technologies. It widens participation in computing education through arts practice and dance, specifically ballet. Dance is part of the PE curriculum in the UK [6], enabling the cross-curriculum teaching of dance and computing through the development of data-driven generative art and immersive experiences. A move from the constraints of just words ‘the representational to the ‘presentational’ in capturing the nuances of understanding the human and non-human of data ethics. Dance through and with data enables possibilities that may not be available in a computing lab, not just to generate data but creative practices that ‘rupture and recognised alternative research outputs beyond qualitative research’ [7]. Alternative forms through data-driven digital artefacts embrace failure and continuous improvement in the lab and the dance studio.

II. STUDY DETAILS

All participants involved in the biometric data capture were aged 18 and above, located in the UK. This paper’s data was generated by several participants: one choreographer/dance lecturer, two dance practitioners, and one technologist. All research was conducted online, both synchronous and asynchronously, over six months managed through AgileDBR increments and iterations that draw together Agile and Design-Based Research approaches and practices. Through a series of virtual workshops: (i) Introduction to the project (ii) Introduction to choreographer and technologist to understand the pragmatic details of a fully online data-driven dance project (iii) Choreography rehearsals and motion capture recordings (Fig. 1.) and (iv) Retrospectives to discuss, reflect, and capture the ongoing project development and the participants’ lived experiences.

![Fig. 2. Motion capture still, showing error detection.](image1)

A. Methodology

AgileDBR is a fusion developed as part of the PhD study that draws together Design-based Research (DBR) and Agile, specifically the SAFe(c) framework [8], to create an iterative, generative, and transparent approach to collaborative research. Agile provides a grounded scaffold through the blending and use of research sprints, vision boards, Kanban, inspect & adapt events, and retrospectives. AgileDBR has enabled all collaborators (participants) to see what is happening in the research cycle at any given point, linking to educational research as the research of the ‘particular’ [9] and DBR as a methodology that can be summarised as follows: a systematic yet flexible methodology designed to improve educational practices through iterative analysis, design, development, and implementation [10]. An iterative approach to data analysis using Agile analytics [11] for emergent analysis during the data collection period. A dedicated data analysis increment for in-depth interview and survey data. Interview data utilised a grounded theory [12] approach to thematic analysis coupled with natural language processing (NLP) in Python for triangulation. Python was chosen over R as it is commonly used at GCSE level in computing classrooms.

B. Materials and Methods

Copyright-free music was used to enable global sharing and alignment with digital rights management computing curriculum. We created a choreography specifically for this study. The research data used: the Emotiv Insight headset [13] for raw EEG used to collect biometrics and Motion capture, interviews, and retrospective documentation are included in the research data. Data analysis through Agile analytics [11] for emergent findings and in-depth analysis using Natural language Processing of surveys and interviews using interpretative phenomenological analysis (IPA) [14].

The study utilised RGB video for motion capture with MocapNet 2 [15], providing 3D pose estimation from 2D video. The development of additional software for joint translation [16] data for Unity and optimisation of the source video using YOLOv5 [17], see Fig. 2. EEG was capture for the dance and education cohorts as data sets for creative computing and data ethics awareness rather than neuroscience. Dance creates a magnitude of artefacts in the data that are removed in neuroscience research [18]. The look and feel and 3D avatars were co-designed with the dancer participants. The dancers’ biometric data creates the movement for the 3D rigged characters and specific effects linked to each AR dancers.

Each participant created a visual representation bringing arts practice directly into the research process itself, see Fig.3., which is less dehumanising than the use of codes or pseudonyms. The online avatars creation tool ‘Boring Avatars’ [19] was used to anonymise all participants and enable online access.

![Fig. 3. BoringAvatars.com.](image2)

C. Findings

Q1: Is there a difference in sense of self (identity) between the human and the virtual? ‘There is a difference - human self is authentic, but virtual self is part of your identity’. By using biometric data in this study, the abstract concept of lived experience, a form of hidden data, can be concretized and made tangible. Living in a datafied society [1] means making the hidden visible, and this project allows access and learning opportunities for students and educators. As a result, both the virtual self and the human self are equally authentic.

Q2: How does sharing your personal biometric data make you feel? “I think I should be concerned about it but I don’t know enough about it to understand why”. There is a recurring theme of ‘concern’, yet insufficient understanding of why and how to mitigate it. Accessible resources are needed to help
people understand the ethics of using biometric and data. Currently, there are limited opportunities for exploring data ethics in computing classrooms, which suggests that data ethics are not well understood by participants.

Q3: How do biometric and immersive tools used in the computing classroom raise awareness of data ethics? “Using the technology firsthand with students helps with understanding of biometric data and makes the impacts of that data being shared a more tangible concept.” Through embodied practices of engaging and utilizing biometric data, students can experience data in a tangible way. The ability to see, record, and augment our biometric data gives learners a relational attachment to the data, forming the tangible link to developing discourse on data ethics within the computing classroom [5]. Access to data provides potential for understanding the use and management of biometric datasets. As programming is core to the computing curriculum, the impact of using simple spreadsheets to create music, motion graphics, and digital arts is ideal for the classroom, through sonification of data or motion capture into a rigged 3D character for a game or data-art.

D. Emergent Conclusions

The main themes and outcomes highlight three areas: creating and developing data ethics awareness resources that enable non-specialists to (i) generate their own data using simple tools. (ii) Interrogate that data through creative practices and create digital artefacts. (iii) Develop a more profound awareness through the processes of generation and interrogation. Shifting the computing curriculum beyond the confines of computing as a ‘subject silo’ enables opportunities for ethical and philosophical discussion alongside technological and conceptual understandings of computing. In addition to the aggregated anonymised open-access datasets of motion-capture and EEG data, the study will produce motion capture software and development pipelines for use by computing and dance educators alike. Additionally, creating and sharing classroom resources for pre-university computing educators, such as browser-based Motion Capture using tools such as P5.js and data sonification with Python or SonicPi. ME++ refers to the entangled self, the human, and the data-self, bound together. This study provides a disruption of computing education through arts practice, human data sets, and immersive technologies. This interdisciplinary entanglement requires space for innovation in the curriculum and the classroom for teachers and learners to explore and understand data ethics.

REFERENCES

Doctoral Colloquium—Utilizing Electroencephalography, Eye Gaze, and Learner Analytics to Examine Student Engagement in a Virtual Reality Classroom

I. INTRODUCTION

Educational institutions all around the world have been shifting to online methods of instruction in the past few years, a trend that has been accelerated by the COVID-19 pandemic [1], [2]. As institutions try to adapt to these changes, gaining a better understanding of how students and instructors interact with online learning environments has become the need of the hour. Gauging the engagement levels of students receiving online instruction seems to be one of the most interesting questions that need to be investigated [3]. It is more difficult for instructors to assess students’ engagement in online settings as opposed to face-to-face instruction where students’ behaviors (like nodding and taking notes) can be directly observed. This is even more true for students that view pre-recorded content without any real-time interaction with instructors.

Engagement is a complex, dynamic and multidimensional construct that has affective, cognitive, behavioral, and social components [4]. The Interactive-Constructive-Active-Passive Framework proposes a direct relationship between the level of cognitive engagement a learning activity facilitates and the learning outcomes it supports [5].

As the level of engagement required by an activity increases, the learner needs to engage in more constructive cognitive processes. Different kinds of cognitive processes lead to different kinds of learning outcomes. Passive learning activities such as simply listening to a lecture lead to the most superficial learning (like recall) and interactive and constructive activities where a learner is actively involved in the learning process lead to the most robust learning (flexible knowledge that is transferable to different contexts).

Most of the previous research on student engagement relies heavily on self-report data where researchers prompt students occasionally to report their level of engagement at different points of a task (called attention probes or experience sampling). However, this poses several conceptual and methodological issues [6]. Firstly, students might not be aware of their exact level of engagement, or their reports may be biased. Second, probes interrupt the learning experience and are hence artificial and difficult to implement in classrooms as they disrupt the continuity of learning activities. Lastly, in order to generate usable data, probes have to be used frequently. However, doing so can have an impact on student engagement. Thus, there is a critical need for complementary, non-self-report information on student engagement.

Given the limitations of self-report measures, there has been growing interest during recent years in various behavioral and physiological measures of attention and engagement such as reaction time, eye tracking, and heart rate [4]. However, previous studies employing these techniques seem to be limited by their use of artificial stimuli and tasks that are far removed from the attentional challenges encountered in real-world classrooms. To mitigate this problem, in this project, we propose to investigate student engagement in an immersive virtual reality (VR) classroom environment. Recent developments in VR technology make it possible to create authentic and realistic learning experiences while still maintaining full experimental control over various components of an environment at the same time [7]. Therefore, a VR classroom environment would represent an optimal trade-off between limited experimental...
control in real-world classroom studies and the ecological validity of laboratory-based research.

II. VR CLASSROOM

The VR environment has been designed and programmed using Unity. The teacher and student avatars and the classroom scene have been constructed from commercially available assets. Participants will be placed within a fully immersive head-mounted display (HMD). After loading into the classroom, they will assume the perspective of a student at their desk (Fig. 1.). Students will be able to turn their heads within the HMD to look around the virtual classroom. They will also be able to interact with the environment using hand-held controllers and respond to prompts and questions via single letter input.

![Prototype of the VR Classroom]

Fig. 1.: Prototype of the VR Classroom a) Pre-recorded lecture: passive learning condition, b) Pre-recorded lecture with instructor, c) Active-learning condition, c) Active-learning condition.

C. Experimental Setup

Research activities will take place in a quiet testing environment. Participants will wear an HTC VIVE Pro HMD with a built-in eye tracker (sampling rate: 120Hz) through which they view the VR Classroom. EEG will be recorded using a Neuroelectrics Enobio 32-channel system (sampling rate: 500Hz). The EEG analysis will mainly focus on alpha bands, and theta/beta ratio both of which have been previously associated with attention and engagement [10], [11]. With regard to eye tracking data, we will measure fixation duration within pre-defined regions of interest (e.g., instructor, slides) as well as fixation dispersion as this measure has been recently shown to reflect engagement with video lectures [12]. EEG and gaze-position will be recorded continuously throughout the four lectures. Additionally, user interactions within the VR Classroom will be recorded from the perspective of the participant through screen recorder software. We will also collect quantitative data to measure usability and learning and qualitative data (e.g., post-usage interviews) to help triangulate our findings. Learning will be measured using pre and post-tests.

IV. EXPECTED CONTRIBUTIONS TO KNOWLEDGE

The IRB protocol for the project is currently under review. Research activities are expected to begin in Summer 2022. Research will take place across two phases: Phase 1 (user evaluation) and phase 2 (experimental design).

The VR Classroom will allow us to address research questions that cannot be easily tested in traditional lab-based settings (on account of being far removed from real-world classrooms) nor in classroom-based research (which require dealing with a variety of complex variables interacting with each other in real-time). Moreover, unlike most previous research that focuses on self-reported data, here we use an innovative multi-dimensional approach that incorporates behavioral and neural measures to understand engagement in a holistic manner. Lastly, this project will support the design of instructional technologies that can be tailored to the needs of individual students and promote education equity by supporting students who might not thrive in traditional classrooms [13], [14].
V. Conclusion

In conclusion, we expect to obtain valuable physiological measures of student engagement with the VR Classroom, such as dispersion of gaze between the lecturer and the slides, fixation duration and alpha bands, and theta/beta ratio associated with attention and engagement. We expect to find higher user engagement in the active learning condition. We expect to gain a deeper understanding of how students interact with and learn in a virtual classroom environment in terms of eye tracking and EEG data. Findings from this line of inquiry can inform the design of future novel evidence-based instructional methods that leverage the unique benefits of a virtual reality learning environment.

REFERENCES


Doctoral Colloquium—Building Intertextual Connections with Secondary Students in Minecraft

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Abstract—This Doctoral Colloquium design case documents the initial development of a literature-themed overworld and two representative locations for students to explore within Minecraft: Education Edition. This innovative design aims to highlight the potential for secondary English students to experience exploratory learning and practice collaborative world-building and intertextual literary analysis.

Index terms—curriculum development, Minecraft, overworld map

I. BACKGROUND & RELATED WORK

Incorporating video games into the secondary English curriculum in accordance with models such as critical literacy and cultural heritage is not uncommon, including treating the games themselves as texts worthy of analysis [1]. Using video games to bridge students’ home literacies with classroom literacies can impact their perceptions of literature’s relevance to their lives and help them view their abilities more positively [2]. However, despite video games’ popularity and recognition as a type of multiliteracy [3], widespread usage in English classrooms remains elusive, likely due to the subject’s traditional emphasis on print-based literature and textual analysis as well as educators’ anxiety over adjusting pedagogical strategies to accommodate the medium’s play aspect [1]. Additional challenges integrating video games into the English curriculum include using games with appropriate content, length, accessibility, and complexity [2].

One commercially available game that holds promise for addressing some of the challenges associated with integrating games into the English curriculum is Minecraft: Education Edition (Mojang Games). Shortly after Microsoft acquired the rights to Minecraft in 2014, Mojang Games developed Minecraft: Education Edition as a resource for classroom teachers, utilizing a platform that would already be familiar to many students [4]. Minecraft: Education Edition has been used in a variety of instructional contexts, including literature [5], [6], research methods [7], art [8], science [9], ancient history [10], and civic engagement [11]. However, the relative lack of ready-made content has presented challenges for educators, who have used Minecraft primarily for collaboration rather than content delivery [4]. Common criticisms of Minecraft: Education Edition range from the student perception of large, empty worlds with little to do [4] to frustration with overly-scripted lessons that violate the flexibility and freedom most players associate with the game [12].

We wanted to explore how educators could more seamlessly integrate the classics with new media literacies by using Minecraft for both content delivery and collaboration. We have devised our method to engage students more deeply in exploration, collaboration, and intertextual literary analysis. The power of video games to engage [13], stimulate play [6], and promote agency [7] is well established; in addition, it is clear to us that English teachers should play a role in integrating newer with traditional literacies [2], [14]. This design case documents the initial development of a literature-themed overworld [15] for students to explore within Minecraft: Education Edition and aims to highlight the potential for students to experience exploratory learning, collaborative world-building, and literary analysis via intertextual connections.

II. MINECRAFT: EDUCATION EDITION

The Minecraft series is defined as much by the freedom and creativity it affords players as it is by its blocky, pixelated aesthetic. Player-designers have built entire cities, detailed models of the Titanic and U.S.S. Enterprise, and even a functioning cell phone [16]. The game’s simple design has resonated with players, as Minecraft is the best-selling video game of all time with a robust online fan community [17].

In Minecraft, players interact with the game in first-person perspective through an overworld map, which displays the spatial relationships of features in the game world and allows them to navigate between locations [15]. User-published lessons in Minecraft: Education Edition maintain the game’s characteristic sandbox but also often provide a more linear structure. Educators can invite students to join pre-built or custom shared worlds using its classroom mode.

III. DESIGN CONTEXT

The rationale for our design is guided by the SAMR model for instructional technology integration, specifically the redefinition component [18]; we aim to present a literature curriculum to students in a novel, visuospatial way by
leveraging *Minecraft* as a collaborative and interactive concept map. Our approach synthesizes multiple constructivist frameworks, including schema theory [19], exploratory learning [20], and the gradual release of responsibility [21], [22].

**A. Minecraft as Concrete Representation**

Instructional manipulatives such as blocks are used primarily in math and science to help students understand abstract concepts, but they can also help students understand visually represent narrative, grammatical, and compositional structures in language arts [23], [24]. *Minecraft* enables a similar use of manipulatives in a simulated 3D world. Although reader response theory prioritizes the experiences and perspectives that students bring to a literary work, students often struggle interpreting these works within their time periods and cultural contexts [25]. This struggle may be due to gaps in students’ historical thinking or ability to interpret past events and orient them relative to the present [26]. Meaning-making activities should therefore help students develop chronological awareness and mental models of historical inquiry [26].

Schema theory posits that new information is stored within units organized into relational structures; learning and recalling new information is easier and more streamlined when it fits into the framework of what we already know [27]. Schemata are constructed for all types of knowledge, both abstract and concrete, and creating schemata is a fundamentally computational exercise [28]. Constructing a spatial representation of schemata can help students perform cognitive tasks such as remembering, understanding, and reasoning [29]. Our goal is to create an environment in which students can interact with a spatial representation of intertextual relationships within which literary analysis is gamified.

Using *Minecraft’s* overworld map, we outline the scope and sequence of the entire literature course, from *Beowulf* to Shakespeare to contemporary literature. Each of these eras would be represented by an iconic structure, such as the Anglo-Saxon ship burial at Sutton Hoo and the Globe Theater in London, similar to location markers indicating points of interest on a map. Each physical location on the map would need to be chosen to conjure its literary and historical era and then designed with an interactive learning activity. Given the flexibility of the *Minecraft* platform, a variety of dynamic activities are possible.

**B. Minecraft as Exploratory Learning**

*Minecraft* was originally released with little documentation by design, with the intention that players would explore the game world to discover its rules and systems [4]. Similarly, the iconic locations in our *Minecraft* world are designed using the exploratory learning model, which promotes social interaction and problem-based approaches [20]. These exploratory locations are intended as supplemental activities to a larger curriculum. The challenge for designers, or the “choreographers” of exploratory learning experiences, is to consider a wide range of learning scenarios and open-ended sequencing rather than a one-to-one mapping of learning objectives onto assessments [20].

For example, before a unit on Anglo-Saxon literature and the epic *Beowulf*, players encounter a cordoned-off mound and a sign explaining that this is a site of possible archaeological importance. They are advised to excavate the site carefully. Here, a player’s prior experience with *Minecraft* may work against them; those who are familiar with the game’s controls and mechanics can “mine” a large area quickly, and in this case they may inadvertently damage part of the excavation site. By proceeding deliberately, the player will discover the outline of a buried ship with artifacts and grave goods: a suit of chainmail armor, iron weapons, gold ingots, and gems. Once players have categorized the artifacts into the collection chests on the dig site, they can start to make inferences about the cultural values and beliefs that inform our reading.

Likewise, players beginning their work on a Shakespeare unit encounter the Globe Theater within our *Minecraft* world and find markers describing its key features and history (Fig. 1). Characters from Shakespeare’s plays or even Queen Elizabeth herself could be placed within the Globe. If a prior unit introduced students to classical mythology underpinning many of Shakespeare’s works, perhaps they may see a Greek amphitheater on the horizon which had been similarly explored and be able to draw comparisons between the two theatrical time periods.

![Fig. 1. The Globe Theatre.](Image)

**C. Minecraft as Collaborative World-Building**

Under the gradual release of the responsibility framework [22], students assume more independence in their learning as they develop competence through modeling, guided instruction, and collaboration with peers [21]. As students develop expertise with navigating the *Minecraft* world and interpreting literature, they will encounter fewer premade locations and assume responsibility for co-designing the world with peers by creating new iconic structures. We have chosen *Minecraft*’s “infinite” map to illustrate that the literary canon, which traditionally consists of the Great Books, is expansive and can accommodate any number of new works.

Temporally connected works would also be spatially connected in this world by direct roads representing chronological order, but student-designers are responsible for breaking ground on new roads by making intertextual connections between the different locations. New roads between structures can then be marked with signposts explaining the thematic, historical, and structural connections. We hypothesize that as the *Minecraft* world populates with
student-designed structures connected by student-laid roads, it will illustrate the growing complexity of their understanding of the historical and thematic connections between literary works. Shared, collaboratively-designed worlds with their own narratives, rituals, and relics can also act as “sacred sites” [30], inviting learners into the classroom culture. Thus, our *Minecraft* world slowly grows along with the students’ experiences with the literature, and as no piece of literature exists in a vacuum, its structure would make explicit their collaboratively constructed schema throughout the duration of the course.

### IV. DISCUSSION & FUTURE WORK

In this paper we described a constructivist game-based approach to a literature course, although there are certainly broader applications for the humanities and social sciences.

For future research, we plan to design a study that will examine the effectiveness of our approach in a secondary English classroom. A control group will experience the typical literature curriculum enhanced by activities such as web quests, research, group work, and more traditional instructional practices while the experimental group will engage in activities within the *Minecraft* world. Using surveys and student achievement data, we will gauge our approach’s impact on student engagement, collaboration ability, comfort with exploratory learning, and ability to perform literary analysis with an emphasis on intertextual comparisons.

### REFERENCES


Special Track 1: Self and Co-regulated Learning with Immersive Learning Environments (SCILE)
Step Into My Mind Palace: Exploration of a Collaborative Paragogy Tool in VR

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Abstract—Virtual Reality (VR) can mediate remote collaborative learning and can support pedagogical processes like paragogy. Within education, methods such as spaced repetition and memory palaces exist to support the cognitive process of remembering. We identify an opportunity to enhance learner-led collaborative paragogy involving these methods through immersive VR experiences. We present CleVR, a VR-mediated collaboration-based system that supports the memory palace and spaced repetition techniques. As an exploratory study, we aim to identify the applicability, viability and user perception for such a system combining these two techniques in VR. CleVR is a novel implementation which provides a location-driven metaphor to populate and present multiple resources related to a topic for peer-led exploration. We discuss the design and provide a prototype implementation of CleVR. We conducted two studies, a targeted expert user review and a broader proof of concept survey. The results of the studies show interesting outcomes, with the system described as 'engaging', 'useful' and 'fun'. Our findings provide insights to the potential of using Virtual Reality Learning Environments (VRLE) geared towards collaborative learner-led activities.

Index terms—Virtual Reality, Education, Method of Loci, Memory Palace, Spaced Repetition

I. INTRODUCTION

Technology-mediated pedagogy is an actively growing area. The COVID-19 pandemic has put the role of technology at the forefront of education and policy-makers have realized the need for seamlessly integrating technological systems to organically transform education [1]. Efficient communication and access to information at a pace determined by the learner are two roles of technology that facilitates a learner-centric pedagogical model [2]. The pandemic has disrupted education and fast-tracked the adoption of remote learning. Learning management systems deployed by schools and universities facilitate asynchronous learning, allowing learners to access information at their convenience. However, the increased reliance on these systems during remote teaching has unexpected implications, like reduced peer interaction. From a pedagogical perspective, this face-to-face interaction is central to learning [3] and needs to be facilitated beyond chats and forums as they have a low uptake [4]. For equitable access, educators need to provide the students with a system designed specifically for the purpose of peer-learning.

Virtual reality (VR) devices can play a pivotal role in transforming teaching and learning through immersion, telepresence and novelty [5]. VR has been explored for collaborative [6] and online pedagogy [7]. However, designers of VR-based solutions need to design solutions that are equal in opportunity of access. They should not aggravate the widening gap in skills between lower-income students and their higher-income counterparts.

In this paper, we present CleVR – a collaborative learning environment in Virtual Reality. The aim of CleVR is to facilitate collaborative paragogy mediated through VR. CleVR provides an adaptive set of tools for students to customize their learning experience to suit their educational needs. CleVR focuses on self-directed student learning experiences and collaboration between peers, alleviating concerns of reduced face-to-face interaction. We discuss the design of CleVR which implements two learning techniques (mind-palace and spaced repetition) which are augmented with VR-based peer-learning features. We
analysed the usage of the system through two studies to understand the perception of the end-users towards the application.

II. RELATED WORK AND BACKGROUND

A. Collaborative Learning and Paragogy

Paragogy describes peer-to-peer learning where students provide a supportive structure for each other to learn and grow [8]. It is a heutagogy method of learning that builds on the idea that the learner is the initiator and main agent of acquiring knowledge [9]. This places paragogy in an ideal position when considering remote and independent learning activities. Researchers have explored paragogy through tutor-led activities, Learning Management Systems (LMS) [10] and mediated through VR [6]. In such systems, the tutor establishes the thematic organization of learning content and identifies the activities which require students to engage in paragogy. Collaboration has been studied extensively for its benefits of improving cognitive abilities, skill attainment and the transfer of knowledge to peers in education [11]. Plass et al. [12] demonstrated that collaborative learning games promote situational interest and a desire to repeat learning exercises. Collaboration in peer learning enables peer feedback in absence of teacher participation [13] and enhances students’ exposure to unexplored strategies, solutions and points of view [14]. There is evidence to suggest that technology which mediates connections between peers [15], through collaborative virtual learning environments, allows students to connect and share information in ways that are not possible in real life [16].

Experience with LMS suggests that the structuring of learning content and activities is driven by the tutor or institution, with student-focused elements such as interaction and discussion being underutilised [17]. Unlike students, they are well equipped to create scaffolding based on pedagogical principles. However, paragogy can manifest beyond peers simply contributing to an overall product (e.g., a presentation or other educational artifact). Paragogical activities, which occur outside of the planned learning, occur during periods of self-study. While the learners may be highly motivated, they lack the tools and understanding to suitably scaffold their learning activity within a self-study (or group-based study) session. The positioning of CleVR is within this gap where paragogy occurs outside of activities planned by the tutor, and instead is a student-initiated activity which builds towards another activity (e.g., study preparations for exams). Such a tool can scaffold the learning activity through well-understood pedagogical approaches leaving the learner unencumbered to focus on the actual learning.

B. Learning Activities

Bloom’s taxonomy [18] describes six key elements of learning: remembering, understanding, applying, analysing, evaluating and creating. Each scaffolds the next and enables deeper learning within the cognitive domain. A student must attain proficiency in the lower order before advancing to the next. Memory palaces and spaced repetition are two well-studied examples of learning activities that students use for remembering. These two activities complement one another and can be included in the review and reflect element crucial to contemporary active learning [19].

1) Mind Palaces

The concept of a mind palace is a technique for memory recall [20]. Literature uses the terms “mind palace” and “memory palace” interchangeably. In this paper, we use another common term, “method of loci”, to include both ‘mind-palace’ and ‘memory palace’. It is a spatial mnemonic technique where information is associated with various aspects of an imagined environment. The environment can be hosted by immersive technologies as a 3D environment [21]. Memory palaces in VR enhance productivity through superior memory recall [22]. Pedagogical efficacy differs based on the visual implementation and immersion. Memory palaces in VR show performance is increased versus traditional desktop alternatives [21]. Reggente et al. [23] showed spatially mediated spaces are effective in supporting memory palace techniques. This motivates our choice of selecting the memory palace technique for integration into CleVR’s active learning space to assist the cognitive processes of students. The mind-palace technique follows a set of steps. The first places the user in a familiar environment, e.g., the user’s home. Next the user recollects and visualizes a piece of information that needs to be remembered. The user then “places” the visualized form of the information within their environment. This is repeated for each piece of information to be stored and each is positioned at a different location. To retrieve the information, the user retraces their path, observing and interacting with the pieces of information in their locations.

This conceptualization of the mind-palace experience is grounded in enactive thinking [24] and provides the basis for our interpretation that a memory palace consists of a location, visualizations, and a journey. The location sets the context of the virtual journey and the visualizations are pieces of information the participant wants to remember or recall. The journey is a way of serializing this information, aiding its mnemonic recall. The journey is created and controlled by the user while technology mediates the location and visualization aspects. Studies suggest the memory palace approach should utilize familiar environments [25], [26], but evidence to the contrary [27] suggests it is recognizability instead of familiarity that matters. CleVR grounds the use of virtual mind-palaces as a learning tool and furthers the exploration in creating shared experiences. Such experiences set in a common mind-palace, involving shared conversations around visualizations are underexplored in a paragogical context.

2) Spaced Repetition

Spaced repetition is a repetitive technique used to train the brain to retain knowledge for long term memory [28]. Using spaced repetition, e.g. flashcards, in active learning strategies strengthens the “review and reflect” elements of active learning. This heuristic technique strengthens long term memory and reduces memory decay [29]. It also increases efficacy of learning compared to mass learning [30] and boosts learner confidence [31]. The focus of research in spaced repetition is the identification of timing protocols and algorithms to identify the optimal times [32] when repetition is to be carried out.

Technology is ideally placed to mediate the use of spaced repetition without manual actions from a teacher/lecturer.
Spaced repetition is beneficial under collaborative conditions [33]. Spaced repetition follows a set of steps. The first is the identification of the content in need of repetition. In its simplest form, the content can take the form of single words or word-pairs. This can be expanded to cover relevant details associated with the initial content. The expansion of details can continue until the whole topic is covered. The second is to aggregate the content into groups with common elements, like complexity or relevance. At each repetition iteration, the cards can be reorganized based on difficulty or errors in recalled content using an algorithm [34]. As a system, the key components are widgets representing the information to be repeated, a storage or organization system and the interactive actions to reorganize the widgets as required.

3) Virtual Reality in Education

Technology-enhanced education focuses on scaffolding student’s engagement in the subject through attention and immersion [35], [36]. VR enhances attention [37], increases motivation [38] and inspires self-directed discovery [39] through different interactive applications like virtual proxies of learning locations [40] and learning tools [41]. For a practical approach to pedagogy in VR, media and resources play an important part in the learning process of the users. Considerations need to be made when designing interactive elements catered for the practice of teaching. This includes deploying reusable elements in teaching and passing on material for other didactic purposes [42].

A key strength of VR assisted learning experiences is the detailed visualization of objects [5], [43]. Visualization creates variety of stimulation which in turn increases memorability of experiences [44]. Systems like iScape [45] visualize the semantic relationship within learning content. In VR, text can be replaced or augmented by videos or 3D objects that learners can watch, hear and interact with. Visualization, audio and interactivity lends itself well to the different learning styles described within the VARK learning styles model [46]. Suitable design ensures learners have a multi-modal approach to learning styles. CleVR derives further guidance on presentation style of learning artefacts from the associated learning paradigm defined by Kolb [47] which classifies learning styles within a two-dimensional learning space, delineated by ‘Abstract Conceptualization - Concrete Experience’ and ‘Active Experimentation - Reflective Observation’.

III. DESIGN

The design of CleVR is grounded in concepts that are well-understood from a pedagogical perspective. It is also informed by personal learning experiences such as participation in self-directed group study activities. The pandemic-driven change to learning processes, especially isolation and social distancing of learners motivated us to design a system which could bring users together in the same environment in which they can learn by sharing resources and interacting as if they did not have the limitations of an online learning platform.

A. Choice of VR over AR

During design discussions, the alternative of augmented reality (AR) was also considered. AR and VR are considered closely related technologies on Milgram’s continuum [48] and the pedagogical advantages of either technologies are comparable. Initially, the idea of an AR mind-palace was extremely attractive where the learner could transform their own room into a mind-palace. However, from an equality of access perspective, we want CleVR to be accessible from a wide range of devices including laptops, desktop PCs and mobile devices and not constrained to specialized or expensive hardware. AR could also lead to information clutter, privacy concerns and overt technological focus on registering and mapping the room’s easily mutable arrangement to learning content. However, Legge et al. [27] suggest that the mind-palace doesn’t need to be a familiar place. In a collaborative context, the mind-palace can be anything which is common to the learner group and established in a neutral setting. This further strengthened our decision to choose VR as our enabling technology which could be deployed as both desktop and immersive VR.

B. Learning Resources vs Interactive Objects

The main objective of CleVR is to present learning resources in a collaborative environment. These learning objects (eLRs) are derived from existing material which can be text-based resources (cards, text snippets, annotations, notes), image-based (diagrams, sketches, scans), audio/video resources and finally interactive 3D models. These eLRs are commonly curated within an LMS which typically contains a multitude of individual tools, which could include CleVR. For CleVR, the upload and curation of the eLRs is managed by the learner instead of the tutor. The learner is free to organize the eLRs in a manner that suits them best for future access and consumption within the CleVR environment. The CleVR environment is also populated with artefacts unrelated (in a pedagogical context) to the content but helps facilitate the creation and interaction with the mind-palace. Artefacts tagged with eLRs are intentionally animated to distinguish them from non-interactive artefacts of the mind-palace. CleVR allows users to use predefined artefacts or populate their own objects which are either more familiar with the user or stand out in the environment. Customization of the artefact tagged with eLRs is desirable to increase memorability but not central to the experience.

C. Virtual Mind Palace

VR to create a virtualized representation of a mind palace has been explored before. For single-user virtual mind palaces Yang et al [49] studied retrieving knowledge from scholarly articles using a virtual mind palace. Vindenes et al.’s [50] showed that desktop VR has comparable (if not slightly better) performance than immersive VR, in contrast to findings of Krokos et al. [22]. A key difference between CleVR and these prior examples is the use of the virtual memory palace in a paragogical context. The learner can invite a peer and CleVR mediates the conversation and interaction with the peer.

1) Virtual mind palace workflow

A virtual memory palace needs to support a location, a visualization, and a journey. The location can be a popular real-world site or based on a visually memorable rendering of a locale. The learner can select a spot or artefact within the environment for depositing one or more related eLRs. The learner is reminded of the tagged artefacts through animation which sets the artefact apart from other untagged artefacts. When the learner wishes to access the eLR, the system populates
the eLR content into the environment. For example, annotations, text, images or videos can appear as floating planes, while 3D models appear within the environment. The journey is defined as a series of navigation steps within the environment, retracing a path undertaken by the learner to step through different pieces of information in a serialized order. When engaging in peer-based collaborative recall, the learners can decide to take alternative paths based on the retrieval and recall of the subject as a group.

2) Interactivity and Communication
The learner or their peer(s) interact with tagged artefacts located across the virtual environment. Navigation and its control should not compete for the attention of the users and should only facilitate movement between artefacts. This can be achieved through teleportation and guided rails that minimize the cognitive load of providing precision input to perform locomotion within the mind palace. Additional interactions are needed to trigger tagged artefacts and control the play-through of the visualized eLRs. Similar inputs are required to ‘store’ or deactivate a visualized eLR once the learner is done with the resource. Since the system expects one or more concurrent users, there needs to be two-way audio communication between the learners. Any modification or results of interaction within the environment is visible to all learners within the viewing area.

D. Spaced Repetition within 3D space and time
The mind palace offers an interesting approach to the implementation of spaced repetition. First the learner can organize eLRs with each representing a point in time. This concept emerged from the discussion that a single lecture usually covers aspects of single topic. To revise such a topic, all related content is hosted within the same “room” within a mind-palace. CleVR then keeps track of the actual content which has been repeated and provides cues to access more difficult or less repeated content. As the learner completes spaced repetition sessions, more frequently accessed content floats towards the ceiling while more difficult content stays firmly positioned over the floor. Two predefined rooms are provided – a bedroom and a sparse warehouse in which the eLRs are grouped into appropriate cubes or boxes. The metaphor of the cubes is associated with the lecture event during which the stored eLRs were covered. The ‘age since last access’ or associated difficulty in recall of the eLRs is conveyed through color-based cues displayed on the cube walls. To improve the individual outcomes for learners, the system needs to customize the indications differently for group-learning sessions than for individual sessions. In either implementation, an algorithm like Leitner’s [34] can help keep track of the repetition schedule.

IV. IMPLEMENTATION
We developed a prototype to showcase the capabilities of CleVR. As we were also concerned with the equality in opportunity of access, we needed a platform-independent solution capable of running on a wide range of devices and without high-end requirements. We chose WebXR and A-Frame to develop our prototype.
A. Interactivity and Workflow
A-Frame provides off-the-shelf implementations for various common input modalities (e.g., touch, mouse and gaze). It supports specialized inputs through plugin components (e.g., Quest controllers). To support low-end cardboard-style VR headsets, we enabled dwell-based gaze-interaction techniques. The gaze-input allowed learners to trigger open/close and start/stop functions of associated eLRs. Since CleVR is expected to host content of entire modules (i.e., courses), we enabled navigation waypoints (Fig. 1 bottom-right) as a metaphor for menu-based selection of topics and particular day/week. Tagged artefacts were presented as interactive objects with animation cues (Fig. 1 top left, top right) This allows the user to differentiate between interactive and non-interactive objects.

B. Single Learner Experience
As a mind-palace, CleVR can be used by a single learner any time. A learner can customize or select the environment (location) and tag eLRs to artefacts (visualization). A learner populates the eLRs at their own pace, creating their own personal journey through the mind-palace. The learner decides their own journey through the location, depositing the eLRs in a way that suits them best. This contrasts with existing LMS which follow a standardized structure of displaying the eLRs for all learners and even across entire degree programs. CleVR does not host the actual eLRs, rather only providing linked placeholders. The eLRs are provided online [51], integrated within an existing LMS. For the sake of prototyping, the integration with an existing LMS was replaced with static hosted links. The spaced repetition schedule helps users keep track of how often the users need to come back to the topics for them to register this knowledge into their long-term memory. In its single-learner form, CleVR is comparable to previous mind-palace implementations.

C. Peer Learning Experience
CleVR facilitates peer-learning activities as its key feature. The experience begins with a pre-populated virtual mind-palace curated and organized by one of the learners. The learner invites a peer (i.e., ‘step into my mind-palace’) into CleVR’s specific instance of that learner’s mind-palace. The environment
becomes a synchronized shared environment accessed through the web. The learners are represented as low-fidelity anthropomorphic avatars (Fig. 1 top left, top right). The avatar fidelity is prototyping pragmatism and future versions can trivially support high-fidelity avatars. The “host” learner can interact with one or more peers. We assume a maximum of five peers, i.e., the nominal size of a private study group. The “host” learner takes the peers through the host’s own journey within the mind-palace, interacting with the artefacts associated with the topic of discussion. The collocation within the virtual mind-palace enables the learners to discuss shared topics with a better sense of context and utilizing the full range of eLRs including 3D models, voice recordings and images. As a future feature, we envision that the invited peers can either duplicate the host journey or record their own to carry back to their own instances of CleVR’s mind-palace. With the current prototype, the invited peers would have to manually create their own journey once they return to their own virtual mind-palace.

V. Evaluation

The motivating factor behind the creation of CleVR is also the reason why controlled in-lab studies could not be carried out. Due to COVID-19 lock-down restrictions, we opted for a mixed model of analysis. We conducted an expert user review [52] and an online survey adapted from a standard UES (User Experience Survey) [53] to obtain feedback on the user experience and perception of using CleVR. The studies were conducted following the standard ethics approval process from Lancaster University FST Research Ethics Committee. Both studies started with a consent form and all responses were anonymized.

A. Expert User Review

We see CleVR as a system utilized in conjunction with LMS of higher education institutions (HEs). The end-users are HE students, engaging in learning activities, and as such have extensive experience with group study activities. We use these ‘domain experts’ as subjects for our study similar to previous studies [52].

1) Participants

The purpose of the expert user review was to assess the suitability of CleVR for our target audience of higher education students. The expert ‘reviewer’, and therefore the target population for the survey, were individuals over the age of 18, currently engaged in higher education. Participants were asked to confirm their age and self-certify their educational status. We recruited seven participants for this part of the study. Six participants were aged 18 – 24 (the seventh participant being 25 – 34). Participants were recruited online.

2) Procedure

Participants were accompanied virtually by an experimenter within CleVR. This allowed us to replicate the experience of collaboration. To reduce experimenter bias, the experimenter followed the same pre-set structure of interactions for each iteration. Participants were asked to complete CleVR’s tutorial to familiarize themselves with the system. After, participants were asked to interact in the CleVR world. Finally, the participant was asked reflective questions about the system. If the participant was using headset/binocular VR for exploring the CleVR environment at any point during the survey then they were required to fill in a motion sickness questionnaire [54]. Due to the variable time taken for the participant to interact with CleVR, each review took a minimum of 25 minutes.

3) Results and Analysis

The expert user review contained demographic questions to determine age, their experience with VR, memory palaces and spaced repetition. All participants responded that ‘Most’ or ‘All’ of their current studies are carried out online and five out of seven stating they were ‘Somewhat satisfied’ with their current online learning experience. One participant answered ‘All’ to ‘Before the pandemic, how much of your studies were carried out remotely/online’. Four out of seven the participants had used VR before. When the participants were asked to provide feedback on the experience, the overall sense was that the program was user-friendly. ‘I was able to navigate my way through easily’ and ‘the instructions were clear so I was able to move around even though I had never done anything like this before’.

Six out of the seven participants responded they would be interested (to different extents) in the final product. Some of the ideas on how they would use CleVR were: ‘Customizable and interactive revision materials’, ‘Having all revision materials in one place (including other’s resources)’ This suggests that for most participants, CleVR could be a program that they could use in future revision. One participant mentioned that they were ‘not sure what type of a problem [they] could solve with it’.

Finally, we asked the participants to rank the system features in order of importance/relevance to their studies (1 being most important, 7 being least important). The features in question were virtual memory palace, spaced repetition revision prompts, customizability of the virtual space, replaying time spent in the space, synced viewing, hosting other users in your environment and full immersion. Virtual Memory Palace ranked the highest and no feature ranked 5 or below. The results are tabulated in Table 1.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Memory Palace</td>
<td>2.3</td>
</tr>
<tr>
<td>Spaced Repetition revision prompts</td>
<td>4.0</td>
</tr>
<tr>
<td>Customisability of the virtual space</td>
<td>3.7</td>
</tr>
<tr>
<td>Replaying time spent in the space</td>
<td>4.7</td>
</tr>
<tr>
<td>Synced viewing</td>
<td>4.6</td>
</tr>
<tr>
<td>Hosting other users and visiting other’s environments</td>
<td>4.1</td>
</tr>
<tr>
<td>Full immersion</td>
<td>3.6</td>
</tr>
</tbody>
</table>

B. Proof of Concept Survey

Due to lockdown restrictions and difficulty in scheduling participants who had to be paired with an experimenter, the second study was planned as an online-only survey. The interactive demo and exploration of CleVR was replaced with a video that demonstrated the proof of concept and visualized all the elements mentioned in the survey.
1) Participants

The target population for the survey was individuals over the age of 18 currently engaged in higher education. Our distribution methods followed a convenience sampling method in which a link to a Qualtrics survey was shared on social media. Although convenience sampling does not allow for our results to be generalized to a wider population, we were able to utilize snowball sample distribution to recruit those further detached from the initial convenience sample.

Of the 33 individuals that began our survey 26 were in our target population and these 26 participants completed the survey in full. The age-distribution of the participants was: 18 – 24: 68%, 25 – 34: 9%. One participant was between the ages of 45 and 54. All but one of the participants were students in a higher education setting, with one participant identifying as a teacher.

When asked about their current studies, all the participants identified that ‘some’ ‘most’ or ‘all’ of their studies were currently online with one participant having more than ‘some’ face to face learning. Sixty five percent of our sample were satisfied to some extent with their current online learning. Prior to the pandemic, two participants in this survey carried out their learning entirely online with no face-to-face element, suggesting that they may be participating in an education designed for the purpose of remote/distance learning. This provides another perspective to the remaining participants who have been more displaced by the pandemic, with fifty percent of the sample revealing that ‘none’ of their previous learning took place online.

2) Procedure and Questionnaire

The questionnaire followed a similar structure to that of the expert review but with the removal of the interaction sections and the motion sickness questionnaire. The participants saw a short video that demonstrated interaction within CleVR and included a voiceover description of what was happening at each point in the video. To prevent click-through participation, the starting survey questions required the participants to enter a code which was only displayed in the video.

3) Results

Although all participants responded that they engage in collaboration for studying/revision, ‘Hosting others in the environment’ was ranked, on average, only the 5th most important feature of the revision space. This could be caused by two main factors: the demonstration video serving as an ineffective placeholder to physical interaction with a product and therefore misrepresenting collaboration in the space. Alternatively, CleVR’s collaboration features need more refinement to allow users to collaborate in a way that is important to them.

When asked ‘does this end product sound like something you would be interested in using’, sixty nine percent responded positively, nineteen percent were undecided and twelve percent chose ‘probably not’. No participants chose the option ‘definitely not’.

A. Implications

For the users’ opinion about the system, the open-ended responses included positive comments. These were centred on CleVR being ‘engaging’, ‘useful’ and ‘fun’. Users could visualize the potential in having all their revision materials in the same place. One participant, who identified themselves as a trainee teacher, described potential future applications in the software, ‘This could also be quite a valuable interactive learning tool for school children […] For instance, you could recreate the Titanic as a Virtual Memory Palace and assign information bubbles to specific objects, e.g. lifeboats, boilers, hull/stern/bow, etc.’ Even users who were unsure of how it would personally fit into their studies, offered positive responses. One user responded that ‘if there was a way to use it for essay writing or structuring then definitely!’. This provides insights that variation in learning styles can affect uptake of specific solutions. Another interpretation is that given enough fidelity and flexibility, a system like CleVR could be repurposed for other pedagogical activities.

Three users from the online survey referenced motion sickness/VR induced headaches. Although none of the users had used a VR headset to view the video (let alone used CleVR), it was apparent that users associate discomfort with the use of VR. These responses, alongside ‘Immersion’ ranking as the least important feature, indicate certain pre-conceived notions about VR. This bolsters our decision to make CleVR usable with or without a VR headset.

Closer examination of the participants responses for those who responded that they ‘probably (did) not’ see themselves using the system (twelve percent) revealed differing reasons. This included lack of interest in the featured techniques or concerns over the distraction potential of the software and that they struggled to ‘think visually’. Other users praised the software for helping with the users’ learning style.

We looked at the answers to the question ‘list top three learning/revision methods that they find most useful’ through the pedagogical lens of VARK. 80 percent of respondents answered ‘watching videos/lecture recordings’, with the remaining twenty percent all including ‘watching demonstrations/tutorials’ in their top three. According to VARK, this would indicate that visual learning is a preference to these respondents. CleVR facilitates all components of VARK, allowing students to watch videos, demonstrations (Visual), listen to recordings (Aural), read and write, revision resources (Read/write) and moving around the space, interacting with models (Kinesthetic). The effectiveness of learning style is not considered which is in line with Fleming et al.’s [46] observation that preference of style doesn't imply effectiveness.

B. Limitations

Both studies involved a non-probabilistic convenience sample with a simple distribution method of self-selected recruitment and no cost. Convenience sampling means they may all be a similar type of student and it would be interesting to do further research into differing perceptions of the system depending on degree area. We further lacked the opportunity to ask follow-up questions. We also collected all of this data from
each questionnaire undertaken with no researcher present and so our responses may suffer from recall bias [55]. Although we recognize the limitations of this research, we emphasize that it acts as a pilot study, to inform future evaluation methods. Unfortunately, due to the physical restrictions in place due to COVID-19 we were unable to run tests on participants using headset VR and future research would no doubt investigate the consequences of using this hardware.

From a system perspective, the prototype requires further refinement. For e.g., due to open issues with the component system, especially Networked AFrame, voice chat was not reliable. The prototype has limited configurability for users when tagging additional eLRs to virtual artefacts. For the study, the prototype used pre-tagged virtual artefacts and are already allocated a specific timeline during development.

C. Paragogy and Remote Collaboration

Compared to existing VRLEs which are designed as tutorial LMS or designed with a single application or single user implementation, CleVR occupies a sparsely populated gap of VRLEs designed for learner-led paragogy. CleVR provides a flexible approach to the curation of eLRs as desired by the learner. It also implements two learning techniques, virtual memory palace and spaced repetition. Unlike previous implementations of virtual memory palaces, CleVR also takes into consideration, group-recall and reflection activities, thus enabling paragogy. CleVR also takes advantage of the fourth dimension to learning – time. It provides the users to scan back and forward in time, taking advantage of spaced repetition activities scaffolded in a virtual mind-palace and carried out in groups. Using WebXR, CleVR can be deployed on virtually any modern-day user device and operated without using expensive and specialized hardware. It ensures equitable ease of access for remote learners to come together and provides the scaffolding required for collaborative learning to occur.

VII. CONCLUSION

In this paper we present CleVR, a VR-based learning environment which supports two distinct learning techniques, mind-palace, and spaced-repetition, applied in the context of learner-led paragogy. We demonstrate CleVR as a WebXR based prototype built using A-Frame aimed at showcasing the feasibility of low-cost equitable access implementations for VR-based applications. We conducted two studies which showed that CleVR is liked as an application and it is likely to find use if made available to learners. Overall, our results show that a VR mediated environment combining the memory palace and spaced repetition methods would be a viable, useful and desirable learning tool.

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Virtual Spaces as Learning Media for Flipped Classroom: An Evaluative Study

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Abstract—In recent years, an increasing number of teachers have been adopting a new pedagogical approach called flipped classroom, in which traditional teaching for basic knowledge takes place outside the classroom to free up class time. In this paradigm, teaching content for out-of-class learning is delivered using a variety of digital media, most primarily slides and videos. However, self-directed learning using these media can be a significant challenge for students, particularly if the subject is unfamiliar to them or involves abstract concepts. Virtual spaces can be a good alternative as learning medium in flipped classroom approach because of their affordances, such as visualization and rich interactions. This paper describes the implementation of flipped classroom using virtual spaces as self-learning media in a 14-weeks long undergraduate biology course, and then reports how students perceived this approach. It was shown that the virtual learning spaces were well accepted by the students, and the majority of the students found them useful for learning using 3D visualizations and interactions. However, their engagement with pre-class learning was not entirely satisfactory. Some suggestions to develop virtual spaces as a viable option for flipped classroom will be discussed.

Index terms—virtual reality, flipped classroom, STEM, Mozilla Hubs, virtual spaces

I. INTRODUCTION

In order to maximize the learning outcomes of students at school, it is crucial to enrich learning activities in and outside the classroom. Flipped classroom allows lectures to be delivered before classrooms to free up lecture time and prepare students beforehand for more active learning activities in classrooms. It is now introduced to classrooms across a variety of disciplines, including natural sciences and medical and health sciences [1]. It has been shown that flipped classrooms have positive effects on learning outcomes and academic achievements in the cognitive domain (e.g., final test scores) as well as the affective domain (e.g., improved attitudes, engagement, and motivation) [2].

There are several ways to deliver pre-classroom learning digitally to students, such as slides, audio, web 2.0 interactive contents (e.g., Google Forms). However, videos are by far the most popular media in the flipped classroom approach [2], since it is the most natural way to digitize lectures and many students are accustomed to watching videos. However, there are many challenges in using videos in the flipped classroom settings [1]. First all, watching lecture videos is often more time-consuming than learning from live lectures. It requires more mental effort from students, and therefore they can easily get distracted while watching. Moreover, students may feel confused and frustrated when learning new concepts from video lectures since there is no immediate feedback from lecturers nor opportunities to ask them questions.

This article proposes virtual spaces as a learning media for pre-class learning materials and reports on their use in a flipped classroom setting for an undergraduate introductory biology course. In previous years, this course had employed a typical flipped classroom approach with video lectures for preclass learning. While this approach succeeded in increasing students’ learning time at home, students’ satisfaction rating for the course dropped, and the engagement of the lecture videos was unsatisfactory, as demonstrated by video viewing logs.

Virtual spaces can help improve the satisfaction and engagement of students in the flipped classroom. Here, I use the word “virtual space” as a 3D virtual environment where users can view and interact with 2D images, videos, 3D objects on a PC, or a head-mounted display. Virtual spaces, most notably Second Life, has been used as an educational medium for subjects including natural science and health science [3]. While collaborative learning in a multiplayer social interaction environment has been the most common learning strategy, strategies for individual learning such as exploration-based learning, task-based learning, and experiential learning have also been employed with virtual spaces. These strategies can encourage students to be engaged in more active and self-directed learning instead of passive learning styles with videos. Because of this, virtual spaces have been shown to have a positive influence not only on cognitive domains (e.g., academic performance) but also on affective domains (e.g., attitudes and motivations) [4].

What makes the learning strategies with virtual spaces unique is their affordances, namely the actions made possible by using or experiencing them. Hollins and Robbins listed the basic affordances of networked virtual spaces (Second Life, in particular) as “Identity,” “Space,” “Activity,” “Tools,” and “Community” [5]. Here, “Identity” refers to the freedom for users to experiment with new identities using avatars. This allows students to experiment with what they want to be and learn by experience from different perspectives. “Space,” namely a 3D computer-generated environment, can provide a variety of ways to interact with objects, other players, or virtual
agents which are not possible in a flat 2D environment. These interactions are essential for the third affordance, “Activity.” Educational activities are central to the learning effectiveness of virtual spaces. They should be interactive to allow students to explore, examine and reflect on the spaces and the objects therein, ideally in a collaborative manner. In virtual spaces, teachers should, instead of merely giving instructions, encourage students to take control of their learning and construct their own narratives so that they can become independent learners.

In order to build an environment that facilitates such ways of learning in a cost-effective manner, the availability of “Tools” will be crucial. While game engines (e.g., Unity and Unreal Engine) and desktop 3DCG authoring tools (e.g., Blender and Maya) are still used in many interactive 3D contents, simpler and more user-friendly tools have become available over the last few years. For example, Spoke by Mozilla (https://hubs.mozilla.com/spoke/) is a web-based virtual space authoring tool for Mozilla Hubs. It provides a variety of sample spaces that work as an effective learning environment and an interface to 3DCG asset databases (e.g., Sketchfab). Therefore, the users only had to devote minimal effort to creating virtual learning spaces, which is highly beneficial for busy teachers. Finally, “Community” is an essential affordance of networked virtual spaces. While online communities are already abundant in existing forms of cyberspace, real-time networked virtual spaces deliver far stronger engagement. In fact, an online survey [6] found that community behaviors, including communication, collaboration, and cooperation, are crucial for the intention to use virtual spaces. Consequently, collaborative learning is one of the most frequently used learning strategies in virtual spaces [3] and gaining more popularity [7].

While Hollins’ five aspects of affordances cover most of the pedagogies used with virtual spaces, it may also be beneficial to analyze the affordances from a different perspective. Warburton identified multiple affordances of virtual spaces for learning, including “Extended or rich interactions,” “Visualization and contextualization,” “Exposure to authentic content and culture,” “Individual and collective identity play,” “Immersion,” “Simulation,” “Community presence,” and “Content production” [8]. Many of these aspects have been heavily benefited from the recent technological development of head-mounted displays. They give a realistic and strong immersive experience as well as natural interactions with the virtual environment, thank to accurate hand and positional tracking.

Immersion can help learners to absorb important information and construct mental models more accurately [9]. Moreover, when the learners are immersed, they can stay focused without external distractions. Natural and rich interactions with virtual objects realize the accurate simulation of procedures, such as medical operations, and encourage students to learn by doing. They can also promote constructivist learning [10] by enabling students to create content more intuitively in a 3D environment. Consequently, the students will start constructing knowledge actively and demonstrate their understanding of a subject by their creations. Through such experience, students will learn to take more ownership and responsibility for their learning [11]. Authentic learning, which places learners in an environment with “real life” disciplinary, professional or cultural context, will also benefit from deep immersion and realistic interactions afforded by virtual spaces [12]. They can give students a strong sense of presence, namely the sense of “being there” in a virtual space. When students are in this mental state, they will be more engaged in the activity and acquire not just knowledge but also the context associated with it, such as awareness of risk or responsibility.

These affordances can facilitate students to learn more abstract concepts. Since they can be hard for students to comprehend just by watching slides or videos, building, and interacting with their representations in an authentic context [13] can be particularly helpful. For example, amino acid structures are often shown in slides or videos as a 2D structural formula or a ball & stick model. When these images are shown to students, they often find it hard to associate them with 3D structures of the molecule or the proteins, which are made of a sequence of amino acids. On the other hand, students in a virtual space can not only view the 3D structure of an amino acid molecule but also juxtapose it with more complex amino acid sequences or proteins. This affordance will help them build a mental image of how a large biological molecule is made of simple building blocks.

In this paper, designs of the flipped classroom approach and the virtual spaces used in this study will be introduced. Then the results from the survey of the students who attended the course will be presented. Furthermore, the characteristics of virtual spaces as learning media for flipped classroom will be analyzed based on the students’ self-reports on their usage of virtual spaces, perceived usefulness, and willingness to use in the future. Finally, the advantages and practical issues of virtual spaces learned from students’ responses in the questionnaire will be discussed for future educational strategies.

II. RELATED WORK

Despite the potential benefits of virtual spaces, flipped classrooms that incorporate them as pre-class learning materials are still scarce. There have been many reports which used virtual spaces as a part of their teaching practices, but it has been rarely used as an integral part of pre-class learning activities for every lecture. This may be because it was hard to secure a sufficient number of devices for the entire class during the whole course period. However, recent improvements in PC and VR devices in performance and affordability have enabled students to experience virtual spaces at home. Sharom [14] used students’ own devices to deliver VR experience as preclass learning activities for their flipped classroom English course, though it was used only for a single lesson. Other technical issues, such as low internet connection speed or time-consuming to set up the software, have also been pointed out in earlier studies [15]. Thanks to the improvement of network technology and the development of modern “social VR” platforms such as AltspaceVR and Mozilla Hubs, those technical issues do not seem to be significant in recent reports of teaching practices using virtual spaces [16]. The technologies to create 3D content, most notably game engines like Unity, are also rapidly evolving. However, it is still challenging to build a 3D environment that can provide a meaningful learning experience in every class, and this technological hurdle may contribute to the slow adaptation of virtual spaces in the flipped classroom.
On the other hand, using a virtual space as an alternative environment to face-to-face communication in a classroom does not require constructions of a complex 3D learning environment and, therefore, is easier to implement. In Grenfell's flipped classroom for an undergraduate art unit [17] a virtual art gallery on Second Life was used as a collaborative learning environment for students and educators. The students were tasked, as an assignment, to design, build and curate an exhibition. While the students participated in group discussions in the classroom, they continued to work on the construction of virtual exhibition space and curation of the exhibition works away from formal class time. The author concluded that the virtual technology-assisted flipped classroom approach resulted in a better learning community and high satisfaction expressed by students. While this case demonstrated the benefit of using virtual spaces for social learning outside the classroom, it may not be suitable when the class size is too large for educators to monitor students or when the knowledge level of the subject is so diverse among the students those effective collaborations could not be expected, which is often the case with first-year undergraduate students.

Meanwhile, the flipped classroom approach employed by Zhenying [18] had more direct teaching using a medical virtual simulation platform. This platform combined experimental videos and operating guidelines and allowed students to learn the course of the experiments. The pre-class preparation in their course included online group discussion over the principle of basic clinical skills (e.g., lumber punctures) from textbooks, videos, and simulations. The authors evaluated the clinical skills and the perceived learning outcomes of the students and compared them with the control group who did not participate in the flipped classroom. They found that the students from the flipped classroom had significantly higher skill scores and felt more confidence and self-learning ability than the control group. For language learning, XiaoDong [20] employed a cloud-based interactive desktop VR system with network capabilities as a supplement to a standard flipped classroom. Namely, students were asked to watch video lectures and complete tests as assignments, but they may also use VR-based learning outside the classrooms to interact with virtual characters or expose themselves to English social and cultural situations. The overall reaction from the participating students was positive, but the author pointed out that preparing a virtual learning environment and content can still be a challenge for teachers.

III. METHODOLOGY
The current study is based on a mixed-method research design, combining statistical and qualitative analysis of a questionnaire about students’ usages and perceptions of virtual learning spaces in a flipped classroom setting. The study was conducted at an introductory course for undergraduate students called Basic Life Science, an introductory biology course for first-year students at Osaka Institute of Technology. A post course questionnaire on Google Forms was sent out after the final exam results were posted, and students were asked to answer the questionnaire on a voluntary basis. Ninety students over 18 years of age from the course agreed to participate in the survey. This survey had been approved by the university’s committee for ethical human subject research.

A. Measures
The experience of students’ learning with virtual spaces was evaluated using a self-reported questionnaire. The questionnaire had nine five-point scale questions and three open-ended questions. Firstly, students were asked about how many of the virtual spaces (eight in total) they used in pre-class learning and exam preparation (scale 5: all eight scenes, 4: almost all (six or seven scenes), 3: about half (three to five scenes), 2: only a few (one or two scenes), and 1: none). Next, they gave their perceptions on the usefulness of the virtual spaces for preclass assignments, for understanding lectures, and for exams (scale 5: very useful - 1: not at all useful). They also reported their willingness to use the virtual spaces in the future (scale 5: very willing - 1: not at all willing). Finally, they answered open-ended questions about their opinions on the advantages and the disadvantages of the virtual spaces and suggestions for possible improvements.

B. Analysis
The average ratings in Likert scale were compared using two-tailed Wilcoxon signed-rank test with significance defined as p<0.05. For the analysis of correlations between the answers to a pair of questions, Spearman correlation coefficients were used. Cross tabulation analyses with dichotomized scales were also performed to evaluate the changes of students’ responses to different questions, using McNemar’s Chi-square test, with p<0.05 as significance. The texts from the responses were processed by UserLocal AI text mining service (https://textmining.userlocal.jp/), and the frequencies of keyword nouns and verbs were counted.

C. Design of the Flipped Classroom
Basic Life Science course comprised of fourteen lectures, including two in-class exams at 7th and 14th lectures. The students were given a set of preparatory learning materials and an assignment a week before a class. The materials included PowerPoint slide files and a link to a virtual space created on Mozilla Hubs. While Mozilla Hubs was a multiplatform browser-based service, most students used PC for browsing. Some of the pre-class learning materials did not have virtual spaces, and, in total, eight virtual spaces were used for this course. Students learned these materials to complete an assignment before the lecture. The assignment had ten “correct this sentence” questions, such as correcting a given sentence “prokaryotes are all unicellular and have mitochondria” to “... and DO NOT have mitochondria.” The assignments were compulsory, and students would fail if they did not submit more than 80% of the assignments. The scores of the two inclass exams, which included True/False questions and short answer questions, counted for the final grade.

All the lectures were delivered remotely on Google Meet due to the shutdown of our university campus in response to
COVID-19. In an online live lecture, students were given answers to the questions on the assignment and extra lessons on the topics related to the questions. In the middle of the lecture, students were asked to work on an activity called “Image Assignment” in the virtual space. Each virtual space had one or more “Try this” features (see below). Then students completed one of the “Try this” exercises and took a screen capture and submitted it via Google Classroom as evidence. After this exercise, students did a revision exercise with multiple-choice questions and sent a response form to comment on the lecture.

D. Virtual Spaces

As mentioned above, students were given a virtual space one week before a live lecture. All the virtual spaces for this course were created using Spoke (https://hubs.mozilla.com/spoke/) and published on Mozilla Hubs. Students could create an instance of a space (called “room”) individually and, if they want, share their rooms with other students, though most students preferred to work on their own. Mozilla Hubs was used in this course because of its convenience. It runs on web browsers for PC, VR Head Mounted Displays (VRHMDs), and smartphones, can be accessed by a web link without a user account and is lightweight. A virtual space was composed of a background 3D model (e.g., mostly chosen from the samples on Spoke) and learning media. The learning media were spatially divided into three units in a virtual space. Each unit had a video clip, 2D images, and 3D models (Fig. 1). The clip was an extract from the video originally used as a pre-class learning material in previous years.

Fig. 1. Components of a unit on amino acid and protein primary structure in a virtual space, with a video, 2D images and 3D models

E. “Try this” exercises

“Try this” is an interactive exercise given in a virtual space. The exercises used in this study can be classified into the following: labeling, pairing, and discovery. The “labeling” exercise is to find something in a structure and give a text label. For example, in a module for protein structures, students were asked to place a “carboxyl group” label to a 3D molecular model of an amino acid molecule. In the “pairing” exercise, students find the right combination of objects. In “Prokaryotes and Eukaryotes” modules, for example, ribosomal “small” and “large” subunits for prokaryotes and eukaryotes were given in a virtual space (note: a ribosome is composed of a small and a large subunit, but the ones for prokaryotes were smaller than those for eukaryotes). The exercise was to find which “small” and “large” subunits form a complete prokaryotic or eukaryotic ribosome and combine them in the 3D space. In the “discovery” exercise, students explore a virtual space and find a place as instructed. This type of exercise was used to let students experience the concept of radioisotopes, which many students find difficult to understand (Fig. 2). In a virtual space, a large 3D model of a human male body was lying on the ground, and an invisible audio source, which worked as a mimic for a radioisotope, was placed somewhere in a body. Since the audio was spatialized in Mozilla Hubs, students could discover the position of the “radioisotope” by the audio volume, in a similar manner to the investigation of radioactivity using Geiger Counter. Then students left a “Here” text label to mark the position. Note that none of these exercises were marked automatically. As explained above, students submit screenshots of their completed works, and the lecturer (the author) evaluated them manually.

Fig. 2. An example of the “discovery” type of “Try this” exercises.

IV. RESULTS

A. Usage Frequency of the Virtual Spaces

In the questionnaire, 69% (62/90) of the students said they used six or more out of eight spaces (“high usage”) for the pre-class learning, while the rest used only five or less (“low usage”) (Fig. 3). On the other hand, less than half (46%, 41/90) of the students answered that they used six or more out of eight spaces for their exam preparation. A cross-tabulation analysis performed for “high usage” and “low usage” groups in the two questions (Table I) showed the difference was statistically significant (p = 0.0002). Although the usage remained high for both the pre-class learning and the exam revision in more than half of the students, the usage dropped in a sizable number of students. Among the “low usage” group in the pre-class learning, the usage remained low for the pre-exam revision.

<table>
<thead>
<tr>
<th>In exam preparation</th>
<th>In pre-learning28</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>High usage</td>
<td>Low usage</td>
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<tr>
<td>High usage</td>
<td>37</td>
<td>25</td>
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<tr>
<td>Low usage</td>
<td>4</td>
<td>24</td>
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<td></td>
<td>49</td>
<td>90</td>
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TABLE I. USAGE PATTERNS OF VIRTUAL SPACES
B. Perceived Usefulness of the virtual spaces

The questionnaire had three questions about the overall usefulness of the virtual spaces: for pre-class assignments, for understanding lectures, and for exams. While average ratings were high in all cases, the average rating of “for understanding lectures” (4.43) was significantly higher (p = 0.0007) than “for pre-class assignments” (4.16), while the average rating of “for exams” (3.86) was lower than “for pre-class assignments” (p = 0.00056) (Fig. 4). Students were also asked specifically about the usefulness of “try-this” exercises. The results were similar in “for understanding lectures” (4.44) but slightly higher in “for exams” (3.97) and lower in “for pre-class assignments” (3.94) (Fig. 5). However, none of the overall vs “try-this” usefulness differences were statistically significant (p = 0.097, 0.872, 0.078, respectively).

To analyze the relationship between the usage and the perceived usefulness of the virtual spaces, the students were grouped by their usage in pre-class learning (High usage and Low usage). Next, the scale for the overall usefulness was dichotomized into “highly useful” (scale 4-5) and “not useful” (scale 1-3) groups, and cross-tabulation analyses were performed between “useful for pre-class assignments” and “useful for understanding lectures” categories (Table II).

A comparison between the “High usage” and “Low usage” groups showed that the rating of “for pre-class assignments” was substantially lower (“highly useful” 64%, 18/28) among the “low usage” group than the “high usage” group (“highly useful” 89%, 55/62). However, it should be noted that more than 10% of students (7/62) in the “high usage” group rated the virtual spaces “not useful” for the pre-class works, despite that they used the majority of the virtual spaces as pre-class learning materials.

Meanwhile the comparison of the ratings for the perceived usefulness showed that the rating of “for understanding lectures” in the “high usage” group (98%, 61/62) was significantly higher (p = 0.041) than that of “for pre-class assignments”. This result suggests the students who consistently used the virtual spaces found their benefit as a help to deepen the understanding of the subject, rather than just a tool for homework that they had to use. The low “preclass” usage students showed a similar trend, but the difference between “for pre-class” and “for lectures” was not statistically significant (p = 0.073).

C. Willingness for future virtual space uses

The students were asked whether they would like to use the virtual spaces again if offered in a similar type of class (“future willingness” – Fig. 6). The average rating was high (4.19), suggesting that, overall, they were satisfied with the use of virtual spaces in a flipped classroom setting. To analyze the responses further, the correlations of the ratings for future willingness with those for usage and for perceived usefulness
were obtained (Table III). Spearman correlation coefficients were all statistically significant, but higher with “perceived usefulness” than “usage”. The highest was “perceived usefulness for pre-class assignments”, with correlation coefficient = 0.686. This result may suggest that students’ perception of pre-class works influences their attitudes to virtual spaces in a flipped classroom setting.

<table>
<thead>
<tr>
<th>TABLE III. SPEARMAN CORRELATION COEFFICIENTS BETWEEN THE WILLINGNESS FOR FUTURE USES AND OTHER MEASURES</th>
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<tbody>
<tr>
<td>Usage in pre-class learning</td>
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<tr>
<td>Usage in class learning</td>
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<td>Note: all coefficients were statistically significant (p&lt;0.05)</td>
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Fig. 6. Willingness for future virtual space uses.

D. Perceived advantages and disadvantages of the virtual spaces

The questionnaire asked following open-ended questions: Tell us what you thought good / bad about virtual spaces as learning materials. In good responses (47 responses), “three dimensional/three dimension/3D” (14 times) and “understanding” (13 times) were the most common nouns, while “can do” (13 times), “move things” (8 times) and “look” (6 times) were the most common verbs. In bad responses (35 responses), on the other hand, “manipulations” (8 times), “assignments” (6 times) and “movements” (6 times) were the most common nouns and “require” (5 times) was the most common verb.

E. Suggestions for improvements

Eighteen responses were obtained an open question on suggestions for improvements. Six of them were about the manipulations, such as “want a better instruction for manipulations” and three of them were about navigations, including “it was difficult to find where the videos were” and “it was difficult to know the order in which to browse”.

V. DISCUSSION

This article presented virtual spaces developed for an undergraduate biology course with a flipped classroom design. It showed and analyzed how the course was perceived by the students, in order to explore and possibly improve the learning benefits of virtual spaces. As Clark pointed out [21], newer technologies such as virtual technologies tend to suffer from novelty effects due to students’ increased effort or attention which diminishes after several weeks. In this study, however, students experienced learning with virtual spaces for 14 weeks, which should be long enough for the novelty effects to subside. Therefore, the fact that 69% of students used most of the virtual spaces and rated highly (average 4.43 out of 5) for their usefulness in understanding lectures demonstrated that the virtual spaces used in this study were genuinely perceived as effective for learning.

While pre-class assignments were compulsory, students were not strictly required to use virtual spaces for assignments, and in fact, it was possible to answer the questions using only PowerPoint slides. Therefore, those who used the virtual spaces frequently can be considered “motivated” for virtual learning was not markedly higher than the video usage in previous years, where videos for pre-class learning were played on average roughly 0.7 times per student per video. This means that there is a sizable group of students who prefer the simpler learning medium (i.e., slides) to those which require more time and effort. Meanwhile, the overall usage in exam revisions was higher than expected, although it was still significantly lower than pre-class. The result was surprising because students tend to use only slides when revising, and, in previous years, videos were hardly played during the exam periods. This difference was probably because interactive exercises were hard to recap without visiting virtual spaces, while declarative knowledge could be learned using slides.

The usefulness of the virtual spaces was rated lower for pre-class learning and for exam preparations, and some of the students who did use most of the virtual spaces rated them as “not useful”. The pre-class assignments and exams had short answer questions and true/false questions to test students’ knowledge. However, the virtual spaces in this study may not have offered enough scaffolding to link the experience in the spaces with the questions they had to answer. Since learning in virtual spaces gives more freedom and flexibility, students can be confused if there is no scaffolding to help students learn by gradually taking responsibility and ownership for their learning with motivation and engagement [22]. It has been argued that scaffolds that are aligned with the learning objectives, activities, and assessment are crucial for self-directed learning in virtual spaces [23]. From a systematic review of educational uses of VR in K-12 and higher education, Luo [7] found that scaffolding improved learning performance in VR, regardless of whether it was provided by computers (e.g., text guidance) or by teachers (e.g., debriefing after a VR session).

Possible improvements for better scaffolding may include 1) re-designing “Try-this” exercises to be more congruent to the assigned tasks outside the virtual spaces, and 2) more explicit instruction on what the virtual spaces and other learning materials are intended. Scaffolding may be particularly important for the “low-usage” group in pre-class learning. In this group, 64% and 82% of the students answered that the virtual spaces were useful for pre-class learning and understanding lectures, respectively, suggesting that their low usage was not due to their aversion to the virtual spaces. Therefore, they may become more willing to use them with better guidance for pre-class learnings using virtual spaces.
The design of pre-class learning may also be important to improve the willingness to use virtual spaces in the future. The willingness of using the virtual spaces in the current form (i.e., flipped classroom) seems to be closely related to perceived usefulness, particularly for pre-class learning. Meanwhile, the majority of the students who were unwilling for virtual spaces still found them useful for understanding lectures. This result seems to support the notion that students’ perception of virtual spaces as learning materials in flipped classroom depends on how the pre-class learning is designed with appropriate scaffolding. On the other hand, it is also possible that learning with virtual spaces may not have been convenient for the lifestyles of busy students. For example, some students complained that Mozilla Hubs was too time-consuming, and others said that the requirement of PC or VRHMDs for performing interactive exercises was inconvenient if they wanted to try them on commuter trains only where they could find time for homework.

The virtual spaces used in this study essentially had two features: “looking” and “trying”. “looking” included 2D illustrations and 3D models for students to learn by looking, and “trying” was the interactive “try-this” exercises explained above. The responses to the open question about the perceived advantages of virtual spaces show that students appreciated both “looking” and “trying” features, especially with 3D objects, to assist the understanding of the subject. While the author expected students to be highly enthusiastic about the game-like interactive natures of “trying” features [24], the students’ perceived usefulness of “try-this” exercises was not significantly higher than the overall usefulness. This may suggest that students equally appreciated “looking” and “trying” features.

The students who participated in this study majored in Information Science and Technology and were familiar with ICT and computer games that use 3D spaces, such as FORTNITE (Epic Games) or APEX LEGENDS (EA). Therefore, it seemed reasonable to assume that students would learn exploration and manipulations in Mozilla Hubs with minimal instructions. However, responses in the open questions showed that at least some students had trouble with the operations, and they requested more precise instructions. It may have been due to the difficulties of using Mozilla Hubs on PC rather than HMD, but the poor design of the virtual spaces may have contributed too. The background 3D models for the virtual spaces were chosen from the samples provided by Mozilla, but there were very few which were suitable for creating a learning environment. Therefore, the layouts of some virtual spaces used in this study may have been clumsy and confusing. If virtual spaces are going to be widely used for learning outside classrooms without teacher’s support, spatial affordances of virtual spaces [25] will be crucial for navigating the spaces without cognitive load that can hamper learning [26]. It may also have been beneficial to utilize the network functions of social VR platforms, such as room-sharing and text chats, to encourage peer learning and help each other learn in unfamiliar virtual environments. However, the students who participated in this study had tendencies to avoid communication with other students and prefer working on their own, and therefore the effect of social VR function would probably be limited.

Finally, a limitation of this study should be mentioned. The entire findings of this study are based on a single questionnaire. While it was designed to cover diverse aspects of students’ perceptions and behaviors toward virtual learning spaces, it is clearly more desirable to employ a multi-method approach, which may include qualitative methods such as interviews, participant observations, and focus groups, as well as quantitative methods including logging of students’ motions in virtual spaces.

VI. CONCLUSION

Virtual spaces can be a viable option for flipped classroom along with other digital media, such as slides or videos, because of the affordances they can offer to help self-directed learning. The virtual spaces presented in this article were utilized by the students for their pre-class learning and exam preparations, and most of the students found them a useful learning tool. The students learned and showed improvements in the understanding of class learning and exam results by observing and manipulating objects in 3D environment. This finding should be positive enough to warrant further development of flipped classroom strategies incorporating virtual spaces. However, in the current implementation, poor scaffolding and spatial design of the virtual spaces seem to have limited the usages. Therefore, it is essential to develop a pedagogical framework that integrates the learning experiences in virtual spaces and outside (such as textbooks or written assignments) to ensure that the learning outcomes obtained from virtual spaces are readily transferable to other learning activities. It is also important to develop digital tools to make the design of virtual learning spaces more efficient, because it is prohibitively time-consuming for teachers to construct their own virtual learning space for each lecture using the 3D authoring tools currently available. Once these hurdles are overcome, more and more practitioners will start using virtual spaces in their flipped classrooms.

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