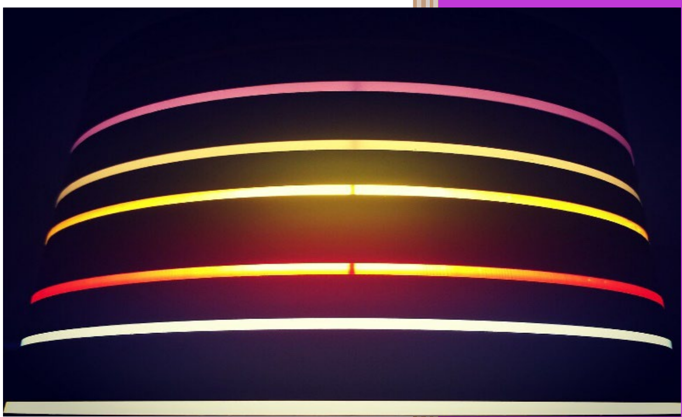
2024

EJEL Volume 22, Issue 3



Editors

Heinrich Söbke and Pia Spangenberger

Published by Academic Publishing International Limited
Curtis Farm, Kidmore End, Nr Reading, RG4 9AY, United Kingdom
karen.harris@academic-publishing.org

eISSN: 1479-4403

EJEL Volume 22, Issue 3

Special Issue on Extended Realities 2025

A Review of Virtual Reality from Primary School Teachers' Perspectives

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https://doi.org/10.34190/ejel.21.4.3060

Abstract: Virtual reality (VR) is used across the educational spectrum (higher education, high school, primary school, and even pre-school); however, primary school teachers' perceptions of using VR in their classrooms require further research. A brief review of the literature of 100 existing articles related to teaching within the primary school context was conducted. The articles were obtained by performing a word search within Google Scholar, with the keywords 'virtual reality primary school teachers 2018 - 2023'. Teachers indicated both hesitance and enthusiasm for incorporating VR. The findings of this study indicated that only a low number of articles (n = 11) addressed VR and primary school teachers, compared to the total number of articles reviewed (n=100). Researching VR and teaching assists in supporting the wider fringe aspects of e-learning practices, such as VR. It advances the compass of e-learning knowledge by integrating immersive learning tools into the primary school classroom.

Keywords: Virtual Reality (VR), Primary school teaching, VR resources, Immersive, Learning, Teachers

1. Introduction

'Virtual reality is the first step in a grand adventure into the landscape of the imagination' (Biocca and Levy, 2013, p. 184). Multimodal virtual reality (VR) resources influence teachers' teaching. These VR resources take learners into environments they may not be able to go into, by wearing a VR headset or goggles. It creates a visual and auditory display for the learners to experience. This paper highlights the limited amount of research that has been conducted with primary school teachers and their opinions on the use of VR as a teaching resource. Articles about pre-service teachers being exposed to VR were also included to extend the scope. The focus is on primary school teachers' perspectives of VR in research conducted between 2018 and the beginning of 2023. The research is based on previous studies and research on learning in VR (Bricken and Byrne, 1992) and integrating VR into specific learning areas (Stojšić, et al., 2016). To assist in obtaining articles on virtual reality within the primary school, the Internet was used as an exploration tool, specifically Google Scholar. After an analysis of 100 articles, thirteen were identified to address the following question: What are the perspectives of teachers on virtual reality in the classroom? (Eleven articles were about teachers teaching and three articles were student teachers still studying.) The review explores the influence of virtual reality as an educational resource in the primary school context, across a range of countries and various types of virtual technologies (Mukasheva, et al., 2023). Teaching professionals determine the educational value and relevance of the e-learning tools they use in their teaching and learning environments. They motivate the inclusion or rejection of digital technologies, such as VR, in their lessons, as well as the connection to the designated curriculum and the professional knowledge of the teacher (Fransson, Holmberg and Westelius, 2020; Li, Liu and Chen, 2022). The importance of understanding teachers' perceptions about VR (Alalwan, et al., 2020) helps to demonstrate viewpoints related to technology and provides considerations for when to include it. This review highlights the importance of engaging researchers with teachers to understand their points of view related to VR technology. These findings might influence policymakers toward benefits of access and availability for technologies such as VR into the primary school classroom. These VR devices and scenarios are not a solution to all educational needs, but are effective teaching tools (Nesenbergs, et al., 2021), while teachers' attitudes affect the level of confidence and comfort with incorporating VR technology into lessons (Yıldırım, Yıldırım and Dolgunsoz, 2019; Li, Liu and Chen, 2022). The next section addresses the current understanding of what VR technology is.

Cite this article: Walstra, K.A., Cronje, J. and Vandeyar, T. 2023. "A Review of Virtual Reality from Primary School Teachers' Perspectives", *The Electronic Journal of e-Learning 22(3)*, pp 01-11, https://doi.org/10.34190/ejel.21.4.3060

2. What is Virtual Reality?

VR is a digitally created multisensory immersion that allows participants to perceive the 'virtual' experience (Franchi, 1995). VR development of head-mounted displays with two tiny stereoscopic screens positioned close together in front of the eyes resulted in the potential for VR to be created (Woodford, 2007). VR integrates computer graphic images, interactive buttons, and sounds (Cochrane, 2016; Fuchs, Moreau and Guitton, 2011) absorbing the user in an immersive artificial, sensory, digital environment (Massis, 2015). As technology companies developed VR products, these virtual worlds became more accessible and their impact on education increased (Jowallah, Bennett and Bastedo, 2018; Rudran and Logishetty, 2018). The virtual scenario (Jowallah, Bennett, and Bastedo, 2018) provides an immersive environment in which students may interact and work. VR substitutes the user's reality as they wear the headset, while augmented reality (AR) enhances the physical world with an augmented digital image (Rogers, 2017). Multisensory, authentic VR learning experiences within interactive environments (Al Farsi, et al., 2021; Philippe, et al., 2020) are potentially beneficial for teaching and learning in schools (Craddock, 2018).

3. Literature Survey

As new and innovative technologies such as VR emerge, so do ideas for incorporating them into classrooms to enhance learners' interactions and learning. VR provides opportunities for primary school teachers to explore different technologies. VR is seen as an immersive (Jowallah, Bennett, and Bastedo, 2018) and accessible resource (Billingsley, et al., 2019; Rudran and Logishetty, 2018; Makransky and Lilleholt, 2018), capable of being used in different school contexts (Craddock, 2018; Dick, 2021), within learning theories such as the theory of experience (Parong and Mayer, 2018), experiential learning (Asad, et al., 2021) and constructivism (Niţu, et al., 2018). Teachers consider VR scenarios as useful teaching resources (Nesenbergs, et al., 2020) which digitally replicate learning environments (Abdullah, Mohd-Isa and Samsudin, 2019; Makransky and Lilleholt, 2018; Peltekova and Stefanova, 2016), and may potentially deepen learners' understanding of concepts (Parong and Mayer, 2018; Wu, et al., 2021). Virtual reality allows learners to feel as if they are immersed in a situation. VR applications enable learners to gain experience in dangerous situations or situations that are impossible to reach in real life (Serin, 2020). The factors to be considered when integrating technology are the perceptions of learners and teachers, institutional support, potential integration barriers, the reason for integrating technology, and the previous experience of using VR (Alfalah, 2018). Teachers' perceptions of educational VR solutions determine how effectively these technologies are incorporated into lessons (Albirini, 2006).

The eleven articles reviewed provided insights into VR in primary school situations.

- Alalwan et al. (2020) addressed the challenges and prospects of VR and augmented reality by primary school science teachers. Their findings highlight teachers' lack of practice in mastering VR technology, suggesting that teachers should be trained in educational technologies.
- Garcia, Nadelson and Yeh (2023) explored 360° virtual field trips for primary school learners, working with teachers and parents during the Covid pandemic lockdown, to take learners on virtual outings. They found that learners were positively engaged and actively participative.
- Hui, et al. (2022) explores virtual reality technology for teaching art in primary school. The experimental group of learners demonstrated a slightly better command of the details in the creation procedures, based on teachers' feedback. The study advocates using technology to lead teaching reform by investigating strategies for integrating virtual reality into teaching.
- The study by Khukalenko, et al. (2022) obtained their findings through a large-scale survey of more than 250,000 teachers and reports on their attitudes toward the use of VR for education, their relationships between the level of VR integration of teachers, their teaching approaches, and the frequency of VR use.
- Li, Liu and Chen (2022) explore the use of Immersive Virtual Reality (IVR) in science lessons and its influence on the learning performance of six graders and a teacher**.** The research suggested that investing in teacher training in VR would result in successful integration of VR into school classrooms.
- Maher and Buchanan (2021) researched the effectiveness of 360-degree video, on desktop virtual reality combined with analytics software, with eye tracking and chat features in the primary school classroom. The study indicated that teachers could access engagement information about learners using the analytics tool.
- Mukasheva, et al. (2023) researched a contextual framework for a VR learning environment to interpret the expectations of teachers and students, living in rural areas, regarding how VR should be included in the learning process. The teacher participants see VR as a beneficial technological

opportunity for humanity; however, approximately half of the participants expressed concerns about the potential negative health effects of VR. Most of the teacher participants expected schools to purchase VR headsets in the next five years and use them for teaching learners.

- Patterson and Han (2019) provide reflections on observations and interviews with one teacher who taught his learners by integrating VR into the curricula, and thereby enhancing his teaching practices and learner interaction. The study found that the individual teacher participant embraced innovative technology integration, suggesting that it would be beneficial for teachers to participate in collaborative lesson creation for effective technology integration.
- Rodríguez, Romero and Codina (2021) explores teachers' and learners' reactions to the interactive, manipulative geometry VR software, as they create and configure 2D and 3D shapes. The VR software was a new teaching tool for teachers, to be used to improve learners' 3D visualisation and the understanding of geometry. The findings illustrate how the teachers applied strategies to include all the students in building their geometrical knowledge.
- Serin (2020) gained teachers' perspectives about VR in education when they submitted a survey. The research recommended that VR be introduced as a teacher training course in education technology for preservice teachers to see the benefits of the technology and be motivated to integrate VR technologies into their lessons.
- Wu, et al. (2021) explored the teaching of elementary school students using VR for scientific enquiry. The teachers taught the lessons. These findings expressed that VR may promote learners' cognitive levels and abilities. The observations of the teachers were not presented, but suggestions of how they might teach and integrate VR, are.

In addition to the above articles, there were three preservice teacher research articles, which involved students who wanted to teach in primary schools.

- The research of Lin and Sumardani (2023) explored VR in science classrooms as *preservice teachers* implemented the technology. The study identified that VR helps build scientific concepts by provoking learners to expand on their VR learning content. This demonstrated the need for the teacher to guide the learners during the lesson.
- Thohir, et al. (2023) explored the effects of TPACK and the acceptance of VR in science education with *preservice teachers* from various Indonesian universities as participants. The participants' involvement in the VR training course was highly recommended.
- Li, Liu and Chen (2022) conducted a study in a rural area to establish the acceptance of VR among undergraduate *preservice teachers* as participants who intended to teach in preschools or elementary schools. These participants expressed hope in VR as a resource to help overcome educational inequality for future learners, as well as to demonstrate equal access to educational resources in both rural and urban settings. The projects referred to in the articles used a range of virtual technologies, from less immersive to highly immersive, as well as virtual desktop experiences. The selection of these articles is described in the research method.

4. Method of Analysis

The question addressed in this paper is: What are the perspectives of teachers on virtual reality in the classroom?

The researcher conducted the research using the Internet and searched within the Google Scholar website for academic articles and articles within the search keyword 'virtual reality primary school teachers', and decided to analyse the first 100 results within this query. With results on each page, the researcher meticulously worked through pages one to ten. Each paper was opened and briefly reviewed, and then categorised according to the following headings. The headings were developed as the papers were assessed in relation to virtual reality and the primary school teacher.

The Google Scholar search groupings after reviewing:

- VR and primary school teachers
- VR and preservice / teacher training
- VR and Primary school learners
- VR and other educational fields
- VR and secondary / high school learners
- VR and preschool learners

- VR in Higher Education
- VR literature review / Research VR to enhance learning
- Software development / evaluation in schools
- Comparison / Analysis between VR and Ar.
- AR and education
- AR and learners

The table below(Table 1) provides the breakdown for each of the headings.

Table 1: One Hundred Articles from Google Scholar Search - Virtual Reality primary School Teachers 2018 - 2023

Google scholar search: virtual reality primary school teachers 2018 - 2023	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Search 7	Search 8	Search 9	Search 10	Total / Sub-Totals
VR & Primary school teachers	2	1	0	0	3	2	1	0	0	1	10
VR preservice / teacher training	0	0	0	0	0	1	0	0	2	0	3
VR & Primary school learners	7	5	3	3	1	3	3	2	3	2	32
VR, learners & other educational fields	0	0	0	0	0	0	1	1	1	0	3
VR & secondary / high school learners	0	0	1	1	2	1	0	0	1	1	7
VR & preschool learners	0	0	0	0	0	0	0	1	1	0	2
VR in Higher edu	0	0	0	1	0	0	0	0	0	0	1
VR lit review / Research VR to enhance learning	1	1	1	0	0	0	0	0	0	1	4
VR software development / evaluation in schools	0	0	1	0	0	2	2	0	0	0	5
Comparison between AR & VR	0	0	1	1	1	1	0	1	0	0	5
AR & education	0	0	0	1	2	0	2	1	1	1	8
AR & learners	1	3	3	3	1	0	1	4	1	3	20

Google scholar search: virtual reality primary school teachers 2018 - 2023	Search 1	Search 2	Search 3	Search 4	Search 5	Search 6	Search 7	Search 8	Search 9	Search 10	Total / Sub-Totals
Total / Sub-Totals	11	10	10	10	10	10	10	10	10	9	100

An interesting observation was the number of articles per year that appeared in the search from 2018 to 2023 (see Figure 1) . Forty-seven articles emerged from 2023, with twenty-six of them on VR in education.

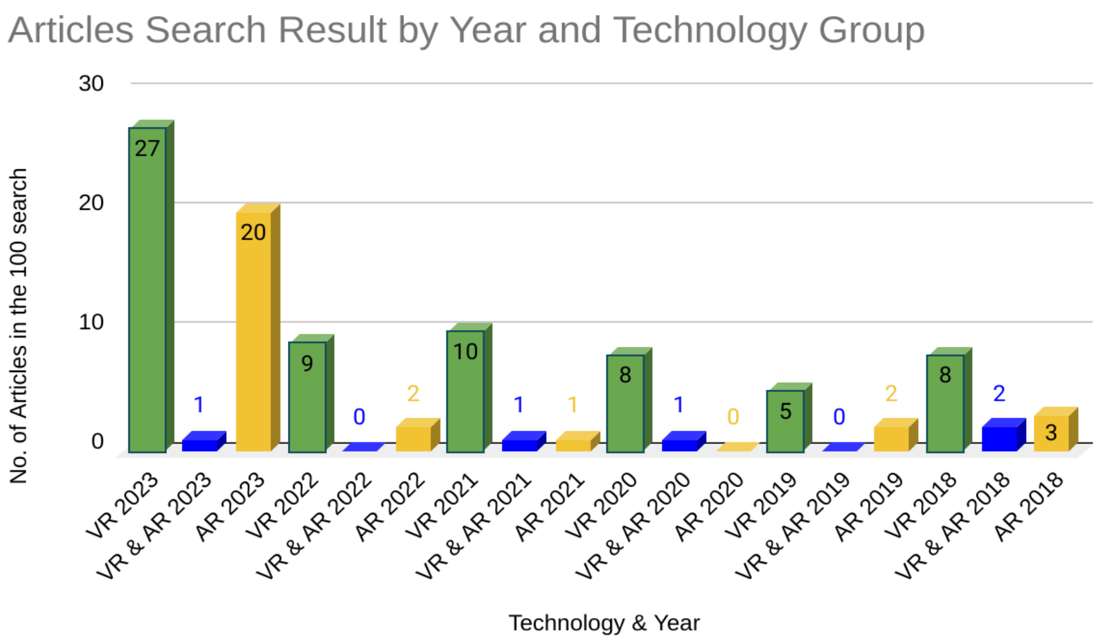

Figure 1: One Hundred Articles Search Result by Year and Technology Group

In this review, the term 'primary school' is interpreted from a South African perspective, where primary school is from grade 1 to grade 7. The target audience was teachers within primary schools using VR. The vast majority of articles related to VR (n=67) across a range of topics, and augmented reality (AR) (n=28) was the next group of articles. The final small group of articles was comparisons, combinations, or analyses of VR and AR (n=5). The papers related to virtual reality but were not all primary school teachers focused. These papers focused on

- 31 papers: VR and learners, and no teacher voice was provided.
- 3 papers: VR and other educational fields, which included:
    - The effects and emotions on learners when participating in a creative performance (Huang and Chang, 2023)
    - Exploring a World Heritage Site as a VR Experience (Zhu, et al., 2023)
    - Using VR to identify risky pedestrian behaviour in children (Luo, et al., 2020)
- 7 papers: VR in secondary or high school education
- 2 papers: VR and preschool learners
- 1 paper: VR and Higher Education
- 4 papers: Review of the VR literature or general research related to VR
- 5 papers: VR Software Development or Evaluation within Primary Schools
- 4 papers: VR related to Higher Education

This left 13 papers that included the views of primary school teachers, qualified teachers (10 papers) and pre-service teachers (3 papers) within their research. These articles either focused entirely on the teachers or included teacher views within the research.

Each article was analysed and the information was categorised under the following headings:

- Alignment of the curriculum and lessons with VR resources (n=14 comments)
- Teachers' concerns about VR (n=18 comments)
- Positive views and observations (n=17 comments)
- Challenges the teachers referred to with respect to their students (n=10 comments)
- Prospects and opportunities that teachers referred to with respect to their students (n=28 comments)
- Positive perceptions of pre-service teachers of VR integration in lessons (n=5 comments)

The VR devices used in these studies varied greatly, from head-mounted devices (HMD), such as Google cardboard or other similar headsets, such as the Xiaomi head-mounted display (Patterson and Han, 2019; Yıldırım, Yıldırım and Dolgunsoz, 2019), powered by mobile phones (Alalwan, et al., 2020; Serin, 2020) to high-immersion virtual reality (VR) technology for education (Khukalenko, et al., 2022; Li, Liu and Chen, 2022; Lin and Sumardani, 2023; Mukasheva, et al., 2023). One project had individual VR Neotrie equipment consisting of a VR visor and controllers, with a standard videogame computer (Rodríguez, Romero and Codina, 2021). Another had ten immersive virtual reality (IVR) devices, which were high-performance computers, an HMD, and two controllers for each user, as well as a mobile tablet containing the IVR teaching system with the set of systematic IVR lessons (Liu, et al., 2020). Another was a group of desktop virtual reality computers, containing 360-degree video footage, and an analytics platform (Maher and Buchanan, 2021). Wu, et al. (2021) used a spherical video-based VR (SVVR) system. Finally, a full VR classroom equipped with 30 sets of PICO VR integrated headset displays and a series of HTC VIVE VR headsets connected to the teacher's equipment and a teacher machine was used. The teacher was able to manage the devices of the learners as these technologies were used to explore immersive VR in lessons, across a range of countries.

The projects were carried out in twelve countries. The countries where the selected research articles were conducted were two European countries, Poland and Spain; two countries in the Middle East namely Saudi Arabia and Iraq; two projects in Southeast Asia, one in the Philippines and one in Indonesia; eight Asian sites, one in Russia, Kazakhstan, Taiwan, and four projects in China (Jinhua City, Shanghai, Beijing, and rural China among minority groups of people). Figure 2 indicates the places on the map.

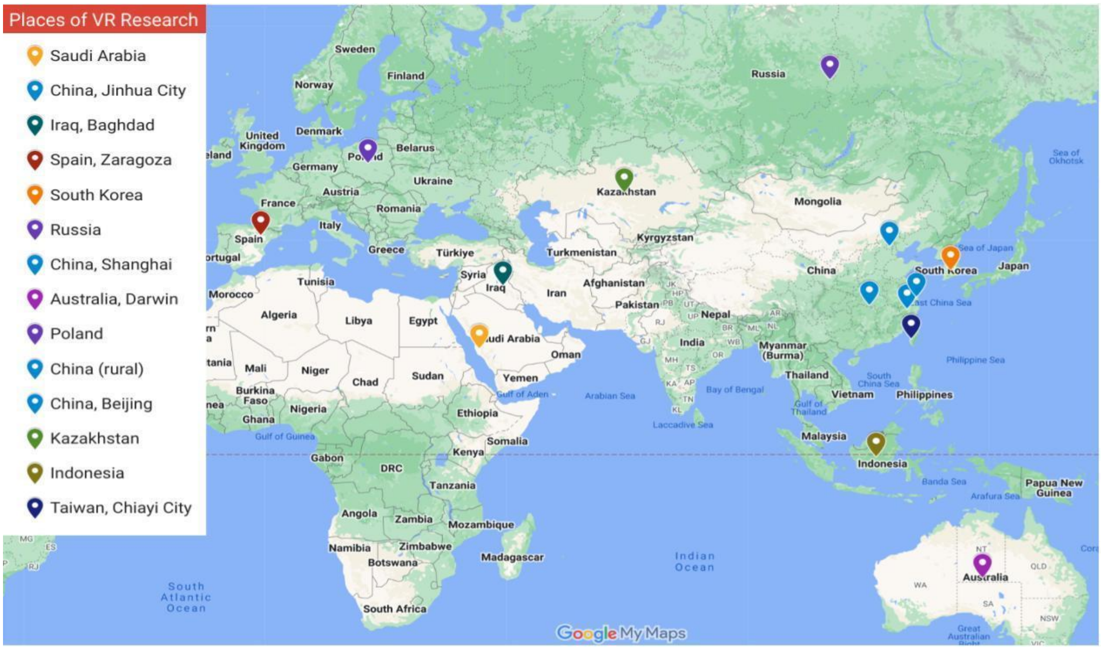

Figure 2: Map of Research Areas

These articles were related to primary school teaching and the incorporation of VR within lessons. Subjects that these studies focused on were science (Alalwan, et al., 2020; Liu, et al., 2020; Wu, et al., 2021), mathematics (Rodríguez, Romero and Codina, 2021), language, specifically Korean literacy (Patterson and Han, 2019), and art (Hui, et al., 2022), geography (Maher and Buchanan, 2021). Three of the articles had a range of subjects that teachers taught, as these were large surveys. The one took place in Iraq, where 14 middle school and 15 high school teachers received the information and the link to the online questionnaire to complete (Serin, 2020). The second article was a survey that took place in Russia, where more than 20,000 teachers answered the survey

(Khukalenko, et al., 2022). Participants taught subjects such as computer science, chemistry, physics, biology, technology, mathematics, social science, Russian (as the first language), foreign languages, and literature (Khukalenko, et al., 2022). The subjects taught are related to the curricula in those countries. The teachers' thoughts and points of view are explored in the next section.

5. Teachers' Perspectives

5.1 Curriculum Alignment

Exploring teachers' perspectives of VR in the classroom further begins by addressing curriculum affiliation. A subject-based curriculum consists of various subjects, such as Mathematics, Science, or Social Sciences, to be taught within a grade. A curriculum outlines the teaching and learning content, outcomes, and performance criteria (Schmidt, et al., 1997). Six of the articles were associated with lesson content, which was aligned with specific curricula. In turn, the VR activity supported curriculum learning. 360-degree VR assisted learners to meet the geography outcomes (Maher and Buchanan, 2021). VR immersive resources are integrated into the science curriculum and used to help meet national curriculum standards (Liu, et al., 2020). When planning the lesson, the content of the VR resource was aligned with the curriculum topic. The teacher created a technology-enhanced social studies curriculum lesson (Patterson and Han, 2019). When planning lessons with VR resources, the teacher must understand how to align the lesson content with the curriculum and must ensure that the lesson addresses learning needs (Khukalenko, et al., 2022). VR technologies, Neotrie, enhance familiar subject curriculum content and provide additional relevant mathematical information (Rodríguez, Romero and Codina, 2021). In this instance, the technology is seen as an amplifier of learning material and a learning context reorganiser (Rodríguez, Romero and Codina, 2021). Contrary to this, the use of VR in primary school science curriculum was hindered due to the limited VR instructional materials (Alalwan, et al., 2020). One study aligned with Vygotsky's sociocultural theory (Vygotsky, et al., 1978), where a social process is mediated through interactions with tools, describing their 360 images and analytics platform as a sociocultural-multimodal framework (Maher and Buchanan, 2021). Developing students' problem-solving skills as an aspect of using VR resources aligned to the curriculum involves engaging them in diverse modalities and a variety of strategies (Wu, et al., 2021). Integrating VR resources into lessons, implies that policymakers, teachers, and e-learning developers must align the merging of pedagogy and technology (Jowallah, Bennett, and Bastedo, 2018). Participating in these VR lesson activities resulted in the teachers expressing their concerns.

5.2 Concerns Integrating VR

Some teachers were concerned about costs and budget constraints, and other teachers were requesting a VR-equipped environment for their schools (Hui, et al., 2022). Others found the cost reasonable, as VR devices were included in the lesson, learners' mobile device, and no additional costs for application usage (Patterson and Han, 2019). Teachers were concerned about informing parents about the need for learners to bring mobile phones to school (Patterson and Han, 2019), or that learners may not be able to acquire devices (Alalwan, et al., 2020). Concerns were highlighted about the limited number of immersive VR devices (Liu, et al., 2020) in a lesson, or an unreliable Wi-Fi connection (Patterson and Han, 2019) which meant that the VR application would not function. From a technical perspective, with learners using their personal mobile devices, even when they have installed the VR application at home, there were issues related to the individual phone settings of the range of devices (Patterson and Han, 2019). The time constraint due to timetabled lesson times was also raised (Alalwan, et al., 2020). When preparing the lessons, teachers raised the concern of the limited range of VR content (Alalwan, et al., 2020). Being prepared and knowing how to use technology is important, as explained in the next section. Raising concerns resulted in the teachers expressing positive views.

5.3 VR as a Good Teaching Tool

Teachers valued VR as good teaching tools, helping learners learn science content, believing that these resources are capable of explaining abstract concepts and stimulating learners' interest (Alalwan, et al., 2020). VR was positively correlated with learning engagement, which contributes to understanding knowledge (Hui, et al., 2022) and promoting independent learning (Alalwan, et al., 2020). The teacher observed that the learners who struggled to learn, became more interested when using the VR resource (Hui, et al., 2022; Rodríguez, Romero and Codina, 2021). Teachers modified their initial lesson plans from more traditional methodology to integrate VR resources (Patterson and Han, 2019). These changes result in an inductive learning approach that affects spatial reasoning (Rodríguez, Romero and Codina, 2021), where traditional lessons were altered to become interactive. Teachers adapted existing lessons with VR-infused learning resources, accommodating learner needs (Patterson and Han, 2019) and improved classroom teaching engagements (Hui, et al., 2022). VR learning environments can be used to present the attractiveness of science and STEM education, can improve learning outcomes, increase motivation, and create an interest in learning (Mukasheva, et al., 2023). Virtual reality environments promote an alternative to traditional classroom learning. A teacher expressed the impact of using an immersive, interactive VR activity to teach geometry that radically changed the way geometry was taught. VR assisted in teaching the difficult spatial geometry topic in an easy and attractive manner (Rodríguez, Romero and Codina, 2021).

It is important to know how technology works. The value of professional development was noticeable, since one teacher received three months of VR training prior to conducting the study (Liu, et al., 2020) and was comfortable in planning and presenting the lessons. There are benefits in personal development for teachers with regard to educational VR technologies (Billingsley, et al., 2019). In preparing prospective teachers for the integration of viable and affordable technology into their lessons, it is relevant to identify the important aspects of VR for effective adoption (Thohir, et al., 2023). For teachers to understand the potential technical difficulties and to know how to use the technology, they must be trained (Hui, et al., 2022). These ideas were reinforced by the notion that teachers who were comfortable and familiar with VR technology attempted to use it more often in lessons (Khukalenko, et al., 2022). Teachers understanding and using the analytics platform linked to the virtual experience began to understand the online behaviour of their learners, using the eye tracking information to appropriately adapt future lessons and assess the online behaviour of learners (Maher and Buchanan, 2021). Teachers also expressed potential challenges during lessons.

5.4 Challenges Regarding Students

Some teachers were concerned about the adaptation of VR lessons. Khukalenko, et al. (2022) detected that most teachers had a low level of confidence using VR technology in their lessons. Teachers were perturbed about learners viewing other content, not related to lesson, therefore they selected guide mode (Patterson and Han, 2019). Another teacher was sceptical about the effectiveness of VR, from finding relevant resources to create a structured VR lesson that flowed well and did not create chaos in the classroom (Patterson and Han, 2019). Other teachers were not convinced about teaching science using VR technology (Alalwan, et al., 2020). Teachers also considered the health risks for their learners when using VR (Alalwan, et al., 2020); a few learners felt minor dizziness. However, none removed their headsets nor stopped to take a rest during the class (Patterson and Han, 2019). Teachers felt that young learners could use Google Cardboard head-mounted devices safely, with adult supervision, remaining seated while viewing, and for a limited time (Patterson and Han, 2019; Alalwan, et al., 2020). Lin and Sumardani (2023) suggest that teachers need to be aware that learners may have phobias such as a fear of heights, and learners should be informed that they can stop the experience if they feel uncomfortable or concerned. Teachers should preview the content and know what learners will experience. The lack of technology competency among students made teachers think training programmes need to be revamped, to improve VR learning skills (Alalwan, et al., 2020) Teachers raised these concerns and saw opportunities in relation to their learners.

5.5 Prospects and Opportunities for Students

The benefits of VR for learning are described as interesting and encouraging learners to be active (Serin, 2020) in an immersive, exploratory, interactive experience (Alalwan, et al., 2020; Hui, et al., 2022; Rodríguez, Romero and Codina, 2021), building schematic and visual thinking (Serin, 2020). Providing learners with a general idea of the subject (Serin, 2020), VR provided 3D real-time experiences worldwide, providing the user with the sensation of being in another place (Hui, et al., 2022). Other teachers considered VR to provide learning opportunities for learners to understand concepts across a wide range of resources (Alalwan, et al., 2020). Learners solved problems analytically and developed 2D and 3D concepts by manipulating and creating shapes (Rodríguez, Romero and Codina, 2021). The teachers felt the knowledge learners gained assisted in underpinning learning and drove discussions in the follow-up class lesson (Maher and Buchanan, 2021). VR was also found to increase the creativity of learners and assisted them in creating procedures and details of art (Hui, et al., 2022). The VR device was considered very easy for elementary learners to use (Patterson and Han, 2019). Preservice teacher participants described their VR experience as feeling real, expressing that they felt as if they were in space (Lin and Sumardani, 2023). The assumption was that this feeling would be experienced by their learners as well.

6. Conclusion

After exploring these primary school studies and asking the question 'What are teachers' perspectives on virtual reality in the classroom?', the following inferences are made. Teachers have both concerns and see the value of integrating VR into their lessons. The VR environments and resources do influence teachers' teaching practices, both positively and negatively. For effective inclusion of VR as a teaching resource, one needs to consider the teaching strategy to be used (Alalwana, et al., 2020). The value of the VR-infused lesson plan correlated with curriculum topics with the considered classroom management organisation (logistics, time constraints, and planning) (Graeske and Sjöberg, 2021) result in a relevant and meaningful learning experience. However, the range of research from the teaching perspective of teachers when integrating VR technology into the primary school is limited. The need for both in preservice and in-service professional development in VR is required for building knowledge on how to integrate the VR resources into lessons, as well as upskilling teachers' understanding and confidence in utilising VR in their teaching practices. To integrate VR effectively into lessons, teachers must see the value of their subject and their students. Potential areas of research include VR professional development to assist primary school teachers in using technology and sourcing content; VR and classroom management in the primary school classroom; and long-term research focusing on primary school teachers' assessment of VR resources to facilitate learning outcomes achievement and improve learning outcomes. The wide variety of VR resources offers opportunities for continued research into all these technological areas of virtual learning to drive integration within the classroom.

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Analysis of Factors Affecting User Inclination to use Virtual Education Exhibitions in the Post Pandemic Covid-19 Era: Case Study in Indonesia

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https://doi.org/10.34190/ejel.21.4.2993

Abstract: Social distancing policies during the COVID-19 period have opened a space for interventions in the use of digital technology that was previously rejected by the public. Currently, most of the community activities have been carried out online, including those related to education, such as hosting virtual exhibitions with an educational purpose. Virtual exhibitions (VE) are online exhibitions that display information on specific topics. However, to the best of our knowledge, research on VE in the educational context is still lacking. This study aims to identify the variables that affect users' intentions to attend the virtual exhibition frequently. The channel expansion theory, flow theory, technology acceptance model, and expectation confirmation theory serve as the foundation for the research model that is constructed. The model was tested using data from 321 respondents who had visited VE, then analyzed using Structural Equation Modeling (SEM) with the aid of the SmartPLS application version 3.3.3. The findings show that 11 factors significantly influence the intention to continue using VE, while the other 2 factors have no significant influence. Thus, perceived usefulness has a significant effect on satisfaction and continued use intention to use VE, but not on perceived enjoyment. Furthermore, the perceived ease of use of VE has a significant impact on perceived usefulness and perceived enjoyment. However, media richness does not significantly affect perceived enjoyment. It's just that media richness influences perceived ease of use significantly. Confirmation also has a significant impact on perceived enjoyment, perceived usefulness, and satisfaction. Perceived enjoyment has a significant effect on satisfaction and continued use intention, and satisfaction has a significant effect on continued use intention to use VE. The findings are useful for VE providers and developers in developing a transformation strategy to increase the intention to use VE in every educational exhibition.

Keywords: Virtual exhibition, Continuance intention, Channel expansion theory, Flow theory, Expectation confirmation theory, Technology Acceptance Model

1. Introduction

During the Covid-19 period, the Indonesian government's social distancing policy (based on WHO guidelines) opened up new intervention spaces in the midst of society regarding the use of digital technology, which was previously rejected by many people. Covid-19 has been classified as a global pandemic by the World Health Organization since March 11, 2020 (Cucinotta and Vanelli, 2020). The covid-19 virus is classified as a global pandemic because outbreaks of disease caused by viruses have spread to multiple continents and countries, affecting a large number of people (Maital and Barzani, 2020; Deepa et al., 2022). The pandemic, which is still affecting people, has had a far-reaching impact on all sectors' lives, including the education sector.

Prior to the Covid-19 pandemic, digital technology use in Indonesia was limited and met with a lot of resistance (Toto and Limone, 2021). Digital technology is mostly used for academic administration, such as managing lecture implementation data through an academic information system. However, following the Covid-19 pandemic, digital technology has become increasingly popular, including for the implementation of e-learning with the help of various learning support technologies such as Learning Management Systems (LMS),

Cite this article: Binowo, K., et al. 2023. "Analysis of Factors Affecting User Inclination to use Virtual Education Exhibitions in the Post Pandemic Covid-19 Era: Case Study in Indonesia", *The Electronic Journal of e-Learning, 22(3)* pp 12-28, https://doi.org/10.34190/ejel.21.4.2993

collaborative tools, video conferencing, and so on. This technology has become an essential part of all students' daily activities. The Covid-19 pandemic has transformed all educational activities into digital-technology-based activities. Prior to Covid-19, learning activities in class were typically conducted face-to-face (offline) learning in class. However, due to distance restrictions imposed by the Indonesian government, all of these activities had to be carried out online when the Covid pandemic occurred. Teachers and lecturers were forced to change the way students learn. For example, by recording asynchronous learning material that students can access whenever they want, or synchronously, for example, by using video conferencing to simulate learning in a traditional classroom setting. Since physical exhibitions are no longer as effective in promoting education as they once were, online exhibitions, also known as virtual exhibitions, have been created as a technological breakthrough.

Online exhibition (virtual exhibition) is an exhibition that is carried out online to show information with certain themes, for example, the theme of education education (Nentwig, 1999; Kamariotou, Kamariotou and Kitsios, 2021; Zhuang, 2021; Monaco et al., 2022). Virtual exhibition (VE) differs from physical exhibition in that it allows users to view information virtually and collections in digital form such as educational materials, photo/video galleries, digital artifacts, interactive maps, or educational games (Kamariotou, Kamariotou and Kitsios, 2021). The website virtualexpoid.com is one of the VE sites we use as an example. Figure 1 depicts one of the features of the virtual expo (VE), namely the forum, where prospective students can interact with other prospective students or with the campus to discuss all matters related to campus activities (curriculum, costs, etc.). The lobby element in Figure 2 contains a list of event details, therefore that is an example of a form of virtual information. Figure 1 and Figure 2 can prove that VE is not a site that provides physical exhibition, but virtual. VE can be relied on as a medium for conveying significant information, overcoming the limitations of distance and time that physical exhibitions have (Kim and Hong, 2020). However, VE also has several drawbacks, such as the inability to hold in-person meetings and the need for an internet connection in order to use it.

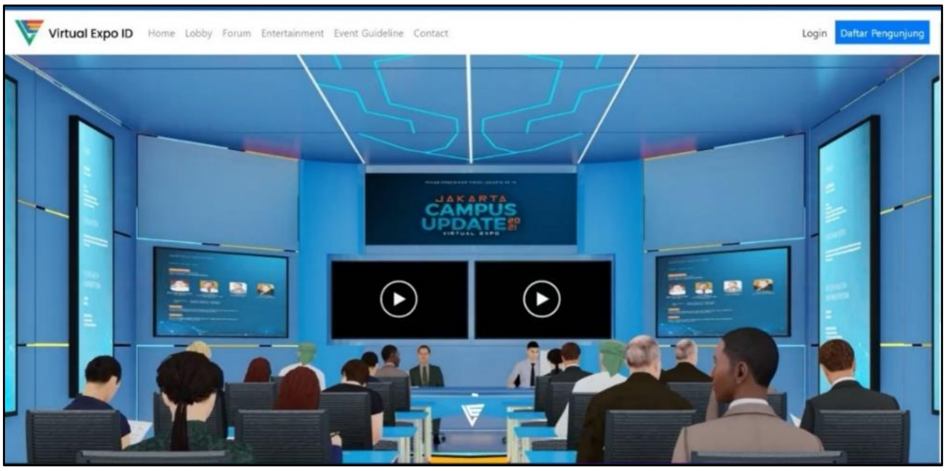

Figure 1: Forum Feature Display

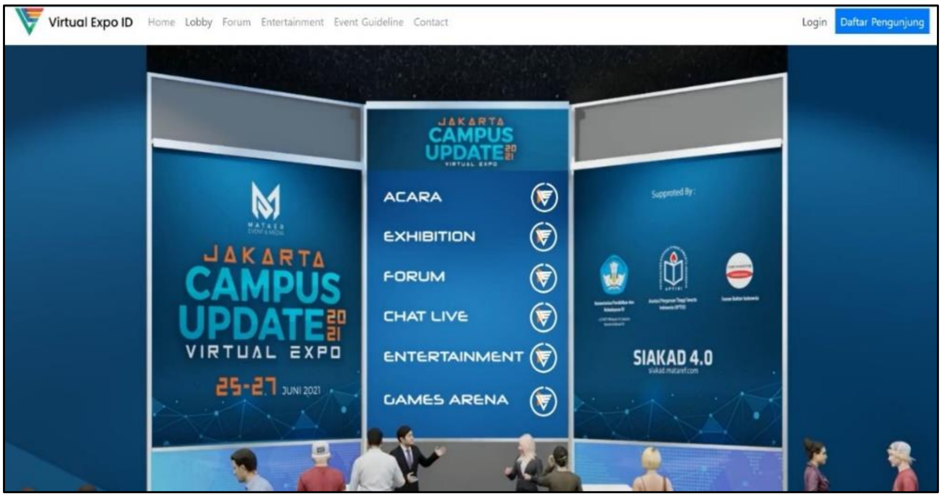

Figure 2: Lobby Feature Display

VE can provide great benefits in the education sector, especially for students. The continuity of the use of VE after the COVID-19 pandemic is crucial for this investigation, however, research in the context of VE in the education sector to the best of our knowledge is still uncommon (particularly in Indonesia). Therefore, an in-depth investigation is required to determine what is the most compelling reason for someone to continue using VE. VE. As far as we know, there has been no research in the context of the Covid-19 pandemic that focuses on discussing the continuance intention factor for the use of VE in the education sector, and we have not found similar research in Indonesia. This gap is the driving force behind the need for VE research. It is because of this gap that VE-related research is required.

Studies on the purpose of technology sustainability in the field of Education (specifically VE) have received little attention thus far. The majority of research in the tourism sector focuses solely on virtual tours, such as work by (El-Said and Aziz, 2022; Kim and Hong, 2020; Kamariotou, Kamariotou and Kitsios, 2021). Previous studies have also focused on other sectors, such as Hooi and Cho (2017)'s intention to continue using virtual worlds, or Oghuma et al. (2016)'s use of mobile instant messaging, and many other studies outside the education sector, including (Oghuma et al., 2016; Hooi and Cho, 2017; Zhang et al., 2017; Mouakket, 2018; Wang et al., 2019; Ashfaq et al., 2020; Shao et al., 2020; Lim et al., 2021; Yan et al., 2021). Thus, to the best of our knowledge, no one has discussed the intention of continuing VE in the education sector indefinitely after the Covid-19 pandemic. Therefore, the purpose of this study will be to discuss the intent to continue using virtual education exhibitions.

The purpose of this study is to determine the relationship between factors that can influence the continuance use intention of VE after the Covid-19 pandemic. There are four theories that we use to analyze the relationship between factors that can influence the intention to continue using VE on an ongoing basis in order to determine the research objectives. The first is Channel Expansion Theory (CET), which we adopted because it allows communication between cast booth keepers and visitors (students) in VE. The decision to employ CET was made because it can combine user (learner) experience with media perception richness when using VE channels. The availability of richness in the context of VE affects how well a user can interact with the media when visiting VE. Websites should attempt to deliver information through rich media formats since more detailed information will foster higher trust.

The second theory is Flow Theory. The flow theory was chosen because it is anticipated that customers who use VE will last a long time, so exploration with schools is required for VE's sustainability. In addition, this theory will be used to measure the perceived enjoyment that users feel when using VE and to identify the user experience with VE technology (Carlson and Zmud, 1999; D'Urso and Rains, 2008). User experience means whether the user feel satisfied using VE or feel enjoyed when using VE. The third theory is the expectation confirmation theory (ECT), which we choose since it would be used to assess the satisfaction factor of users (satisfaction) against VE, the factor of perceived usefulness, and confirmation factors to consumer behavior post-use of VE. The fourth theory, the Technology Acceptance Model (TAM), was chosen as in the context of VE the perceived ease of use factor is a factor needed by students to use a system technology. VE is considered difficult to master by students who are new to using it, so it requires perceived ease of use factor to analyze the ease of acceptance of an adoption technology.

The structure of this paper is written as follows: Part 2 exposes the literature on VE and the theories used for this study. In Part 3 we present research models and hypotheses development. We describe Part 4's research approach, which includes data collecting and measurement items. Meanwhile, in Part 5 we present the results of the research. Discussions and implications are outlined in Section 6. For conclusions and limitations, we present in Section 7.

2. Literature Review

2.1 Virtual Exhibition

According to Kamariotou, Kamariotou and Kitsios (2021), the existence of virtual exhibitions can aid in boosting the number of traditional museum visitors by providing a wide collection of artifacts that can keep up with contemporary trends. Virtual exhibitions can overcome difficulties about the limitations of space, time, and location (place). There is also a virtual exhibition that can be accessed anytime and anywhere without additional cost. Virtual exhibitions are in the nature of being a means of spreading culture for users who cannot visit the museum in person (people with impairments will find this to be particularly beneficial, or those with financial constraints, or other hurdles, like the pandemic.). Virtual exhibitions can provide additional information compared to physical exhibitions, for example, providing information about artifacts in the form of ownership history, follow-up episodes, or information about the title of (Kamariotou, Kamariotou and Kitsios, 2021).

2.2 Channel Expansion Theory

Channel Expansion Theory (CET) is a theory about the relevance of a person's experience to the use of a medium, this theory was proposed by Carlson and Zmud in 1999. CET investigates a person's experience to develop rich perceptions within a particular channel (Carlson and Zmud, 1999). Experience is crucial for CET since it may occasionally enhance media richness to a communication channel efficiently and effectively. The main variables in CET are media richness perception, channel user experience, and social influence felt from a channel (Carlson and Zmud, 1999; Anders, Coleman and Castleberry, 2020). CET states that the level of experience using media channels and the perceived social influence can expand users' perception of media richness. Therefore, the perception of a person's media richness is based on experiences about topics, media, and communication partners (Carlson and Zmud, 1999). User perception is considered important because it relates to the experience with the partner, the media, and the topic chosen so it will be very important in understanding the choices individuals make when choosing a channel (D'Urso and Rains, 2008). In this study, the perception of media richness of each individual is based on the topic, media, and content provided by the VE visited. The user experience in communicating with the booth keepers through the channels of communication channels provided will allow these individuals or users to better understand what the booth provides.

2.3 Flow Theory

Flow Theory, according to Mirvis (1991) is measuring the perceived enjoyment that users feel when visiting a virtual exhibition to form an experience that makes users focus on the activities they are doing, namely visiting the virtual exhibition, so that they lose their self-awareness (Muñoz-Carril et al., 2022). Flow experience refers to the user's awareness when truly enjoying the meaning of involvement in an activity (Cheng, 2021; Mirvis, 1991). It creates intrinsic motivation in the user when the activity takes place and not only when the activity is completed. In other words, users feel pleasure or comfort when visiting a virtual exhibition so that they feel an experience such as losing self-awareness, such as forgetting time, or not being aware of the surrounding situation because they are too focused on visiting the virtual exhibition.

2.4 Technology Acceptance Model

Based on the Technology Acceptance Model (TAM) by Davis (1989), states that perceived ease of use is the most important factor in the acceptance of technology. Perceived ease of use within TAM is believed to predict the perceived benefits of using the technology. Perceived ease of use is defined as the degree to which a technological system is simple to comprehend and employ (Natasia, Wiranti and Parastika, 2021). TAM is a theory that explains how users react to new technologies and how they might be employed. In TAM, the perceived ease of use factor is a factor that can influence the attitude toward use, and the intention of behavior to use new technology (Aeni Hidayah et al., 2020). The perceived ease of use factor means that a person feels easy and has no difficulty using a certain technology (Mohamad, Amron and Md Noh, 2021; Khanh, Do and Ngoc, 2022). This element also indicates that using a system's technology is simple, does not make things tough for users, and does not become a burden (Scherer, Siddiq and Tondeur, 2019; Inayatulloh, 2020).

2.5 Expectation Confirmation Theory

The Expectation Confirmation Theory, which is the basis of the Expectation Confirmation Model (ECM) has been widely used in the marketing domain to measure consumer satisfaction and post-purchase consumer behavior (Bhattacherjee, 2001; Bhattacherjee and Premkumar, 2004). In this case, we will measure user satisfaction and user behavior after using the virtual exhibition. According to the ECT, initially, users follow every process and rule to be able to use the virtual exhibition properly. Before using the virtual exhibition, users will form initial expectations for the virtual exhibition. After initially trying to use a virtual exhibition, users will form perceptions about the performance or services provided in the virtual exhibition and compare them with their expectations and expectations expectations (Davis, 1989; Bhattacherjee, 2001; Bhattacherjee and Premkumar, 2004). Because the author intends to evaluate how well and successfully the virtual display works, Expectation Confirmation Theory is crucial to this study. The level at which expectations meet the performance or service that the user feels will determine the level of user satisfaction. Satisfied users will form an intention to re-participate in the virtual exhibition, while dissatisfied users will stop using the virtual exhibition next time.

3. Research Model for Virtual Exhibition and Hypotheses Development

In this study, we utilized the Expectation Confirmation Model (ECM) to confirm the user's continued intention to use VE. VE displays information in a more entertaining and current educational context than traditional physical exhibitions. Visitors from various locations can enjoy all the content on VE through their smartphones or digital devices. Therefore, in this study, we propose to include three theories in the context of VE to be united in ECM. Therefore, this section will explain in detail the reasons for the factors adopted, as well as the reasons for adoption in the context of VE. Each of the adopted factors includes perceived ease of use, media richness, and perceived enjoyment. The reason we add to the perceived ease of use factor in the context of VE is that for new students (students or students) VE is considered difficult to use in facilitating educational exhibitions. VE is considered not easy to master by new users (learners) because they have no prior experience with it. So it requires a factor perceived ease of use in the context of VE to facilitate the use of technology and task performance for learners and to be an expectation that can determine the attitude of users towards the ease of adoption of technology.

The reason we added flow theory to the VE context is that VE will remain in use for a long time. Whether it is still in the pandemic phase or after the pandemic, VE will undoubtedly be used for a very long time. As a result, it requires an enjoyment element to stay at home and be glad to use VE because, in the absence of this, VE may be affected by people abandoning it. Given that technology is already widely accepted in society (among students), it requires an element of enjoyment. One of the reasons that we also change from the flow theory to the VE context is because it is to be used to explore various schools and various activities in the scope of education so that an enjoyment factor is needed so that users feel at home and do not get bored quickly when using VE. In prolonged use, factors can be the main determinants of behavioral intentions using VE. Tech-savvy users will not immediately assume the use of VE is easy-to-master, but it requires an enjoyment factor to be able to have a direct impact on the mastery of VE.

The Covid-19 pandemic has resulted in a high level of digital technology acceptance (for example, in Indonesia, elementary school children are required to accept online learning using digital media technology), as a result, all educational activities were conducted online .. All activities in VE allow interaction between booth keepers and users (students), so it is necessary to add a media richness factor to the context of VE. Information will be produced in the VE context when booth keepers and visitors exchange information. A media richness factor is required to be able to improve the flow of information in line with established procedures, which is necessary for information to be properly delivered and in compliance with protocols. In the context of VE to avoid ambiguous meaningful information, it is necessary to add a media richness factor as a complement to information that is right on target. Rich information and good communication will give the impression of greater trust, so VE must strive to convey information more efficiently and effectively through media richness formats. Media richness in the context of VE emphasizes how efficient and effective communication can be made by users with the media when visiting VE. The relationship between factors in conceptual form can be seen in Figure 3. In this study, we defined that the continuance intention for the use of VE in the scope of education is the intention of a person (learner, etc.) to continue using VE in the future.

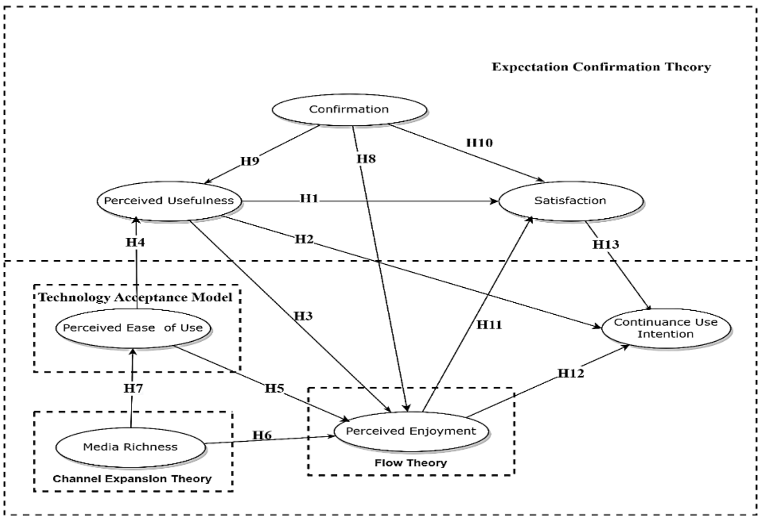

Figure 3: Research Model for VE Analysis

3.1 Perceived Usefulness

Perceived Usefulness is a user's perception of the expected benefits of using a technology (Davis, 1989). This relates to the performance aspect of the use of such technology (Venkatesh et al., 2003; Bhattacherjee and Premkumar, 2004). In addition, perceived usefulness describes the desire that arouses the intention to use technology (Jumaan, Hashim and Al-Ghazali, 2020). Perceived usefulness is also defined as the level of the user's assessment of the technology, with the hope of whether the technology can increase efficiency and a feeling of enjoyment for continued use (Jumaan, Hazarina and Al-ghazali, 2020; Park, 2020; Sasongko, Handayani and Satria, 2021).

In this study, perceived usefulness can be interpreted as the perception of a person or user regarding the benefits obtained when visiting VE. The benefits or uses of VE can be felt directly by users when visiting it so that visitors feel satisfied. The use of VE causes perceived enjoyment and of course, if it is enjoyable then it can cause an intention to continue the use of VE.

Perceived usefulness is the basis of the ECM because it has a positive influence on others, that is to say, perceived usefulness has a significant effect on satisfaction, continuance use intention, and includes perceived enjoyment. In particular, perceived usefulness has a positive relationship with satisfaction (Bhattacherjee and Premkumar, 2004; Limayem and Cheung, 2008; Ashfaq et al., 2020; Bölen, 2020; Park, 2020; Wu, Chiu and Chen, 2020; Sasongko, Handayani and Satria, 2021; Yan et al., 2021; Si et al., 2022; Wu et al., 2022), and affecting continuance use intention (Bhattacherjee, 2001; Bhattacherjee and Premkumar, 2004; Wu and Chen, 2017; Ritu and Elena, 2019; Ashfaq et al., 2020; Jumaan, Hashim and Al-Ghazali, 2020; Park, 2020; Sasongko, Handayani and Satria, 2021; Si et al., 2022). User satisfaction is an affective attitude towards a particular technological product by end users who interact with the product directly (Davis, 1989). When the user gets the benefits or uses of the VE he visits, then the user will also feel satisfied and get a sense of pleasure (enjoy) and this can certainly increase the intention to visit the VE as a continuous pickle. Therefore, we can hypothesize as follows:

H_1: Perceived usefulness influences satisfaction

H_2: Perceived usefulness influences continuance use intention

H_3: Perceived usefulness influences perceived enjoyment

3.2 Perceived Ease of use

Perceived ease of use is the perceived ease of acquiring proficiency in using technology. Perceived ease of use can affect acceptance intentions directly or indirectly through the perceived benefits of technology (B. Wu & Chen, 2017). Perceived ease of use is fixed on a person's intentions to the extent to which they believe that the use of a particular technology does not require difficult efforts to adjust (Yan et al., 2021). Perceived Usefulness is a user's perception of the expected benefits of using an information system (Oghuma et al., 2016). In addition, according to Davis (1989) perceived enjoyment is defined as the feeling of pleasure obtained when a user uses technology in the form of an information system product.

In the context of this study, perceived ease of use can be defined as the extent to which users believe that visiting VE through a system does not require considerable effort. . This indicates that it is simple to use, which contributes to or modifies the perception of enjoyment. We assert that perceived ease of use and perceived usefulness have a positive relationship and can influence intentions to use specific technologies or systems; this assertion is supported by (Park, Lee and Choi, 2018; Yan et al., 2021; Muñoz-Carril et al., 2022). Similarly, perceived ease of use is an important antecedent of user enjoyment when making virtual visits, this statement agrees with the findings of an investigation conducted by El-Said and Aziz (El-Said and Aziz, 2022).

When users feel the convenience or do not need to spend a lot of effort when using the system to visit VE, then users will feel the benefits or uses of the system. In addition, users will also feel a feeling of pleasure (enjoyment) when visiting VE. Therefore, the following we can hypothesize:

H_4: Perceived ease of use has a positive influence on perceived usefulness

H_5: Perceived ease of use influences perceived enjoyment

3.3 Media Richness

Media richness in the context of VE refers to how effective communication a user can communicate with the media when visiting VE. This is determined by several factors, namely the capacity to immediately respond (feedback), the number of communication channels or channels used, the level of personalization provided, and the ability to communicate using natural language (Chen and Chang, 2018). D'Urso & Rains (2008) suggests that the amount of information that can be transmitted by various forms of communication depends on the media's capacity to provide various types of feedback over time. Richer information will inspire greater trust, so websites should seek to convey information through rich media formats by (Chen and Chang, 2018), and (Li andTsai, 2022). However, the choice of media format depends on the relationship between technology, the environment, and the internals of the organization. Meanwhile, Davis (1989) defines perceived enjoyment as a pleasant sensation obtained when users use an information system. Based on this definition, we assume that effective communication between users and the media when visiting VE will increase the sense of enjoyment and comfort (enjoy). If the user receives a response for a long time, communication channels are limited, and no personalization is provided, then we assume the level of comfort and pleasure that the user feels when visiting the VE will be reduced.

Meanwhile, the user's level of convenience when utilizing a system to access a virtual display is known as perceived ease of use (Bölen, 2020). Based on the Technology Acceptance Model (TAM) introduced by Davis (1989), perceived ease of use is one of the most important factors in the acceptance of a system. The presence of rich media as a communication channel has an impact on this. In order to make using technology systems more convenient for users, media richness can aid promote interaction and communication between users and technology systems. In these cases, the degree to which the media can effectively communicate in the VE will be gauged by its media richness. Therefore, we propose the following hypothesis:

H_6: Media richness has a positive influence on perceived enjoyment

H_7: Media richness has a positive influence on perceived ease of use

3.4 Confirmation

Confirmation is a form of affirmation of the command given. It is closely related to the user experience to confirm an expectation of a given command. Confirmation usually refers to the expectation of information that the user will obtain from the system used (Bhattacherjee, 2001). Confirmation focuses on users of technology who anticipate the suitability of its functionality (Jumaan, Hashim and Al-Ghazali, 2020). According to the ECM, the user of the technology feels an inner comfort, if the expectation of pre-acceptance of the technology proves to be pleasant and corresponds to its usefulness, as well as satisfactorily confirmed. Confirmation in the context of this study will have a connection to the use of VE itself. The factor influencing the level of use of VE is the level of comfort and the level of quality of the information obtained by the user. It is expected that the pre-acceptance of VE users is fulfilled in satisfaction and will experience enjoyment by perceived usefulness. According to Bhattacherjee (2001) and Oghuma et al (2016), users may be able to experience cognitive dissonance if their pre-acceptance usefulness is not confirmed during actual use. To reduce this, users can try to adjust their perception of usefulness to better match reality.

Confirmation will also increase the user's perception of usefulness, while disconfirmation will reduce user perception. Several studies mentioned that confirmation has a positive effect on perceived usefulness, and perceived enjoyment (Bölen, 2020; Dai, Teo and Rappa, 2020; Jumaan, Hashim and Al-Ghazali, 2020; Park, 2020; Franque, Oliveira and Tam, 2021; Gunawan et al., 2021; Pereira and Tam, 2021; Sasongko, Handayani and Satria, 2021; Si et al., 2022; Wu et al., 2022). Users will likely experience the same cognitive dissonance when it comes to perceived enjoyment, continuously adjusting their expectations to match reality. According to previous studies as well, confirmation affects user satisfaction (Bölen, 2020; Dai, Teo and Rappa, 2020; Franque, Oliveira and Tam, 2021; Pereira and Tam, 2021; Sasongko, Handayani and Satria, 2021; Si et al., 2022; Wu et al., 2022). When the information obtained matches or exceeds expected expectations, then confirmation is present to improve the user experience in obtaining benefits from the use of a system. In this case, confirmation will measure how much the user experience in participating in the virtual exhibition can meet user expectations. Therefore, such expectations lead to the following hypothesis:

H_8: Confirmation has a positive influence on perceived enjoyment

H_9: Confirmation has a positive influence on perceived usefulness

H_{10}: Confirmation has a positive effect on satisfaction

3.5 Perceived Enjoyment

The definition of perceived enjoyment is the level of pleasurable technology use, and this includes significant elements that may affect future technology use intentions (Park, 2020; Gunawan et al., 2021). The habit of using

IT continuously is a satisfaction that can be influenced by perceived enjoyment. Perceived enjoyment has a validated relationship with satisfaction (Park, 2020). In addition, perceived enjoyment is also an important factor that explains the intention of using technology continuously (Pereira and Tam, 2021). The perceived enjoyment of technology can determine the satisfaction and intention to stick with technology.

Perceived enjoyment in this study is defined as the feeling of satisfaction visitors have after viewing a virtual display. In addition, the degree of pleasurable attention in technology use can be utilized to determine perceived enjoyment (VE). The enjoyment of using VE indicates contentment and intention to continue using it.

According to Flow Theory by Mirvis (1991) Perceived enjoyment measures how much fun users have using technology to create a satisfying experience and keep their attention on the tasks at hand. Some previous research has shown that perceived enjoyment has a positive effect on satisfaction satisfaction (Ashfaq et al., 2020; Dai, Teo and Rappa, 2020; Park, 2020; Pereira and Tam, 2021), and also has a positive effect on the use and acceptance of technology so that it can increase continuance use intention (Ashfaq et al., 2020; Gunawan et al., 2021; Oghuma et al., 2016; Park, 2020).Therefore, the following can be hypothesized:

H_{11}: Perceived enjoyment has a positive influence on satisfaction

H_{12}: Perceived enjoyment has a positive influence on continuance use intention

3.6 Satisfaction

Satisfaction is happiness felt by IT application users when they feel comfortable with their use (Sasongko, Handayani and Satria, 2021). Satisfaction refers to a person's affective habits towards experience in the use of IT (Jumaan, Hashim and Al-Ghazali, 2020). Satisfaction is a strong driving factor towards user behavior for the intention to use IT on an ongoing basis. In this study, contentment refers to visitors' feelings of satisfaction regarding the virtual exhibition they visited.

Users' intentions to continue using IT are heavily influenced by satisfaction based on exposure via ECM. Previous research shows that satisfaction is an important factor for users to continue using an IT application (Ashfaq et al., 2020; Bölen, 2020; Jumaan, Hashim and Al-Ghazali, 2020; Park, 2020; Franque, Oliveira and Tam, 2021; Gunawan et al., 2021; Pereira and Tam, 2021; Sasongko, Handayani and Satria, 2021; Yan et al., 2021; Si et al., 2022). Dissatisfied users will use other services, while satisfied users will reuse existing products (Jumaan, Hashim and Al-Ghazali, 2020; Yang, 2021). According to the literature, if a user is pleased with their experience at the VE, they are far more likely to return than the dissatisfied to do so. Therefore, we propose the following hypothesis:

H_{13}: Satisfaction has a positive influence on continuance use intention

4. Research Methodology

4.1 Measurement Items

All measurement items in this study (*Appendix A*) were adapted from previous studies. Items for confirmation and continuance use intention were sourced from Bhattacherjee (2001), Oghuma et al. (2016), Park (2020), Wu et al. (2022), Jumaan, Hashim and Al-Ghazali (2020), Gunawan et al. (2021), Dai et al. (2020), Sasongko, Handayani and Satria (2021), Si et al. (2022), Bölen (2020), Pereira and Tam (2021), Franque (2021), and Wu et al. (2022). Perceived enjoyment and perceived usefulness items were derived from (Davis, 1989), Park (2020), Dai et al. (2020), Ashfaq et al. (2020), Pereira and Tam (2021), Bhattacherjee and Premkumar (2004), Limayem and Cheung (2008), Yan et al. (2021), Bölen (2020) Sasongko, Handayani and Satria (2021), Si et al. (2022), Wu, Chiu and Chen (2020), and Wu et al. (2022). The items for perceived enjoyment were sourced from Muñoz-Carril et al. (2022), Park, Lee and Choi (2018), and Yan et al. (2021). Media richness items were sourced from Park (2020), Dai (2020), Ashfaq et al. (2020), and Pereira and Tam (2021). The item satisfaction is sourced from Ashfaq et al. (2020), Franque, Oliveira and Tam (2021), Bölen (2020), Gunawan et al. (2021), Jumaan, Hashim and Al-Ghazali (2020), Park (2020), and Sasongko, Handayani and Satria (2021). These items were scored on a Likert scale from 1 to 5, with 1 indicating strongly disagree, 2 disagrees, 3 neutral, 4 agrees, and 5 strongly agrees.

4.2 Data Collection

In this study, data was gathered through a survey using an online questionnaire created with Google Form. The respondents for this study must be Indonesians who use social media and have visited virtual exhibitions related to education. This research questionnaire was distributed via virtual exhibition social media groups such as LINE, WhatsApp, Instagram, and Twitter to Indonesians who have social media. The data was collected in Indonesia from November 2021 to December 2021. The total number of respondents who completed the questionnaire survey were 406 respondents, 85 respondents were eliminated as invalid because they did not meet the criteria of this study, namely they had never visited a virtual exhibition. As a result, we have 321 respondents with valid data responses based on the research criteria. Males have 44.55% and females have 55.45%. More details can be seen in Table 1.

Table 1: Demographic Characteristics

Items	Characteristics	Frequency	Percent (%)
Gender	Male	143	44,55
	Female	178	55,45
Age	≤ 18	41	12,77
	19 – 25	185	57,63
	26 – 33	63	19,63
	34-40	21	6,54
	< 40	11	3,43
Education	Below high school	10	3,12
	High school	53	16,51
	Bachelor's degree	243	75,70
	Graduate degree	15	4,67

5. Result

Partial Least Squares (PLS) was used to analyze valid data from 321 respondents. PLS is used to predict and assess the relationship between unobserved factors in items that were made (Muñoz-Carril et al., 2022). The SmartPLS application is used to analyze modeled items. To ensure the accuracy of the measurement model items, we perform a measurement model test. In addition, we ran a structural model, with the results showing that 11 hypotheses were accepted and 2 were rejected. The following can be used to explain the research findings.

5.1 Measurement Model Test

To ensure the accuracy of the measurement model, we use reliability tests, convergent validity, and discriminant validity. Convergent reliability and validity were measured using loading factors (LF), Cronbach's alpha (CA), composite reliability (CR), and average variance extracted (AVE). The values of LF, CA, and CR for each indicator exceed 0.7 (see Table 2). Table 2 also shows that the AVE value for each indicator exceeds the maximum limit of 0.5. Thus, this research model demonstrates the reliability of constructs and the validity of convergents that are good and acceptable. Convergent validity is rated as good if the AVE value exceeds 0.5, while the reliability of a good construct must have a CA and CR value exceeding 0.7 (Muñoz-Carril et al., 2022). As shown in Table 2, the AVE values range from 0.690 to 0.766. This means that the value is greater than the minimum limit of 0.5. Table 3 shows that the square root of the AVE for each construct is greater than all correlations between constructs. The maximum correlation of each construction pair is 0.746, while the minimum square root of the AVE is 0.831 (see the bold diagonal in Table 3). Therefore, it can be concluded that the measurement model of this study explains and shows that the reliability, convergent validity, and validity of discriminants are adequate.

Table 2: Loading Factors Value, Cronbach's Alpha, Composite Reliability, and AVE

Construct	Items	Loading Factors	Cronbach's Alpha	Composite Reliability	Ave
Confirmation	CFT1	0.852	0.798	0.881	0.712
	CFT2	0.845			
	CFT3	0.834			
Satisfaction	STF1	0.852	0.775	0.870	0.690
	STF2	0.848			
	STF3	0.791			
Continuance Use Intention	CUI1	0.853	0.826	0.896	0.742

Construct	Items	Loading Factors	Cronbach's Alpha	Composite Reliability	Ave
	CUI2	0.900			
	CUI3	0.829			
Perceived Enjoyment	PEJ1	0.879	0.847	0.907	0.765
	PEJ2	0.873			
	PEJ3	0.872			
Perceived Usefulness	PUS1	0.852	0.848	0.908	0.766
	PUS2	0.916			
	PUS3	0.856			
Perceived Ease of Use	PEU1	0.837	0.816	0.891	0.731
	PEU2	0.864			
	PEU3	0.864			
Media Richness	MRC1	0.808	0.782	0.872	0.695
	MRC2	0.860			
	MRC3	0.832			

Table 3: Discriminant Validity

	CFT	CUI	MRC	PEU	PEJ	PUS	STF
CFT	**0.844**						
CUI	0.601	**0.861**					
MRC	0.533	0.565	**0.834**				
PEU	0.538	0.508	0.526	**0.855**			
PEJ	0.659	0.564	0.549	0.557	**0.875**		
PUS	0.517	0.470	0.621	0.535	0.534	**0.875**	
STF	0.746	0.584	0.578	0.552	0.714	0.540	**0.831**
Note: The numbers in bold (diagonal elements) represent the square root of the AVEs.							

5.2 Structural Model

Figure 4 shows the structural model's results. Two of the thirteen hypotheses were rejected (see Table 4). These two hypotheses were rejected because the p-values (0.181 and 0.138) were greater than the maximum alpha value (0.05), so H_3 and H_6 were rejected. In this test (see Table 5), the R^2 analysis can explain the structural model's strength, namely 40.3% of Continuance Use Intention, 27.6% of Perceived Ease of Use, 52.7% of Perceived Enjoyment, 36% of Perceived Usefulness, and 65.3% of Satisfaction.

Perceived usefulness, which is the result of this processing, significantly affects satisfaction and future use intention. Perceived use and satisfaction are significantly influenced by perceived simplicity of use. Media richness has a major impact on perceived ease of use. Confirmation, meanwhile, strongly influences satisfaction, perceived usefulness, and perceived enjoyment. Satisfaction and the inclination to continue using a product are substantially influenced by perceived enjoyment. Additionally, satisfaction greatly influences the intention to continue using a product. However, perceived usefulness and media richness have no significant influence on perceived enjoyment.

Table 4: Summary of the Structural Model Results

Hypotheses	Relationship			Original Sample	Sample Mean	t-value	p-value	Results
H1	PUS	→	STF	0.117	0.117	2.117	0.034	Supported
H2	PUS	→	CUI	0.165	0.165	2.622	0.009	Supported
H3	PUS	→	PEJ	0.127	0.139	1.338	0.181	Rejected

Hypotheses	Relationship			Original Sample	Sample Mean	t-value	p-value	Results
H4	PEU	→	PUS	0.361	0.363	5.627	0.000	Supported
H5	PEU	→	PEJ	0.187	0.183	3.384	0.001	Supported
H6	MRC	→	PEJ	0.152	0.141	1.483	0.138	Rejected
H7	MRC	→	PEU	0.526	0.531	9.585	0.000	Supported
H8	CFT	→	PEJ	0.412	0.414	6.141	0.000	Supported
H9	CFT	→	PUS	0.323	0.324	5.152	0.000	Supported
H10	CFT	→	STF	0.454	0.453	7.988	0.000	Supported
H11	PEJ	→	STF	0.352	0.353	5.367	0.000	Supported
H12	PEJ	→	CUI	0.250	0.256	2.782	0.005	Supported
H13	STF	→	CUI	0.316	0.313	3.438	0.001	Supported
Note: PUS: perceived usefulness; PEU: perceived ease of use; MRC: media richness CFT: confirmation; PEJ: perceived enjoyment; STF: satisfaction; CUI: continuance use intention								

Table 5: Result of Determination Coefficient Test (R^2)

Parameter	R Square (R^2)	Percent (%)
CUI	0.403	40.3
PEU	0.276	27.6
PEJ	0.527	52.7
PUS	0.360	36
STF	0.653	65.3
Note: CUI: *continuance use intention*; PEU: *perceived ease of use*; PEJ: *perceived enjoyment*; PUS: *perceived usefulness;* STF: *satisfaction*		

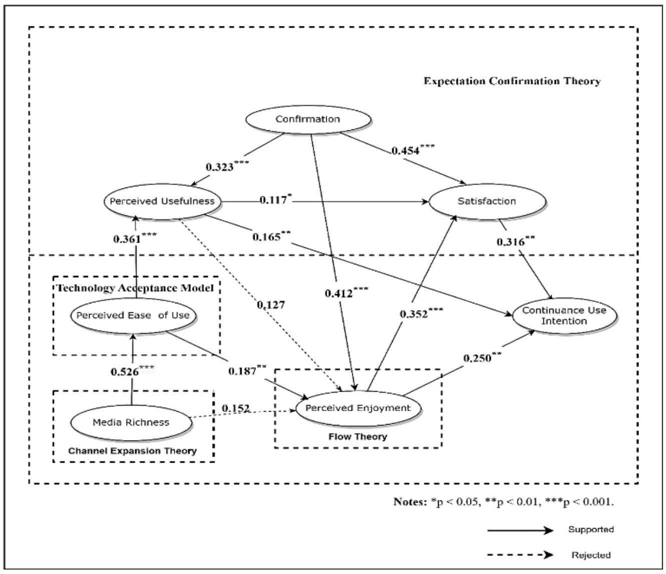

Figure 4: Result of the PLS VE Analysis

6. Discussion and Implications

In this section, it is critical to discuss our research findings in order to understand the relationship between factors that can influence the community's intention to continue visiting educational exhibitions using VE in post-pandemic the Covid-19. . First, it shows that STF is the strongest predictor (has the highest weight) of CUI when using VE, compared to PEJ, and PUS. These findings indicate that the STF is the same as previous studies, which have consistently significant effects on CUI, such as the findings of Ashfaq et al. (2020), Franque, Oliveira and

Tam (2021), Bölen (2020), Gunawan et al. (2021), Jumaan, Hashim and Al-Ghazali (2020), Park (2020), Sasongko, Handayani and Satria (2021). It makes sense given the findings indicating how satisfied VE customers in Indonesia were to visit educational exhibitions using VE on a regular basis. The results of the analysis also show that PEJ has the second highest result after STF. PLS analysis reveals that PEJ has a positive effect on CUI, implying that using VE gives VE customers in Indonesia a sense of enjoyment. However, the findings of PEJ that were considered to have a significant effect on CUI were inconsistent according to several findings, such as the findings of Park (2020) and Gunawan et al. (2021) that state that PEJ has a significant effect on CUI, but this differs from the findings of Pereira and Tam (2021) that state that PEJ has no significant effect on CUI. Furthermore, the third factor is PUS, which has the smallest number between STF and PEJ. Based on the findings, PUS has an effect on CUI. It is inconsistent with previous studies, for example the findings of Wu (2022), Bölen (2020), Franque, Oliveira and Tam (2021) who discovered that PUS did not have a significant effect on CUI, but this is different from the findings of Ashfaq et al. (2020), Jumaan, Hashim and Al-Ghazali (2020), Park (2020), Pereira and Tam (2021), Sasongko, Handayani and Satria (2021), Si et al. (2022), Wu and Chen (2017) who discovered that PUS had a significant positive effect on CUI.

Second, the results prove that CFT is a strong predictor and has a positive effect on PEJ, CFT itself has the highest number among the 3 variables (2 does not affect PEJ). An expectation of information that users will get from the VE system can be said to be enjoyable if it is successfully confirmed according to their expectations. In addition to CFT, the PEU factor has also been shown to affect PEJ. Based on the study's findings, PEU has a positive impact on PEJ; these findings provide insight into how using VE for educational participants can provide pleasure to customers who use VE in Indonesia. However, based to the PLS analysis, two factors, namely PUS and MRC, have no effect on PEJ. This is most likely due to the fact that perceived usefulness (PUS) was not obtained directly by VE customer users in Indonesia during the Covid-19 pandemic, and perhaps VE did not have rich media (MRC) that could provide information in a pleasant way for these customers. Third, the results show that PEJ, PUS and CFT have proven to have a positive effect on STF. These findings are consistent with previous studies such as by (Sasongko, Handayani and Satria, 2021), (Bölen, 2020), (Si et al., 2022), and (Wu et al., 2022). Out of the three factors, the highest result is the CFT factor. The high number can be caused by VE users feeling inner comfort, so the expectation of VE pre-acceptance can be proven to be satisfactorily confirmed. Following CFT, the next sequence is PEJ, indicating that the enjoyment felt by customers in Indonesia using VE during the Covid-19 pandemic can determine their satisfaction and intention to continue using VE when participating in educational exhibitions. So, PEJ in this context can be defined as the sense of satisfaction gained by the user after using and visiting the VE. Next is PUS, which, if defined in the context of this study, is a person's perception of the benefits gained when visiting VE. As a result, because customers (respondents in this study) get the perceived benefits when using VE, they are satisfied (indicating that PUS influences STF).

Fourth, the results of this study show that PUS can be influenced by CFT and PEU. Among CFT and PEU, the strongest factor that has a positive effect is PEU. These findings agree with previous studies such as by (Wu and Chen, 2017), (Park, 2020), (Wu et al., 2022), (Jumaan, Hashim and Al-Ghazali, 2020), (Gunawan et al., 2021), (Dai et al., 2020), (Sasongko, Handayani and Satria, 2021), (Si et al., 2022), (Franque, Oliveira and Tam, 2021), and (Park, Lee and Choi, 2018; Yan et al., 2021; Muñoz-Carril et al., 2022). The benefits and uses of VE are certainly the results that PEU can provide. If customers in Indonesia find it easy to use VE, then VE can be claimed to be successful in providing its benefits and applications. Furthermore, the benefits and uses of VE can be confirmed to be useful if its loyal visitors always use VE on an ongoing basis.

6.1 Theoretical Implications

The findings of this study can provide theoretical knowledge regarding the relationship between factors (factors of four theories) according to our analysis that the relationship between factors can influence the intention to continue using VE after the Covid-19 pandemic. First, this study is the first study to explore the continuity of the use of VE in the context of education. Previous studies by El-Said and Aziz (2022), Kim and Hong (2020), and (Kamariotou, Kamariotou and Kitsios, 2021) primarily focus on the use of virtual tours. Second, this study successfully integrated the theory of TAM, Flow, and media richness into CET, thus providing a more comprehensive understanding of the factors that drive use in the continued intention of using VE. From TAM, this study emphasizes the importance of the ease-of-use factor as one of the driving factors of the sustainability of the use of VE. Reflecting on the research findings that media richness (CET) has no effect on perceived enjoyment (PEJ), this provides insight into the critical role of CET features that are rich in communication media in strengthening the relationship between visitors and VE. This research also shows how the role of flow theory, represented by perceived enjoyment, in encouraging the sustainability of the use of VE. Third, this study also succeeded in confirming the CET theory in the context of continuing the use of VE, which previously not many people had explored.

6.2 Practical implications

This study has a number of implications for VE builders and developers. The proposed model can explain a series of relationships between factors that VE providers and their developers can manipulate to increase the intention to use VE on an ongoing basis. This study may provide knowledge interventions for VE providers to focus on increasing the intention to use VE on an ongoing basis. First, it is critical for VE providers and developers to focus on the satisfaction factor, because our findings show that it has a significant impact on the user's intention to continue using VE. It is critical for VE developers to consider usability and user experience factors in order to maintain user satisfaction in using VE in the future.

Second, VE providers and developers must pay attention to user-perceived enjoyment factors, as these factors have a significant effect on continued use intention. Providing a sense of enjoyment to VE customers can help them have a positive and enjoyable experience while reaping the benefits of participating in virtual exhibitions. Therefore, it is critical for developers to concentrate on developing VE while paying attention to perceived ease of use and perceived usefulness factors, as this can confirm all user expectations to use VE on a regular basis. Developers should make VE as user-friendly as possible. One approach is to use usability and user experience design principles while considering who the VE is designed for and making sure the VE design is visually appealing by using various images, narratives (what topics or stories do you want to offer in VE), as well as limiting file sizes for easy access.

Third, VE providers and developers must pay attention to perceived usefulness factors, because our findings show that these factors have a significant impact on the intention to continue using VE. Therefore, it is critical for the developer to pay attention to the perceived ease of use factor (because this factor significant influence perceived usefulness), so that the appearance of the VE interface is not messy, easy to understand, and can display information clearly. Focusing on perceived ease of use factors can confirm all VE users' expectations in seeking information and create unforgettable experiences when using VE in the future.

7. Conclusion and Limitation

This study describes a structured and methodical approach that combines several theoretical models, namely channel expansion theory, technology acceptance model, flow theory, and expectation confirmation theory, in order to gain understanding and predict user intentions to maintain sustainable use of Virtual Exhibition (VE) after the pandemic Covid-19. It should be noted that in the context of VE, 11 interconnected factors play a role in influencing the intention to use VE in a sustainable manner. Therefore, it should be emphasized that; First, perceived usefulness, perceived enjoyment, and satisfaction factors all have a significant influence on continued use intention toward VE long-term sustainability. Second, perceived ease of use and confirmation factors have a significant impact on the perceived usefulness of using VE in a sustainable way. Third, the perceived ease of use, perceived usefulness, and confirmation factors all have a significant impact on the perceived enjoyment of using VE on a continuous basis. Fourth, the role of perceived enjoyment, confirmation, and perceived usefulness has a significant impact on user satisfaction for long-term use of VE. Fifth, the media richness factor has a significant impact on the perceived ease of use of VE.

Furthermore, we can highlight a relationship between 2 factors (perceived usefulness and media richness) that do not significantly influence perceived enjoyment for the intention to use VE continuously. Thus, we can emphasize the importance of ensuring service quality based on perceived usefulness, developing features rich in information and communication media, and designing user interfaces that are easy to use, fun, and satisfying so that customers are interested in using VE continuously and sustainably. Overall, the findings of this study enrich our knowledge and insight into understanding the use of virtual exhibitions in educational exhibitions after the Covid-19 pandemic.

There are some limitations to this study. First, we investigate the use of VE in educational exhibitions during the Covid-19 pandemic in only one country, Indonesia. We do not believe our findings can be generalized to other countries around the world. Second, we felt that when we sampled respondents, we did not account for age. For us, the younger generation is more familiar with emerging technology trends and prefers to use VE when participating in online educational exhibitions. In comparison to the older generation, who may still stutter when using technology and are unaware of the trend of virtual reality technology in online-based educational exhibitions. Third, we did not specifically consider the sample of respondents in terms of education; perhaps students who are temporarily in college are not more interested in participating in educational exhibitions than high school students or recent college graduates. Finally, we realized that the survey we shared did not emphasize that those who were required to fill out the questionnaire survey were people who had used VE for educational exhibitions. As a result, out of a total of 406 respondents, 85 respondents' data could not be processed because they did not meet the research requirements.

Acknowledgement

This research is supported by Universitas Indonesia through PUTI Q1 grant No. NKB-293/UN2.RST/HKP.05.00/2023. We convey our gratitude to our university for their continued support in improving research quality.

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Appendix A: Item of Measurement

Factor (Construct)	Item of Measurement	
Confirmation	CFT1	My experience while visiting a virtual exhibition was better than what I expected
	CFT2	The level of service provided by the virtual exhibition organizers is better than I expected
	CFT3	In general, most of my expectations regarding online exhibitions are met when participating in virtual exhibitions
Satisfaction	STF1	I feel satisfied with the virtual exhibition that I participated in
	STF2	I love the experience of visiting the exhibition online during the virtual exhibition
	STF3	I feel satisfied with the information I got after participating in the virtual exhibition
Continuance Use Intention	CUI1	I am interested in re-participating in the virtual exhibition in the future even though the pandemic has ended
	CUI2	I predict that I will continue to participate in virtual exhibitions even though the pandemic has ended

Factor (Construct)	Item of Measurement	
	CUI3	I intend to continue using virtual exhibitions to view online educational exhibitions compared to other ways even though the pandemic is over
Perceived Enjoyment	PEJ1	I feel happy when I visit the virtual exhibition
	PEJ2	Visiting the virtual exhibition gave me a sense of comfort
	PEJ3	I enjoy the process when I visit the virtual exhibition
Perceived Usefulness	PUS1	In general, virtual exhibitions are useful for finding information related to schools
	PUS2	Through virtual exhibitions, I was able to obtain information related to school more productively
	PUS3	Through virtual exhibitions, I can get information related to schools faster
Perceived Ease of Use	PEU1	It is easy for me to understand the use of virtual exhibitions
	PEU2	Easy for me to interact with a virtual exhibition
	PEU3	It is easy for me to be proficient in using virtual exhibitions
Media Richness	MRC1	The virtual exhibition allows me to get answers quickly from the booth I asked
	MRC2	The virtual exhibition provides various channels to communicate with booth keepers
	MRC3	If there are further questions, the virtual exhibition allows me to communicate more deeply with the booth I want

Augmented Reality for the Development of Skilled Trades in Indigenous Communities: A Case Study

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https://doi.org/10.34190/ejel.21.6.3044

Abstract: The main objective of this study was the design and validation of a mobile learning environment (ML) based on Augmented Reality (AR) visualization with the purpose of developing skilled trades in the field of carpentry in indigenous populations. A pedagogical model focused on lifelong learning was used, in order to promote the acquisition of skilled trades and knowledge in carpentry. The implementation of the ML environment was carried out in the Wayuu community, characterized by its high rate of poverty and limited access to education. During face-to-face meetings, three indigenous people participated in a learning process in which they were instructed on the use of trade tools and became familiar with the different types of trees and wood. To support this process, the AR was used together with the M-L environment. Subsequently, the participants built a chair applying the knowledge acquired during the learning process. During this stage, recordings of the indigenous people were made while they carried out the construction. Then, the performance of the apprentices was evaluated through a competency-based evaluation system, in which three experts analyzed the recordings. Finally, the three indigenous people were able to acquire skills in real time through their mobile device, following the instructions and observing 3D images and videos that showed the entire manufacturing process of a wooden chair, from sanding the material to final assembly and polishing. In addition, it was found that these indigenous people were able to successfully market the products they made in the carpentry workshop, thus improving their family income. The fundamental idea behind the pedagogical implementation of this model in the Wayuu indigenous community of northern Colombia is to provide them with training in various trades that allow them to obtain decent jobs and support their families. That is why the ML environment is ideal for vulnerable people, not only indigenous people, but also for those who are displaced, the elderly or deaf-mute. The visual approach used in this method dispenses with the need for voice and text making it accessible to everyone.

Keywords: M-Learning, Augmented reality, Job competencies, Indigenous populations

1. Introduction

Historically, the Wayuu population has inhabited the northern region of Colombia (Department of Guajira), it has been characterized by a high poverty rate and state abandonment in areas such as education and healthcare. Additionally, the difficulty in accessing its indigenous settlements, the lack of electricity and internet, the persistent malnutrition issues, and the scarcity of drinking water do not allow for social, economic, and educational development. Recent reports have concluded that more than 50% of Wayuu Indians' school-age population does not attend school, which evidences shortcomings in coverage (Hoyos, 2016).

According to Calcagno (2005), illiteracy rates among indigenous populations are concerning in Latin America, which reveals the need to generate urgent actions from governments and within communities, effective, productive, and life-long learning models that lead to poverty reduction, build and appropriate learning cultures that generate peoples with useful ancestral, epistemological, practical, ethical-coexistent, and autonomous knowledge for integral development and sustained progress.

In this order of ideas, it is of vital importance to reflect on, propose and implement pedagogical models for indigenous populations that convert them into learning cultures, places and customs where they develop technical skilled trades that improve their quality of life. Considering the foregoing, it is necessary to think of a proposal that generates cultures of learning throughout life, with autonomy, change and progress from knowledge, that overcomes dependence and solves problems from humanist and complex knowledge. In this sense, AR could be an option to facilitate the development of job competencies in indigenous populations.

Considering the above, the following research question is presented, with the objective of designing and validating an ML environment. How does mobile learning influence the development of carpentry skills in indigenous populations through a pedagogical model of learning to learn knowledge through throughout life?

Cite this article: Beltrán, A.G.A. and Huertas, B.A.P. 2023. "Augmented Reality for the Development of Skilled Trades in Indigenous Communities: A Case Study", *The Electronic Journal of e-Learning,* 22(3) pp 29-45, https://doi.org/10.34190/ejel.21.6.3044

The findings of the study allow concluding that the mobile learning based on AR developed knowledge and technical job competencies using the pilot of a carpentry course in Wayuu Indians, additionally allowed the appropriation of knowledge through the visualization of 3D images with the use of printed markers of the inventory of tools and the inventory of materials mediated by an interactive graphic interface.

2. Augmented Reality

The term "AR" was coined by researchers Caudell and Mizell in 1992, who used it to describe a system designed to improve the assembly and installation process for electrical cables in aircrafts. Since then, it has been used in various studies and contexts to refer to systems that allow simulating activities and training users in order to improve their performance in specific tasks. Several researchers, such as Feiner et al. (1997) and Rosenberg and Feiner (1993), have used the concept of AR in their research related to the simulation of activities and training in specific tasks.

AR is defined in different ways according to the authors. Goldiez (2001) describes it as a technological field in which additional computer-generated elements are superimposed on the real world through a sensory screen. For his part, Kaufmann (2004) argues that AR allows users to visualize the real world with virtual objects superimposed or combined with the physical environment. Perey (2011) defines it as an emerging technology that allows real-time integration of processed digital information with real-world information through appropriate interfaces.

Martins and Santos da Rosa (2016) define AR as an enhancement of a person's visual experience with the real world through the integration of digital visual elements. They emphasize that it involves the combination of the real and virtual worlds, where computer-generated virtual objects are superimposed or merged with real objects. Kesima and Ozarslan (2012) mention that AR combines aspects of ubiquitous computing, tangible computing and social computing, providing unique possibilities by combining the physical and virtual aspects of the environment and allowing continuous and interactive control by the user.

In the field of AR, various applications have been developed in areas such as video games (Thomas et al., 2000), interactive books (Billinghurst et al., 2001) and educational applications for teaching geography (Shelton and Hedley, 2002) and geometry (Kaufmann, 2003). These applications often make use of markers, such as black and white images or QR codes, to recognize and track virtual objects in the real environment (Feng and Kamat, 2014). Chen et al. (2016) explain that a marker is based on geometric characteristics that are used to estimate a 3D object, such as segments, straight lines, contours, or points on cylindrical objects.

The combination of tangible models and AR has proven beneficial in engineering graphics education. Li et al. (2018) highlight that the use of tangible models allows students to physically interact with three-dimensional objects, which improves their spatial understanding and design skills. On the other hand, Zhang et al. (2020) argue that AR is a promising technology to improve the teaching of engineering graphics by combining virtual elements with the real environment, allowing students to visualize complex models in real time and obtain interactive feedback. Liang et al. (2021) highlight that the combination of tangible models and AR in engineering graphics education provides a more immersive and interactive learning experience, which promotes a deeper understanding of concepts and greater motivation for learning.

In conclusion, AR offers new possibilities to visualize and interact with phenomena that could only be approached theoretically before. It has been successfully applied in the educational field, improving content comprehension, information retention, motivation and academic performance (Radu, 2014; Di Serio et al., 2013).

2.1 AR in Indigenous Populations

This section presents research that explores the applications of AR in indigenous communities. Two studies stand out for using markers to generate AR content. The first study, carried out by Maigua (2012), aimed to develop graphic editing skills in indigenous people through the use of AR in the creation of a printed magazine on the indigenous history of Ecuador. This magazine used a "Magic Book", which is a bookmarked book that allows AR content to be generated via a smartphone. The study was carried out in a school for indigenous girls.

The second study, proposed by Martínez (2017), focused on developing image capture skills in indigenous communities, specifically in the field of bird watching. A camera, smartphone, and AR app were used to take photos of local birds, which were stored in the phone's memory. Printed markers were then created for each bird and observed in AR. These photographs allowed expanding the knowledge in this field.

In summary, these studies show that AR can be applied in indigenous communities for training in specialized trades through the use of markers and mobile devices. These findings support the following research proposal, which seeks to verify the effectiveness of AR in the formation of activities and the development of competencies.

2.2 Wayuu Population

The Wayuu population is made up of 278,212 indigenous people (DANE, 2015), of which 97% speak the Wayuunaiki language. The Wayuu society is characterized by having a complex and matrilineal family structure, organized into clans with 30 different clans, each with its own territory and totemic animal. The role of the "putchipu" or "palabrero" is of great importance, since they play the role of bearers of the word and mediators in the resolution of conflicts between the clans. The highest authority within the family rests with the maternal uncle, who intervenes in all family and domestic matters.

In the nuclear family context, children are led by the mother's brother rather than the biological father. Women have a leadership and organizational role within the clan and participate actively and independently in political affairs. The main activities of the Wayuu community include cattle raising, fishing, agriculture, and salt extraction by men, while women dedicate a large part of their time to the elaboration of backpacks, nets, hammocks and domestic tasks. (Ministry of Culture, Republic of Colombia, 2010).

2.3 Job Competencies

According to Novick and Gallart (1998), job competencies refer to the abilities of individuals to solve problems, select resources, manage technology, and develop interpersonal relationships. These competencies are defined as basic characteristics that are causally related to effective job performance and are manifested in various situations over time. Servicio Nacional de Aprendizaje, SENA (2005) defines them as knowledge, skills and attitudes necessary for efficient performance in the productive sector and their evaluation is based on the resolution of specific, critical and public situations.

Competency assessment involves collecting information and evidence of an individual's performance during a specific activity. Colardyn and Durand-Drouhin (1995) define it as the ability of individuals to carry out a job efficiently, evaluated through observations in the workplace, practical simulations, oral questions, projects, among others.

Competency assessment methods have been developed, such as Amerdinger's (2000) 360° assessment method, which uses a questionnaire to assess performance based on observable or desirable behaviors. This approach focuses on unbiased evaluation of performance by co-workers.

In summary, the evaluation and development of labor competencies are essential to achieve efficient performance at work. These approaches seek to identify strengths and areas for improvement, as well as establish objective criteria to evaluate performance and form effective work teams. Continuous skill development is crucial to adapt to the changes and challenges of the ever-evolving work environment.

2.4 AR Visualization Based Mobile Learning Environment

Mobile learning, refers to the use of mobile devices in educational contexts to provide flexible and ubiquitous access to learning content. According to Bello-Orgaz, Menasalvas, and Camacho (2020), it involves the use of smartphones and tablets to facilitate the delivery of educational materials. Li, Zhang and Huang (2021) point out that mobile learning offers personalized and contextualized learning opportunities through mobile technologies and specific applications. This allows students to access educational resources anytime, anywhere. Chen, Kong and Chow (2022) highlight that M-Learning focuses on the use of mobile devices and mobile applications to support teaching and learning.

In this research we designed a learning environment on basic carpentry in AR, for mobile platforms such as smartphone and tablets with the help of a free software called "Scope", which can be referenced in google, there you can generate 3D images, with the help of a menu, then you migrate to the free software also called "Unity Motor" to later be transferred to devices. The environment contained four learning session that are described below:

The first session was developed in two sessions. In the first session, novices were trained in the use of the AR-based application. The purpose of the second session was to introduce the novices to the basic carpentry tools, such as: hammer, saw, screwdriver, wrench, meter, power strip, clamp, pencil, chisel, brush, and brace. During the execution of this session, novices manipulated the markers to see the effect of AR on the mobile device, in this way they got to know the tools virtually (Marcincina, et al., 2013). In addition to virtually learning the tools, videos and animations on the use of these tools were presented (Figure 1).

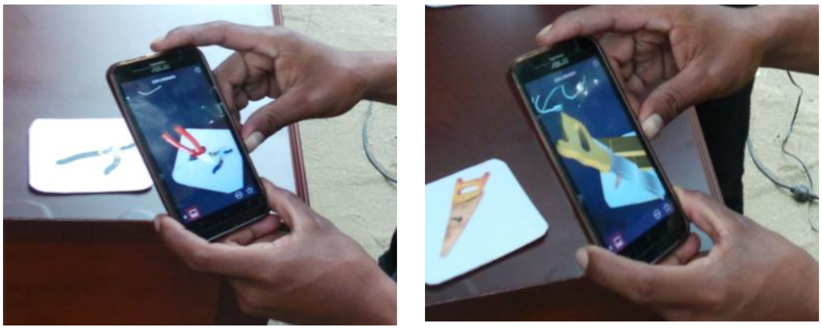

Figure 1: Novices manipulating images in AR

During the second session, novices learned the types of wood in the region suitable for carpentry work due to their physical properties such as density, hardness, and flexibility. Similarly, the application of Scope was opened, in the “Types of Woods” menu, the acknowledgement of the types of trees was carried out with the use of markers and the pine, snail, cedar and oak were observed in AR. In this session, each novice had the opportunity to operate the mobile device and observe the effect of the AR in order to learn about the shape of the tree and the appearance (or look)? of the wood after cutting (figure 2).

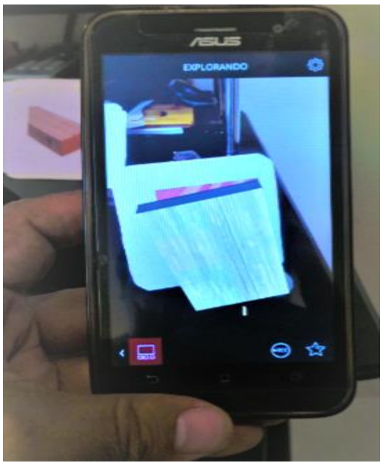

Figure 2: Cutting wood in AR

In the third session, novices were presented with video content of the recognition of tools, regarding uses and maintenance, likewise, they were presented with the topics of measurement and cutting of wood with explanation of cross-sectional and longitudinal cutting techniques, the first is characterized by being perpendicular to the piece of wood and is shorter while the second is done longitudinally. The theme of opening holes was also presented with the technique of pressing the Brace tool so that the drill opens the hole according to the predisposed marks.

In addition to the theme of union of pieces of wood, which is done in two ways, the first is to use the glue carpentry and the second, to secure the union with a nail. Finally the completed chair was presented, with verification of union of pieces, polishing, and finish.

In the fourth session, the novice was permanently advised by an expert carpenter, who supported the entire process of building the chair from start to finish. The corresponding steps were taken following the protocol process to build the nine pieces of the chair correctly. Construction began with the corresponding steps of measuring, cutting and joining the pieces. Followed by the steps of adjustment, polishing, and finish with the steps of verification and completed construction in real time (Figure 3).

Figure 3: Building the chair in real-time

3. Methodology

3.1 Theoretical Foundation

According to authors such as Smith (2010), in the field of carpentry, skilled trades are fostered through active practice and the acquisition of specific technical skilled trades. Apprentices are required to engage in hands-on projects that allow them to develop an in-depth understanding of the processes of measuring, cutting, fitting, and polishing pieces of wood. In addition, Vygotsky's (1978) constructivist theory highlights the importance of active learning and interaction with authentic materials and situations for the development of carpentry skilled trades. In traditional apprenticeship settings, factors such as the availability of adequate resources, expert supervision, and the opportunity to practice technical skilled trades are critical to successful carpentry apprenticeships (Johnson, 2005).

To validate the ML environment based on AR visualization, a case study was carried out with three indigenous people belonging to the Wayuu ethnic group from Torcoromana, Camarones district. These indigenous people in daily life are dedicated to fishing and goat herding, they have no knowledge of basic carpentry. They speak a dialect called "Wayuunaiki" and are illiterate in the Spanish language, the fact of not speaking Spanish limits being able to communicate with the people of the city, getting a job, in addition to not being able to access formal studies.

A fieldwork study was carried out, which according to (Burgess, R., 1984; Pelto, P., 2013), among social anthropologists, fieldwork is synonymous with collecting data through observational methods. However, for sociologists the term is also used to refer to the collection of data through a social survey or data from cultural anthropology that are derived from direct observation of behavior in a particular society. According with the last, a contact was made, with a Wayuu community leader who knew the Torcoromana indigenous people. The leader’s role was to make the training proposal known to the indigenous settlement’s chief and thus arrange a meeting between her and the researchers. After presenting the proposal to the chief, she authorized the entry of the team of researchers to the indigenous settlement. The training process was carried out in the school that had a board and desks, but without access to electricity or internet.

3.2 Study Design

The indigenous people interested in the training process were 15, they authorized the filming, photography, and use of the data obtained for educational purposes. Three participants who voluntarily agreed to be part of the research were randomly chosen, they are between the ages of 20 and 25 years old, these three indigenous people are identified in the following as: Andrés, Carlos, and Fabio. The three participating indigenous people have no knowledge of the carpentry skilled trades, they have no knowledge of the types of wood appropriate for this activity, and they have never been trained for this type of course trade. An indigenous person from the "Los Carbones" community was invited as a control group (E1), who was given a pictorial guide on the necessary steps to build a chair.

During the training stage, five face-to-face meetings were held between the indigenous people and the researchers who focused on the knowledge of the course developed in AR (Figure 4). In the first two sessions they recognized the inventory of carpentry tools and 13 fixed markers and 13 printed dynamic markers corresponding to the same number of tools were used and 8 markers were used to identify the types of wood and trees. Each Marker has the figure of the tool or wood material printed on one of its sides. In the third session they identified types of wood. In the fourth session they learned about cutting and joining pieces of wood. In the fifth session, with the help of a master craftsman, they built a chair individually.

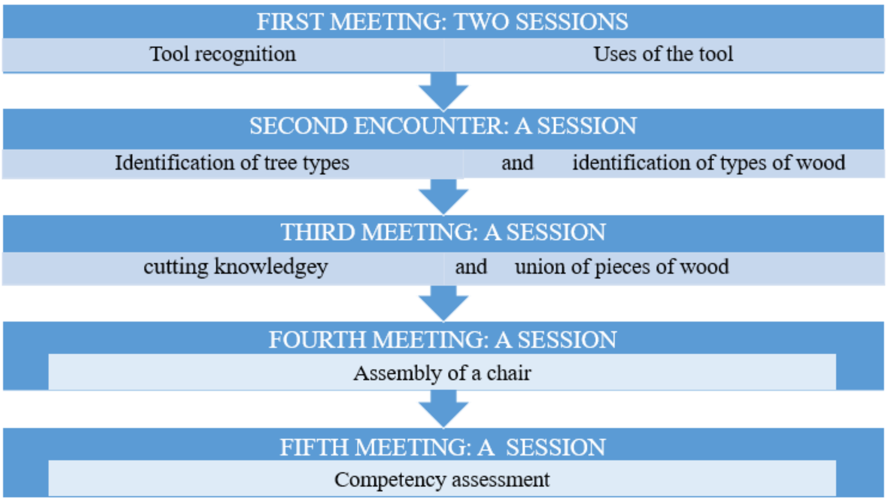

Figure 4: Face-to-face meetings

Finally, in the stage of assessment of skilled trades the indigenous people (sixth session) had the task of building a chair autonomously, Andrés, Carlos and Fabio were recorded, with the help of a professional cameraman, who carried out the recording process individually for approximately one hour for each of the three indigenous people, with the purpose of identifying the impact of the AR course on the development of skills in carpentry . The videos were then analyzed by three experts in carpentry, who have worked for 20 years in the carpentry trade and are instructors of a government institution called "SENA", who used a competency assessment system. The evaluations were carried out taking the average of the three evaluators per apprentice and per competence in each of the three phases (Appendix: Table 7).

This system was created by the researchers, specifically to evaluate the process of learning skilled trades in carpentry, the competency indices were developed by phases, which are described in the chapter on findings.

3.3 Assessment System

A carpentry competency assessment system applied to indigenous people is based on an approach that recognizes and values traditional carpentry knowledge and skilled trades within these communities. This system is based on the understanding that the skilled trades of carpentry in the indigenous context not only implies technical skilled trades, but also a deep connection with culture, tradition, and the natural environment.

According to González (2015), a competency-based assessment system in indigenous carpentry is based on the recognition of traditional skilled trades and the cultural knowledge inherent in this craft. This implies a deep understanding of the connection between the carpentry skills trade and the cultural identity of indigenous communities. On the other hand, Smith (2018) highlights the importance of considering environmental aspects in the evaluation by competencies in indigenous carpentry, recognizing the need to use natural resources in a sustainable manner and in harmony with the environment.

According to the approaches of González and Smith, the evaluation system by competencies in indigenous carpentry is based on a holistic approach that includes technical, cultural, and environmental aspects (Martínez, 2020). This involves valuing knowledge of native wood species, traditional carving, and assembly techniques, as well as understanding the designs and cultural symbols of each indigenous community.

The evaluation of skilled trades in indigenous carpentry is carried out through different methods, such as direct observation of carpentry projects, review of portfolios of previous work, and participation in community projects (Chávez, 2019). These methods allow to assess the technical skill and cultural knowledge of indigenous carpenters, as well as their ability to work collaboratively with the community and preserve cultural and environmental values.

In summary, an assessment system for competencies in indigenous carpentry is based on the recognition and appreciation of the technical, cultural and environmental skills of indigenous carpenters. González, Smith, Martínez and Chávez highlight the importance of this holistic approach to preserve the ancestral knowledge of carpentry, strengthen the cultural identity of indigenous communities, and promote sustainable development.

3.3.1 Description of the competencies assessment system

As mentioned above, the competencies assessment system was developed to assess the performance of the novices while building the chair. This competency assessment system was developed by the researcher taking into account the theoretical bases and conceptual foundations to be implemented in an indigenous community with three volunteer apprentices. The competency indicators in the three phases were prepared with the help of three experts in carpentry who gave their approval to be used in the final evaluation in real time. The system was validated by these three expert carpenters on the subject and presented three phases. Each phase consisted of competencies and indicators that allowed establishing the performance of the indigenous people before, during and after building the chair. Each performance indicator was assessed from 1-5, where 1 corresponds to the lowest score and 5 to the highest score.

The first phase determined indigenous knowledge of the tools and materials through three competencies and fifteen performance indicators (Table 1).

Table 1: First phase: Before building the chair

Competencies	Indicators
1. Describes and possesses in writing 2 Designs and steps of the process of building a Handcrafted chair.	1. Uses proper stroke tools, such as pencil and square, to mark the cut of the wood in the chosen pieces.
	2. Performs early maintenance on the cutting tools (saw), to achieve the cross cuts and longitudinal cuts properly.
	3. Accurately classifies the fastening tools such as: pliers and tongs to be used as indicated in the assembly of wooden pieces.
	4. Carefully prepares tools for cutting and lowering such as chisel and carpentry brush, with proper maintenance and cleaning of the parts.
	5. Identifies and correctly uses tools to polish or finely sand the wood (Rasp).
3. Organizes a complete inventory of tools and materials.	6. Assembles and properly adjust the drill bit on tools to open holes such as the brace.
	7. Identifies and uses, according to the wood's hardness, impact tools such as hammer on hard surfaces and mallet on finished surfaces.
	8. Chooses the right tool to screw or unscrew, as the case may be, by properly handling the screwdriver or fixed wrenches.
	9. Understands and specifically uses measurement tools such as the meter or terminal strip.
	10. Uses the scraping tool in the indicated way, to leave the surfaces of the pieces of wood in a smooth and soft way.
4. Possesses a panel of tools and inputs for the construction and a warehouse with different types of wood.	11. Identifies and uses the brush for cleaning and lacquering wooden pieces.
	12. Describes and differentiates elements such as nails and screws for joining pieces and glue carpentry.
	13. Classifies and arranges the type of wood suitable for cutting.
	14. Correctly calculates the quantity and type of wood to be used.
	15. Maintains in a perfect state with a periodic maintenance, tools such as: saw, brush, chisel and scraper.

The second phase assessed the performance of the indigenous people while building the chair. For this purpose, four competencies and fourteen performance indicators were proposed, which are described in Table 2.

Table 2: Second phase: While building the chair

Competencies	Indicators
1. Develops a constructive process of a handcrafted chair executing the design steps.	1. Accurately measures and marks the parts for cutting and verifies that the measurements are well taken on the marks.
	2. Cuts firmly and accurately transversally the pieces according to measurements and traced marks.
	3. Orders the parts in the correct assembly sequence and check that the parts are in good condition.
	4. Properly brushes the wood until smooth surfaces are obtained.
	5. Achieves surfaces in optimum presentation.
2. Analyze and understand the steps of measuring, cutting and polishing the pieces of wood.	6. Opens the holes making proper use of the drill bit and the marks for each piece of wood accurately.
	7. Accurately measures the depth, length and width of the holes in each piece of wood for a perfect fit.
	8. Accurately cuts each piece of wood longitudinally, according to the depth of the hole.
	9. Checks and polishes properly the tabs at the ends of the longitudinal cut piece.
3. Applies the steps of opening, depth, and polishing of the hole.	10. Accurately marks the piece of wood in the place indicated to open the holes, measures with precision width, length and depth.
	11. Examines the exact adjustments of the tabs of each piece of wood with respect to the depth of the hole.
	12. Adjusts the tabs and hole depth, brushes carefully for a quality finish.
4. Establishes and elaborates the adjustments of the joints.	13. Accurately joins the pieces of wood with glue. Calculates the time needed for it to dry.
	14. Nails accurately and in the right place. Firmly and accurately cuts excess tips.

Finally, the third phase assessed the characteristics of the chair after it was built by the indigenous people. To analyze the final product, two competencies and thirteen performance indicators were proposed (Table 3).

Table 3. Third phase: After building the chair

Competencies	Indicators
1. Develops a careful process of measuring, cutting, adjusting, and polishing pieces of wood.	1. Builds and assembles the nine (9) pieces of the chair following the procedure and evaluating with the checklist and quality.
	2. Evaluates that the assembled pieces are in the correct location.
	3. Uses the measuring, cutting, clamping, and impact instruments safely and firmly.
	4. Accurately cuts longitudinally and transversely.
	5. Makes joints, glues with nails, and other elements accurately.
2. Verifies the assembly and process for proper and quality construction of a handcrafted chair.	6. Precisely applies glue to joints.
	7. Inspects the final sanding for quality.
	8. Makes a final assessment to detect splinters or protrusions.
	9. Verifies with precision tests the assembly and final finishes.
	10. Self-evaluates the final product with a guide of indicators. Note, what do they reference if they cannot read; the guide of indicators is a voice? Is it an image?
	11. Use the materials in a reasonable way.
	12. Carries out the maintenance of the tools in an adequate way.
	13. Properly organizes and stores tools.

4. Findings

To identify the impact of the AR learning process on the development of skilled trades in carpentry, the indigenous people in the sixth session were videotaped while building a chair. Subsequently, the videos were reviewed and assessed with the aid of the competencies system.

The description of the results was based on the phases of the competencies assessment system and the performance indicators for each of the three novices in real time.

4.1 First Phase: Before Building the Chair

In the first phase, three competencies were assessed by means of fifteen indicators, the scores were obtained in a general way averaging the three scores assigned by experts in carpentry in each competency and thus establishing a value for each one that describes the performance of the indigenous people. (Figure 5).

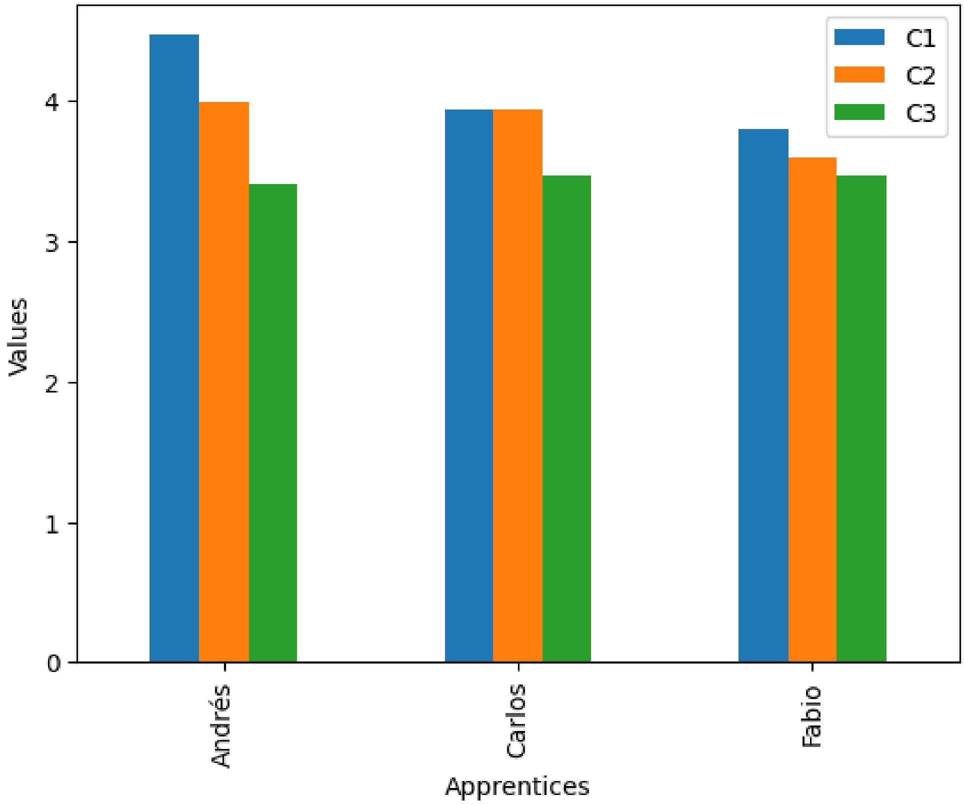

Figure 5: Graphic showing performance indicators

Below is an individual summary of phase I. (Table 4).

Table 4: Individual summary

Novice / Competence	Andrés	Carlos	Fabio
C1: Describes and possesses in writing designs and steps of the process of building a handcrafted chair.	Andrés showed competence in classifying and using the inventory of tools, as well as performing periodic maintenance on them. However, he had deficiencies in fixing the saw. Average rating: 4.45/5.0	Carlos demonstrated proper tool cleaning and maintenance and correctly classified measuring, cutting, and clamping tools. However, he had difficulty using the square for measurements. Average rating: 3.93/5.	Fabio carefully classified, used and prepared the tools for measuring, cutting, drilling and planning. However, he had problems with the cleaning and maintenance of the tools, as well as with the improper use of the tool for sanding wood. Average rating: 3.79/5.0.
C2: Organizes a complete inventory of tools and materials.	Andrés correctly identified the tools for certain tasks but had problems with the	Carlos adjusted and chose tools for specific tasks, but he had problems with the	Fabio adequately prepared the tools for specific tasks but had trouble identifying

Novice / Competence	Andrés	Carlos	Fabio
	proper handling of the screwdriver and the measurement scale. Average rating: 3.99/5.0.	scale and the screwdriver. Average rating: 3.93/5.0.	and using impact tools such as the hammer and scraper to polish wood. Average rating: 3.59/5.0.
C3: Possesses a panel of tools and inputs for the construction and a warehouse with different types of wood.	Andrés calculated the amount of wood accurately, but he had problems with the use of the brush to varnish and adjust with wooden nails. Average rating: 3.40/5.0.	Carlos excelled at maintaining tools and performing regular maintenance. However, he had problems with the use of the lacquer brush, the inappropriate use of materials and the inappropriate use of wood. Average rating: 3.46/5.0.	Fabio had difficulty nailing pieces of wood together, but successfully selected the correct type of wood and effectively used the calculated amount of wood. Average rating: 3.46/5.0.

Based on the information, it can be inferred that Andrés performed relatively better than the other trainees, followed by Carlos, and Fabio had the lowest overall performance.

4.2 Phase II: While Building the Chair

Phase II, which corresponded to the assembly of the parts, four competencies were assessed, followed by the description of the results. (Figure 6).

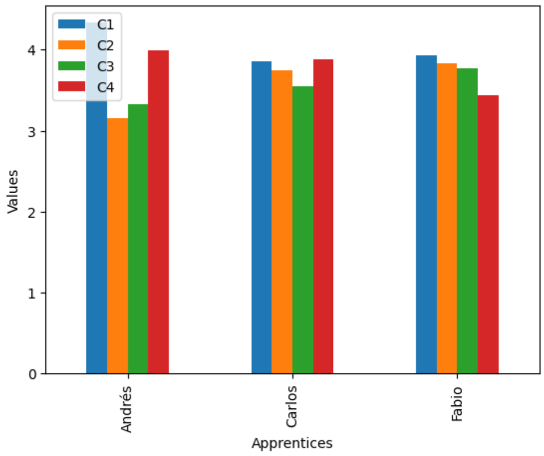

Figure 6: Graphic showing performance indicators

Below is an individual summary of phase II. (Table 5).

Table 5: Individual summary

Novice / Competence	Andrés	Carlos	Fabio
C1: Develops a constructive process of a handcrafted chair executing the design steps.	Andrés demonstrated precision in measuring, cutting, and ordering pieces of wood. He also achieved a correct brushing of the pieces. Average rating: 4.33/5.0.	Carlos precisely measured, marked and planed the pieces of wood. However, he lacked the firmness and precision to cut the pieces lengthwise and arrange them in the correct order of assembly. Average rating: 3.86/5.0.	Fabio accurately measured, marked and cut the pieces of wood. He got a nice superficial presentation. However, brushing him was not done properly. Average rating: 3.93/5.0.
C2: Analyze and understand the steps of measuring, cutting and polishing the pieces of wood.	Andrés had problems with the exact longitudinal cuts and the precise grinding of the tabs for the fit. Average rating: 3.16/5.0.	Carlos punched holes accurately and checked tabs properly. However, he had problems with accurate ripping to the depth of the hole. Average rating: 3.74/5.0.	Fabio used the drill correctly, cut the pieces accurately lengthwise, and polished and checked the ends of the pieces. However, he had trouble measuring the depth of the hole accurately. Average rating: 3.83/5.0.

C3: Applies the steps of opening, depth, and polishing of the hole.	Andrés had difficulty marking the exact location of the holes and accurately examining/adjusting the flanges. Average rating: 3.33/5.0.	Carlos had difficulties marking the pieces accurately and achieving the expected performances. He also faced challenges fitting the tongue into the hole and properly planning the parts. Average rating: 3.55/5.0.	Fabio precisely marked the pieces of wood and examined the fit and depth of the hole. However, he had difficulty achieving a perfect fit between the tongue and the hole. Average rating: 3.77/5.0
C4: Establishes and elaborates the adjustments of the joints.	C4: Andrés successfully joined the pieces of wood but faced challenges cutting off the excess tips of the wooden nails. Average rating: 3.99/5.0.	Carlos successfully glued the pieces together and accurately cut the excess tips of the wooden nails. However, the location of his fingernails was not precise. Average rating: 3.88/5.0	Fabio used and drove the nails in the right place, cut the excess firmly, but did not glue the pieces together well. Average rating: 3.44/5.0.

In general terms, Andrés performed better in competition 1 compared to the other two students. However, his performance decreased in competitions 2 and 3. Carlos and Fabio had similar averages in the competitions, with some strengths and weaknesses in different steps of the carpentry process.

4.3 Phase III: After Building the Chair

Phase III assessed two competencies in each of the three novices, the findings are described below. (Figure 7).

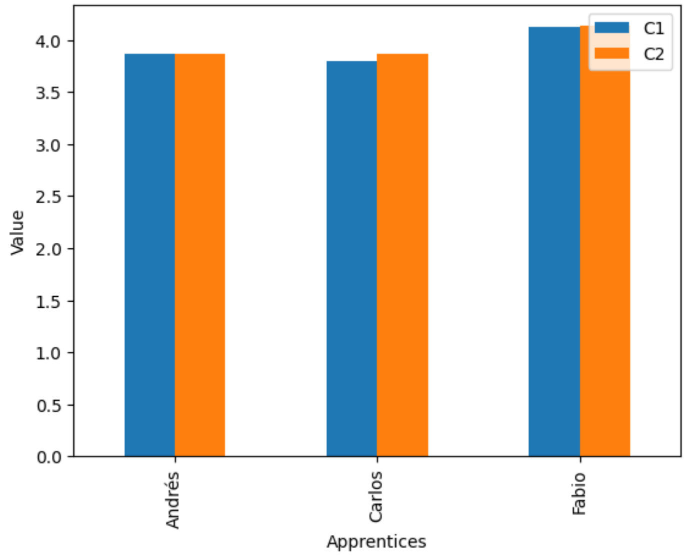

Figure 7: Graphic showing performance indicators

Below is an individual summary of phase III. (Table 6)

Table 6: Individual summary

Novice / Competence	Andrés	Carlos	Fabio
C1: Develops a careful process of measuring, cutting, adjusting, and polishing pieces of wood	Andrés successfully built and assembled the wooden chair, making sure each piece was in the right place and using the tools correctly. However, he faced challenges joining the pieces precisely with nails and glue. Average rating: 3.86/5.0.	Carlos correctly built and assembled the chair, evaluating the correct placement of the pieces and making precise cross-sections. However, he had trouble achieving precise joints and glues using nails and glue. Average rating: 3.79/5.0.	He made precise longitudinal and transversal cuts. However, he used tools irregularly and was unable to glue the pieces together accurately. Average rating: 4.12/5.0

Novice / Competence	Andrés	Carlos	Fabio
C2: Verifies the assembly and process for proper and quality construction of a handcrafted chair	Andrés maintained the same average rating of 3.86/5.0. He checked for splinters in the wood, used the necessary materials, and kept the tools clean and organized. However, he lacked precision when applying the glue and inspecting the quality of the final sanding.	Carlos inspected the quality of the sanding, evaluated the protrusions in the pieces and performed proper maintenance on the tools. However, he faced difficulties in accurately applying the glue at the joints and using the materials sensibly. Average rating: 3.86/5.0.	Fabio successfully built and assembled the wooden chair, following the protocol and ensuring the correct placement of the pieces. Average rating: 4.12/5.0.

Based on the information, Fabio had the highest average rating, indicating a better overall performance. Andrés and Carlos had similar average marks, but Fabio scored slightly higher. (See graph 4).

In conclusion, it was found that Fabio exhibited outstanding performance in the three phases evaluated, demonstrating solid and consistent skilled trades in the construction and assembly of the wooden chair. Andrés was in second place, presenting difficulties in specific steps of the process, while Carlos was in third place, showing an acceptable overall performance but less outstanding than the other two trainees. These findings highlight the importance of practice and experience in developing carpentry skilled trades.

The implementation of AR in ML environment has been shown to have a significant impact on the development skilled trades in carpentry. AR provides a rich and interactive learning experience that facilitates the understanding and application of technical concepts and skills.

Regarding the results of the Apprentices, it was observed that AR contributed positively in specific areas. For example, in the C1 competition, the real-time visualization of instructions and virtual models allowed Andrés and Carlos to correctly build and assemble the parts, improving the precision in the execution of tasks. However, limitations were identified in the proper use of tools in the C2 competence, suggesting the need for more interaction and real-time feedback to guide and correct the handling of specific tools.

On the other hand, Fabio excelled in several competencies, indicating that AR can influence individual performance by aiding in accurate tool identification and selection, as well as accurate cutting and adjustment. However, the need to improve aspects such as the correct use of glue and the precision in the assembly of the pieces was pointed out. However, the invited apprentice's performance in tasks such as cutting, hole opening, and general chair polishing was below expectations, as evaluated by the three experts. He achieved an average score of 2.5/5.0, indicating the effectiveness of AR visualization.

In summary, the implementation of AR in learning environments shows promise for the development of skilled trades in carpentry. Its ability to provide a visually enriched and immersive experience can enhance the understanding and application of technical skills. However, continued attention is required to overcome the identified limitations and maximize the potential of AR in learning environments.

5. Conclusions

The ML environment based on AR aiming at fostering technical job knowledge and competencies development in Wayuu Indians allowed the appropriation of knowledge through the visualization of 3D images with the use of printed markers of the inventory of tools and the inventory of materials mediated by an interactive graphic interface. The environment was developed on a mobile platform where the indigenous people performed simulations of movements in a natural way and visualized on screen the effect of the AR originated from the marker positioned under the camera of the device.

In this sense, the approach of the carpentry tools, their functions and uses through the implementation of a course of "basic carpentry" with AR support allowed the indigenous people to have the opportunity to know and manipulate tools unknown in their community, and with the inclusion of a technology with platform and mobile devices. The Wayuu indigenous community benefited because they developed carpentry trade job competencies on the process of building a chair, which managed to commercialize successfully in the market thus improving their family income.

Visual technology also ensured that the indigenous people acknowledged the tools of the carpentry trade with 13 fixed markers and 13 dynamic printed markers corresponding to the same number of tools used in the training process. Also, it facilitated to the indigenous people the knowledge of the types of trees of the region, the structure, the use, and the characteristics, mainly the visualization of the type of wood after the cut, 8 markers were used that identified the types of wood and trees.

Similarly, it is important to mention that the technology was characterized by portability in the devices, weight, size and autonomy of battery power, avoiding the travel of indigenous people and bringing the ML environment to the indigenous settlement. This technological innovation had an educational component that allowed to improve in terms of knowledge the learning of a trade in indigenous communities that do not speak Spanish. Said technology facilitated for the indigenous man to manage times, review contents and learn at their own pace.

On the other hand, the proposed competency assessment system allowed evaluating the skills of measuring, cutting, joining and assembling pieces of wood, managing the inventory of tools and the use of materials. The competence evaluation system showed good results in the performance of the activities in the process of integral construction of a wooden chair, and it was observed that the indigenous people managed to satisfactorily complete all the processes of the protocol that involves the technical assembly of a wheelchair wood. One of the three participating indigenous people (A1) was randomly chosen and compared with the invited indigenous person (E1) who did not have training with the visual method, where the efficiency of the learning process using AR can be observed. (Table 7).

It can be concluded that the ML environment applied in training processes with indigenous populations, excluded people and people with communication limitations, are viable and effective for the development of technical job knowledge and competencies. In addition, the AR improves the motivation and creativity of novices (Wei et al., 2014), since it allows them to manipulate devices, approach contents virtually, directly observe the object in three dimensions, and actively participate in the construction of knowledge (Bujak et al., 2014; Redondo et al., 2013).

Finally, with the support of the ML environment, made it possible to achieve an effectiveness of the training proposal in the carpentry trade in indigenous populations. Visual method allows achieving greater educational inclusion for people with learning difficulties, basically because it allows inserting the virtual into the real environment without the need to travel to an institution. Visual method allows achieving greater educational inclusion for people with learning difficulties, basically because it allows inserting the virtual into the real environment without the need to travel to an institution. In the future, can develop a methodology that allows the use of the AR in a way that adapts to different topics linked to the improvement and fulfillment of the study plans and courses proposed based on the needs of people and communities. For future implementations, it is recommended to make the model more flexible and apply it to other illiterate populations, such as peasants, displaced persons and street dwellers, this will allow more people in a condition of illiteracy to access learning opportunities and development of skilled trades.

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Appendix

Table 7: Assessment Evaluators

Phase I	Competencies (C)	Indicators (I)	Apprentice A1				Apprentice 2				Apprentice 3			
			Evaluators				Evaluators				Evaluators			
			E1	E2	E3	Average	E1	E2	E3	Average	E1	E2	E3	Average
I. Knowledge of tools and materials - Pre	1. Describes and possesses in writing designs and steps of the process of building a handcrafted chair.	1. Uses proper stroke tools, such as pencil and square, to mark the cut of the wood in the chosen pieces.	5	4	5	**4,66**	4	4	3	**3,66**	4	4	4	**4,0**
		2. Performs early maintenance on the cutting tools (saw), to achieve the cross cuts and longitudinal cuts properly.	5	4	4	**4,33**	4	4	4	**4,0**	3	3	3	**3,0**
		3. Accurately classifies the fastening tools such as: pliers and tongs to be used as indicated in the assembly of wooden pieces.	3	5	4	**4,0**	4	4	4	**4,0**	5	4	4	**4,33**
		4. Carefully prepares tools for cutting and lowering such as chisel and carpentry brush, with proper maintenance and cleaning of the parts.	5	5	4	**4,66**	4	4	5	**4,33**	4	4	4	**4,0**
		5. Identifies and correctly uses tools to polish or finely sand the wood (Rasp).	5	5	4	**4,66**	4	4	3	**3,66**	3	3	5	**3,66**
		TOTAL AVERAGE C1	**4,46**				**3,93**				**3,79**			
	2. Organizes a complete inventory of tools and materials.	6. Assembles and properly adjust the drill bit on tools to open holes such as the brace.	5	4	5	**4,66**	5	5	4	**4,66**	4	4	4	**4,0**
		7. Identifies and uses, according to the wood's hardness, impact tools such as hammer on hard surfaces and mallet on finished surfaces.	5	4	4	**4,33**	4	4	4	**4,0**	4	4	3	**3,66**
		8. Chooses the right tool to screw or unscrew, as the case may be, by properly handling the screwdriver or fixed wrenches.	3	4	3	**3,33**	3	3	3	**3,0**	3	3	4	**3,33**
		9. Understands and specifically uses measurement tools such as the meter or terminal strip.	4	4	3	**3,66**	5	4	4	**3,66**	4	4	4	**4,0**
		10. Uses the scraping tool in the indicated way, to leave the surfaces of the pieces of wood in a smooth and soft way.	4	4	4	**4,0**	5	4	4	**4,33**	3	3	3	**3,0**
		TOTAL AVERAGE C2	**3,99**				**3,93**				**3,59**			
	3. Posee un panel de herramientas e insumos para la elaboración y un depósito con diferentes tipos de madera	11. Identifies and uses the brush for cleaning and lacquering wooden pieces.	3	3	3	**3,0**	3	3	3	**3,0**	3	3	3	**3,0**
		12. Describes and differentiates elements such as nails and screws for joining pieces and glue carpentry.	3	3	3	**3,0**	3	4	3	**3,33**	3	3	3	**3,0**
		13. Classifies and arranges the type of wood suitable for cutting.	4	4	4	**4,0**	4	4	4	**4,0**	5	5	4	**4,66**
		14. Correctly calculates the quantity and type of wood to be used.	3	3	3	**3,0**	3	3	3	**3,0**	4	4	3	**3,66**
		15. Maintains in a perfect state with a periodic maintenance, tools such as: saw, brush, chisel and scraper.	4	4	4	**4,0**	4	4	4	**4,0**	3	4	5	**4,0**
		TOTAL AVERAGE C3	**3,40**				**3.46**				**3,46**			
		GENERAL AVERAGE	**4,0**	**4,0**	**3,8**	**3,9**	**3,9**	**3,8**	**3,6**	**4.0**	**3.66**	**3,4**	**3,7**	**3,7**

Phase III	Competencies (C)	Indicators (I)	Apprentice 1				Apprentice 2				Apprentice 3			
			Evaluators				Evaluators				Evaluators			
			E1	E2	E3	Average	E1	E2	E3	Average	E1	E2	E3	Average
Product evaluation	1. Develops a careful process of measuring, cutting, adjusting, and polishing pieces of wood.	1. Builds and assembles the nine (9) pieces of the chair following the procedure and evaluating with the checklist and quality.	4	4	4	**4,0**	4	5	4	**4,33**	5	5	4	**4,66**
		2. Evaluates that the assembled pieces are in the correct location.	4	4	4	**4,0**	4	4	4	**4,0**	5	4	5	**4,66**
		3. Uses the measuring, cutting, clamping, and impact instruments safely and firmly.	5	5	4	**4,66**	3	4	4	**3,66**	4	3	4	**3,66**
		4. Accurately cuts longitudinally and transversely.	4	3	4	**3,66**	3	4	5	**4,0**	5	5	4	**4,66**
		5. Makes joints, glues with nails, and other elements accurately.	3	3	3	**3,0**	3	3	3	**3,0**	3	3	3	**3,0**
		TOTAL AVERAGE C1	**3,86**				**3,79**				**4,12**			
	2. Verifies the assembly and process for proper and quality construction of a handcrafted chair	6. Precisely applies glue to joints.	3	3	3	**3,0**	3	3	3	**3,0**	3	3	3	**3,0**
		7. Inspects the final sanding for quality.	3	3	3	**3,0**	4	5	4	**4,33**	5	5	5	**5,0**
		8. Makes a final assessment to detect splinters or protrusions.	4	4	4	**4,0**	3	4	5	**4,0**	5	4	3	**4,0**
		9. Verifies with precision tests the assembly and final finishes.	4	4	4	**4,0**	3	4	4	**3,66**	4	4	5	**4,33**
		10. Self-evaluates the final product with a guide of indicators. Note, what do they reference if they cannot read; the guide of indicators is a voice? Is it an image?	4	4	4	**4,0**	4	4	3	**3,66**	4	5	4	**4,33**
		11. Use the materials in a reasonable way.	4	4	4	**4,0**	3	3	4	**3,33**	5	4	4	**4,33**
		12. Carries out the maintenance of the tools in an adequate way.	4	4	4	**4,0**	4	4	4	**4,0**	3	4	5	**4,0**
		13. Properly organizes and stores tools.	4	4	5	**4,33**	4	5	4	**4,33**	5	4	3	**4,0**
		TOTAL AVERAGE C2	**3,86**				**3,86**				**4,13**			
		GENERAL AVERAGE	**3,86**	**3.8**	**3.93**	**3,86**	**3,53**	**4.06**	**3.86**	**3,84**	**4,06**	**4.06**	**4.06**	**4,13**

Phase II	Competencies (C)	Indicators (I)	Apprentice 1				Apprentice 2				Apprentice 3			
			Evaluators				Evaluators				Evaluators			
			E1	E2	E3	Average	E1	E2	E3	Average	E1	E2	E3	Average
II. During the assembly of the chair	1. Develops a constructive process of a handcrafted chair executing the design steps	1. Accurately measures and marks the parts for cutting and verifies that the measurements are well taken on the marks.	5	5	5	**5,0**	4	4	4	**4,0**	4	4	4	**4,0**
		2. Cuts firmly and accurately transversally the pieces according to measurements and traced marks.	4	4	4	**4,0**	3	3	3	**3,0**	4	4	4	**4,0**
		3. Orders the parts in the correct assembly sequence and check that the parts are in good condition.	4	5	4	**4,33**	4	4	3	**3,66**	4	4	4	**4,0**
		4. Properly brushes the wood until smooth surfaces are obtained.	4	4	4	**4,0**	4	5	4	**4,33**	4	4	3	**3,66**
		5. Achieves surfaces in optimum presentation.	5	4	4	**4,33**	5	4	4	**4,33**	4	4	4	**4,0**
		TOTAL AVERAGE C1	**4,33**				**3,86**				**3,93**			
	2. Analyze and understand the steps of measuring, cutting and polishing the pieces of wood.	6. Opens the holes making proper use of the drill bit and the marks for each piece of wood accurately.	3	3	3	**3,0**	4	4	4	**4,0**	4	4	4	**4,0**
		7. Accurately measures the depth, length and width of the holes in each piece of wood for a perfect fit.	3	4	4	**3,66**	4	4	3	**3,66**	3	3	4	**3,33**
		8. Accurately cuts each piece of wood longitudinally, according to the depth of the hole.	3	3	3	**3,0**	3	4	3	**3,33**	4	4	4	**4,0**
		9. Checks and polishes properly the tabs at the ends of the longitudinal cut piece.	3	3	3	**3,0**	4	4	4	**4,0**	4	4	4	**4,0**
		TOTAL AVERAGE C2	**3,16**				**3,74**				**3,83**			
	3. Applies the steps of opening, depth, and polishing of the hole.	10. Accurately marks the piece of wood in the place indicated to open the holes, measures with precision width, length and depth.	4	3	3	**3,33**	4	4	4	**4,0**	4	4	5	**4,33**
		11. Examines the exact adjustments of the tabs of each piece of wood with respect to the depth of the hole.	3	4	3	**3,33**	4	4	3	**3,66**	4	4	4	**4,0**
		12. Adjusts the tabs and hole depth, brushes carefully for a quality finish.	3	3	4	**3,33**	3	3	3	**3,0**	3	3	3	**3,0**
		TOTAL AVERAGE C3	**3,33**				**3,55**				**3,77**			
	4. Establishes and elaborates the adjustments of the joints.	13. Accurately joins the pieces of wood with glue. Calculates the time needed for it to dry.	5	4	4	**4,33**	3	3	4	**3,33**	3	3	3	**3,0**
		14. Nails accurately and in the right place. Firmly and accurately cuts excess tips.	4	3	4	**3,66**	3	4	4	**3,66**	3	3	3	**3,0**
		15. Utiliza y clava las puntillas con la medida precisa y en el lugar adecuado. Corta con firmeza y precisión las puntas sobrantes.	4	4	4	**4,0**	5	4	5	**4,66**	4	4	5	**4,33**
		TOTAL AVERAGE C3	**3,99**				**3,88**				**3,44**			
		GENERAL AVERAGE	**3.8**	**5**	**3.73**	**3,75**	**3.8**	**3.86**	**3.86**	**3,77**	**3,86**	**3,86**	**3.86**	**3,77**

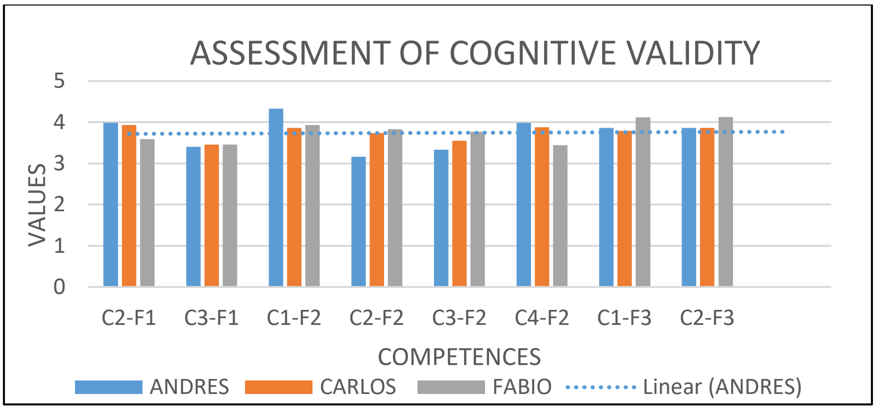

Figure 8: Assessment of cognitive validity

Table 8: Evaluation of the efficiency of the tool in E1 and A1

Column_1	A1	E1
C1-F1	4,46	3,24
C2-F1	3,99	3,2
C3-F1	4,78	3
C1-F2	4,33	3,5
C2-F2	4,76	3,74
C3-F2	4,28	3,55
C4-F2	4,75	3,33
C1-F3	4,86	3,57
C2-F3	4,85	3,21

What is Your VR Use Case for Educational Like: A State-Of-The-Art Taxonomy

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https://doi.org/10.34190/ejel.21.6.3215

Abstract: Virtual reality has emerged as an influential technology in the educational landscape, offering learners and teachers immersive and interactive experiences that enhance traditional teaching methods. However, despite the increasing importance of virtual reality in education, a systematic description and classification of virtual reality use cases in education is still lacking. This limits the understanding and comparability of virtual reality use cases and highlights the need for a structured approach. This study asks the research question: How can virtual reality educational use cases, identified in the literature, be described, and classified? To classify these use cases, this study develops a state-of-the-art taxonomy. The taxonomy was developed in a combination of a conceptual-to-empirical and empirical-to-conceptual approach. The first stage to develop the taxonomy was based on a conceptual-to-empirical approach. Here, the concepts of virtual reality, use case and education serve as meta-characteristics and theoretical structure. To further detail the dimensions and characteristics, a systematic literature review was conducted by following a PRISMA-guided search and selection process. Therefore, the scientific databases Science Direct, AISel and Springer Link were used to search for studies between 2018 and 2023, obtaining a sample of 39 publications. As the conceptual-to-empirical approach did not richly describe the analysed virtual reality use cases from the studies, additional dimensions and characteristics were identified inductively. Therefore, a second iteration was conducted relating to the empirical-to-conceptual approach. This process explored the practical aspects of virtual reality scenarios and added applicable and practical characteristics to the initial theoretical foundation. The result is a comprehensive taxonomy of virtual reality use cases in education that contributes significantly to existing knowledge and provides a solid foundation for future research. The final taxonomy includes 17 dimensions and 37 characteristics. These findings can support educators to understand the nature of virtual reality use cases, enabling them to describe and implement such use cases effectively within educational settings.

Keywords: Virtual reality, Use cases, Education, Taxonomy, Systematic literature review

1. Introduction

Virtual Reality (VR) is an emerging technology that impacts different sectors, including education (Marks and Thomas, 2022). VR disrupts traditional educational scenarios by immersing students in interactive, three-dimensional environments (Alfalah, 2018). The immersive nature of VR opens up unique opportunities for delivering educational content, ranging from virtual field trips to complex scientific simulations. These unique opportunities are increasingly recognized by researchers (e.g., the call for papers for the Special Issue on Extended Realities for Learning from the Electronic Journal of e-Learning (EJEL)), educators (Dai, Garcia and Olave-Encina, 2023; Marks and Thomas, 2022; Sherman and Craig, 2019), and policymakers (European Commission, 2023). Thus, VR's mass-market adoption has expanded the range of its learning scenarios over the past decade (Alsop, 2023). However, despite the increased recognition and application of VR in education, there is still a lack of systematic description and classification of educational VR use cases. The need to define and study the main features emerging from VR characteristics is seen as a crucial step towards understanding the contribution of virtual environments to learning outcomes (Natsis, 2021). Educators have a strong interest in improving their understanding of VR (Gregory 2016), but the complexity of the task is increased by the evolving and often inconsistent VR terminology (Sherman, 2019). Identifying the unique characteristics of VR-supported learning environments is essential for a comprehensive investigation of its educational possibilities (Won et al., 2023). However, literature indicates significant inconsistencies between the understanding of the unique features of VR and its application in learning, hindering the understanding and comparability of VR use cases (Won et al., 2023). Furthermore, EJEL calls for contributions on theory building regarding the implementation of XR (VR and augmented reality)-based learning scenarios. To shed light on this descriptive confusion and contribute a structure to implement VR-based learning scenarios, this study asks the research question (RQ): *How can VR educational use cases, identified in the literature, be described, and classified?*

To answer the RQ, this study develops a state-of-the-art taxonomy of VR use cases in education, inspired by Radiantis' (2020) call to develop "a taxonomy of learning theories and other framing factors for educational VR

Cite this article: Bisswang, N., et al. 2023. "What is Your VR Use Case for Educational Like: A State-Of-The-Art Taxonomy", *The Electronic Journal of e-Learning*, 22(3) pp 46-62, https://doi.org/10.34190/ejel.21.6.3215

applications" (Radianti et al., 2020, pp.22). Taxonomies structure the field of knowledge (Kundisch et al., 2022). To build up such a taxonomy, dimensions and specific characteristics of VR use cases are systematically structured and organized.

The remainder of this paper is structured as follows. To provide a solid conceptual foundation for the taxonomy development, the concepts of *VR*, *use case* and *education* are theorized in the next section. The aim is, to gain descriptive dimensions from these concepts by analysing educational VR use cases deductively. The third section introduces the research design. A systematic literature review (SLR) is conducted to synthesize the existing body of knowledge of VR, use cases and education. The taxonomy development adapts the methodology by Nickerson, Varshney and Muntermann (2013). Then, the taxonomy, its dimensions and characteristics are presented. The fifth section demonstrates the applicability of the taxonomy by classifying a real-world education use case, which serves as an illustrative scenario (cf. Szopinski, Schoormann and Kundisch, 2019). Finally, this study discusses its findings, outlines the implications, reflects on limitations, and proposes future research paths.

2. Theoretical Background

This study utilizes the triad of the concepts *VR*, *use case*, and *education*. Pivotal studies were analysed to identify dimensions, these concepts are comprised of. Pivotal studies are those works widely cited and offering substantial contributions to VR research (Heim, 1994; Mikropoulos and Natsis, 2011; Sherman and Craig, 2019; Steuer, 1992; Suh and Lee, 2005). Complementarily, definitions of current industry leaders (Apple, 2023; Meta, 2023) and a renowned research institute (Gartner Inc., 2023) were also considered to align academic and practical view. Following these studies, *VR* is conceptualized by four key dimensions: (1) *immersion*, (2) *3D environment*, (3) *sensory feedback*, and (4) *autonomy in interaction* (Figure 1).

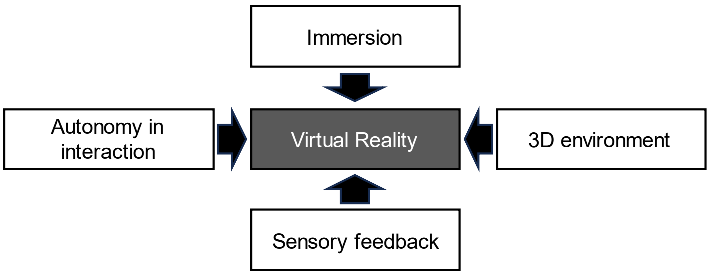

Figure 1: Dimensions of virtual reality

Immersion is the "perception of being physically present in a virtual world" (Sunday et al., 2022a, pp.2). It is either mentally or physically achieved (Sherman and Craig, 2019) by a headset immersing the senses into a virtual world (Meta, 2023). A virtual world is a digitally simulation of a real-world environment (Sherman and Craig, 2019). Recent studies refer to this virtual world as a computer-generated *3D environment* that immerses humans (Gartner Inc., 2023; Jiawei and Mokmin, 2023). *Sensory feedback* means the system's response to user input (Sherman and Craig, 2019), facilitated by e.g., touch-sensitive handheld controllers (Gartner Inc., 2023). *Interactivity* describes the users' ability to influence the virtual environment (Steuer, 1992), like manipulating virtual objects (Sherman and Craig, 2019). This influence implies a users' degree of autonomy, allowing learners to steer their own learning process within the virtual environment. Therefore, this study terms this dimension as the *autonomy in interaction*.

The concept *use case* comprises three key dimensions: (1) *trigger*, (2) *actors* and (3) *richness* (Figure 2).

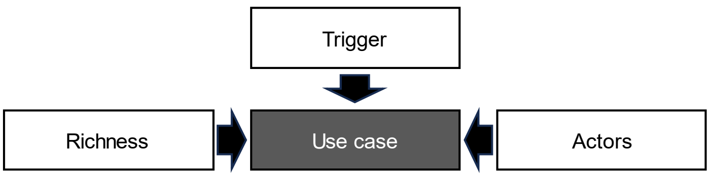

Figure 2: Dimensions of a use case

A *trigger* is a specific event that correlates with a system's behavior (Object Management Group, 2017; Weilkiens, 2007). Considering a VR use case as a holistic (black box) entity, a *trigger* is the motivator or underlying rationale behind the use case development, deviating from its standard definition. *Actors* refer to the various entities or individuals who interact with, influence, or are influenced by the use case (Balzert, 2011; Weilkiens, 2007). Scenarios are collections of goal-achieving interactions between the system and actors (Cockburn, 1999).

This study emphasizes the quantity of scenarios within a VR use case and coins the term *richness* (a virtual world with singular or multiple scenarios, Alfalah et al., 2019). Finally, the result of a use case is a predefined outcome of value (Weilkiens, 2007), which is not explicitly included in this study because all use cases are educational ones. Thus, results are covered more specifically by the concept *education*.

Four key dimensions conceptualize *education*: (1) *educational objectives*, (2) *aimed competencies*, (3) *autonomy in learning* and (4) *field of study* (Figure 3).

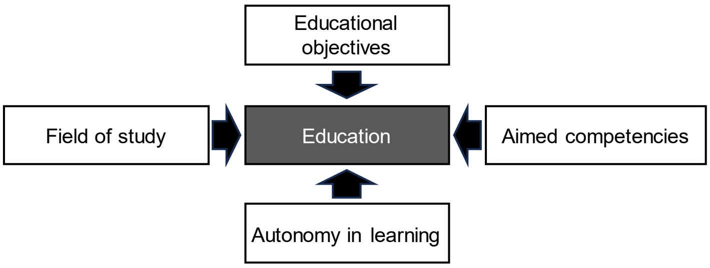

Figure 3: Dimensions of the concept education

Bloom's taxonomy of educational objectives, revised by Anderson and Krathwohl (2001), helps to classify *educational objectives* (Anderson and Krathwohl, 2001; Bloom, 1956). The artefact specifies six types of learning objectives: remember, understand, apply, analyse, evaluate, and create (Anderson and Krathwohl, 2001). While this taxonomy includes cognitive skills in detail, it excludes the emotional and psychomotor aspects that are essential to a comprehensive learning process. Therefore, the dimension *aimed competencies* incorporates cognitive, psychomotor, and social-emotional competencies. Cognitive competencies encompass intellectual skills and such processes that involve thought, understanding, and knowledge utilization. They span from simple information recall to complex tasks such as critical thinking, problem-solving, and the creation of new ideas (Anderson and Krathwohl, 2001). Psychomotor competencies refer to the acquisition and refinement of motor skills and physical movement, ranging from basic physical tasks to more complex, expressive actions that require precision, control, and highly developed motor skills (Harrow, 1972). Social-emotional competencies encompass emotional responses, social interactions, and the development of personal values. They range from receiving and responding to emotions, to understanding, accepting, and adopting various values and attitudes in social contexts (Krathwohl, Bloom and Masia, 1965).

Self-Determination Theory (SDT) helps to define the third dimension of the concept *education*. SDT is a macro level theory of human motivation and personality (Deci and Ryan, 2015). It brings forth the concept of self-determined learning, which refers to autonomously decided learning processes and strategies by learners, based on their individual needs, interests, and goals (Deci and Ryan, 2015). This is in contrast to externally imposed learning processes and strategies dictated by external agencies or systems, such as standardized testing or teacher-directed instruction (Felixbrod and O'Leary, 1973). To address the main motivator of learning, the term *autonomy in learning* is used to express the dichotomy of learning motivation from externally imposed to self-determined. Finally, *education* happens within a discipline or *field of study* (Statistisches Bundesamt (Destatis), 2021). Here the standard of the Federal Statistical Office of Germany is used, proposing eight classes: 1) humanities, 2) sports, 3) law, economic and social sciences, 4) mathematics and natural sciences, 5) human medicine and health science 6) agricultural, forestry and food sciences, veterinary medicine, 7) engineering sciences, and 8) arts and art sciences (Destatis, 2021).

3. Research Methods

This study follows two methodical approaches. To structure the field of knowledge about educational VR use cases, a SLR is conducted. The SLR is structured into use case identification, use case extraction, and data evaluation (Kitchenham, 2007; PRISMA, 2023; Webster and Watson, 2002). All process steps are described in the next section. Data evaluation is done deductively, based on the structure given by the concepts introduced in section 2. After discussing the results of the deductive approach within the author team and noticing the limited richness of the descriptive power, it was decided to complement these results using an inductive approach as well. Finally, the dimensions and characteristics were structured using a morphological box as visualization of the taxonomy (Szopinski, Kundisch and Schoormann, 2020). In this study, dimensions provide the descriptive pattern of the concepts of *VR*, *use case* and *education*, while characteristics are specific attributes of these dimensions (Nickerson, Varshney and Muntermann, 2013). Figure 4 provides an overview of the research methods and taxonomy development process.

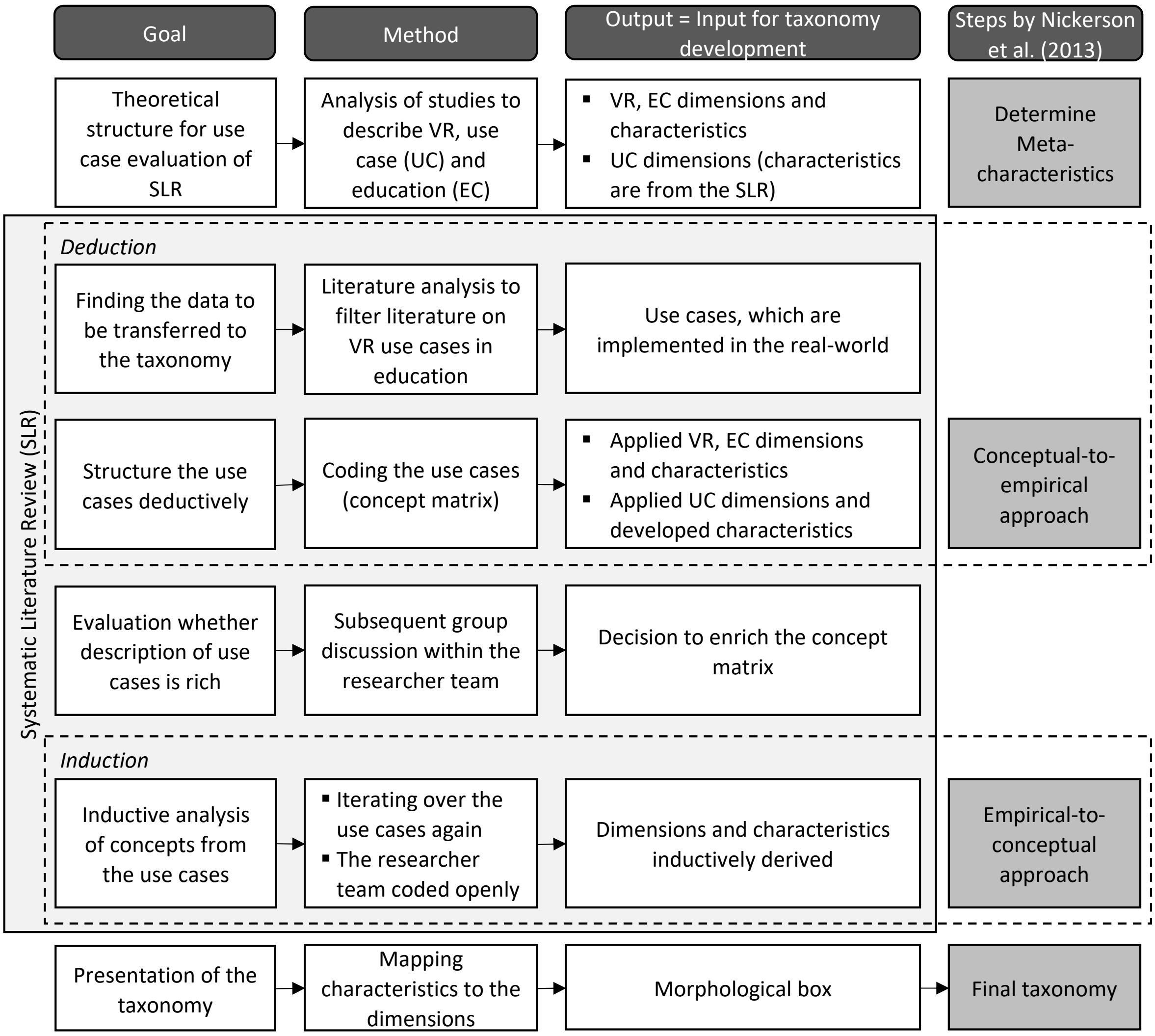

Figure 4: The taxonomy development process

3.1 Literature Review as Foundation for Taxonomy Development

To gather the use cases for taxonomy development, a SLR was conducted following Webster and Watson (2002). The PRISMA-guide was applied for the search and selection process of the publications (Figure 5). First, the search string was determined ("Virtual Reality" AND "Use Case") AND (learn, OR learning, OR teach, OR teaching). The search string was rather inclusive to gather a broad sample of literature and support the validity of the literature search process (vom Brocke et al., 2015). The scientific databases Science Direct, AISeL, and Springer Link with the publishing date between 2018 and 2023 were used. AISeL with its focus on Information Systems (IS) was selected because it highlights the significance of VR (Murphy, 2022). In contrast, Science Direct and Springer Link were expected to provide relevant literature on the use of VR in the education context due to their multidisciplinary coverage. 2018 was chosen due to the introduction of VR in the annually published Horizon Report, highlighting trends and developments in educational technologies for higher education (Becker et al., 2018). The next step selected papers based on boolean search results, applying inclusion and exclusion criteria to titles and abstracts.

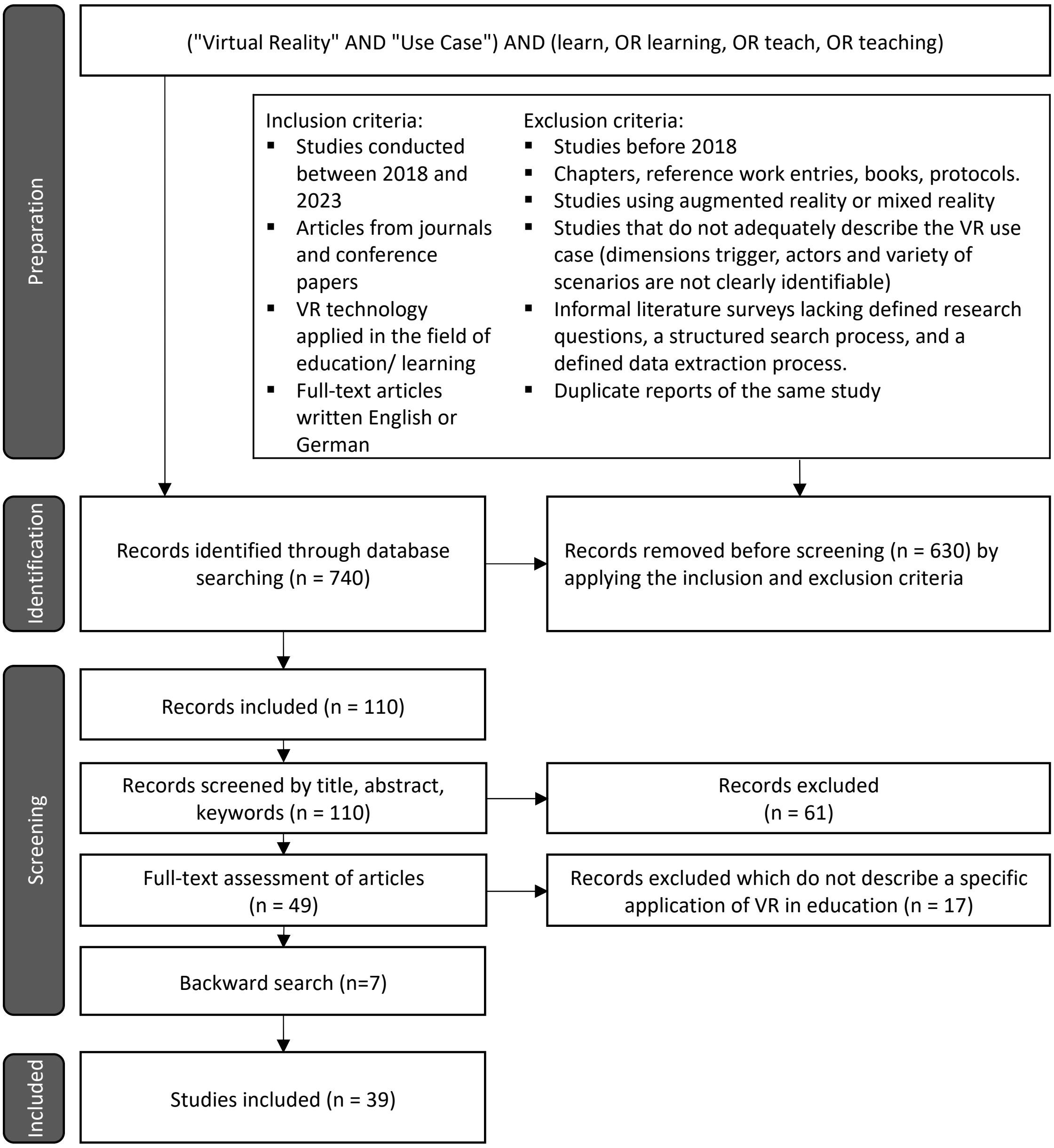

Figure 5: Flow chart for the search and selection process (cf. PRISMA, 2023)

The search was executed in May 2023, yielding 740 articles based on searches with the defined search term. After applying exclusion criteria 110 articles remained. Screening by title, abstract and keywords assessed 49 articles as being appropriate for a full-text review. Another 17 articles were excluded as they described VR in education generally rather than a specific use case. Backward search helped to identify seven further papers not covered by the searches. Finally, a total of 39 publications (30 journal, nine conference proceeding articles) were included in the analysis. Three of them were found in ScienceDirect, ten in AISeL and 26 in Springer Link. Then, the described use cases within the studies, were coded. For the coding process, the VR and education dimensions and characteristics were applied, as well as the use case dimensions.

3.2 Taxonomy Development Process

According to Nickerson, Varshney and Muntermann (2013), the target user groups, and the purpose of the taxonomy should be specified in the beginning of the taxonomy development process. The target user groups of the intended taxonomy are educators at the university level and VR use case designers, aiming to create future VR instantiations for education. The meta-characteristics of the process are the triad of concepts. These concepts shape the design of the dimensions determining the classes of the taxonomy. Last, ending conditions to evaluate the taxonomy are defined (Nickerson, Varshney and Muntermann, 2013). There are objective and subjective ending conditions. Objectively, the taxonomy should include all identified VR use cases in education, ensuring comprehensive coverage. Additionally, it should include the meta-characteristics that represent the main aspects of the VR use cases. By Nickerson, Varshney and Muntermann (2013) dimensions and characteristics have to be mutually exclusive and collectively exhaustive (MECE). This study deviates from this as some characteristics are not exclusive (e.g., an educational VR scenario can target the two educational characteristics “understand” and “apply”). Subjectively, the taxonomy should be concise, expandable, robust, explanatory, and comprehensive (Nickerson, Varshney and Muntermann, 2013). The fulfillment of these requirements is reflected after the taxonomy development in section 5 (Illustrative demonstration).

4. Conceptualization of Taxonomy Dimensions and Characteristics

Initially, the characteristics of *VR* and *education* dimensions are deductively identified. Then, the dimensions and characteristics of the concepts *VR* and *education* were applied for coding the publications selected in the search process of the SLR. The concept *use case* serves as an analogous term. Thus, the *use case* dimensions were applied to identify their characteristics by coding the use cases inductively.

4.1 Characteristics of the Virtual Reality Dimensions

Immersion is achieved through a combination of *vividness* – the richness of representation of a mediated environment (Steuer, 1992) – and *telepresence* – one’s extent of one being present in that environment (Steuer, 1992). The degree of these characteristics differs for each use case. They are not MECE as both are pronounced to at least a low degree as both are characteristic for VR environments. For instance, high *vividness* with low *telepresence* denotes a scenario that is graphically rich and detailed but is not able to engage the user fully having active interaction with the environment. In contrast, high *telepresence* with low *vividness* occurs in a situation where the user feels a strong sense of presence and engagement, even if the visual details and richness (*vividness*) are comparatively low.

The characteristics of the dimension *3D environment* emerge from studies ranging from complex real-world scenarios (e.g., architecture replication) to simpler scenarios for visualizing 3D structures. A VR use case is either *realistic* or *abstract*. *Sensory feedback* can be detected by the five human senses (Sorabji, 1971). At present, *visual*, *auditory*, and *haptic* feedback are common in VR use cases and not mutually exclusive. Olfactory and gustatory feedback are non-existent. Visual feedback occurs in every use case. A virtual world is not possible without visual feedback (Sherman and Craig, 2019). However, *visual* is included as a characteristic as a use case can provide visual feedback by displaying texts and instructions. The degree of *autonomy in interaction* has two characteristics: *open* and *deterministic world*. An *open world* allows user-driven exploration, whereas a *deterministic world* confines users to pre-determined actions and outcomes. The characteristics of the VR dimensions are depicted by Table 1.

Table 1: Definition of the characteristics of the VR dimensions

Dim.	Characteristic	Definition	References
Immersion	Vividness	The degree of representational richness of the VR environment, defined by its formal features, meaning the depth and variety of sensory information the environment presents to the user. This could include high-resolution visuals, multi-sensory input, and full-body motion capture.	(Steuer, 1992)
	Telepresence	The degree to which a user feels present in the VR environment, rather than in their actual physical environment. It is the experience of being in a mediated environment through VR, often resulting in a lack of awareness of the actual physical surroundings.	
3D environment	Abstract environment	A simplified, imaginative scenario with limited objects and abstract representation, transcending the limitations of physical reality.	(Jiawei and Mokmin, 2023; Sherman and Craig, 2019; Sunday et al., 2022a)
	Realistic environment	A complex, real-world-like scenario with diverse interactions, aiming to mimic physical world phenomena.	
Sensory feedback	Visual	This involves the dynamic, real-time visual responses generated in the VR environment in reaction to users’ actions or movements.	(Sorabji, 1971)
	Auditory	Audio responses or sound effects are generated within the VR environment, enhancing the auditory perception of the virtual world.	
	Haptic	Tactile responses or vibrations are generated, typically via handheld controllers, enhancing the sense of touch and physical interaction within the VR environment.	

Dim.	Characteristic	Definition	References
Autonomy in interaction	Open world	It provides users with at least a moderate degree of autonomy. Users have the freedom to explore and interact with the environment at their will, but their actions do not significantly alter the VR environment's overall structure or narrative.	(Steuer, 1992)
	Deterministic world	It offers a lower degree of autonomy. The users' interactions are restricted to predetermined actions, and the outcomes are pre-established.	

4.2 Characteristics of the use Case Dimensions

The first dimension of the concept use case is *trigger*, encompassing three distinct characteristics: *representability*, *practicality*, and *ethical suitability* (definitions in Table 3). The *actors* in the scenarios are *educators*, *learners*, and *VR developers,* described in all use cases. A *learning facilitator* was described by four use cases. The *richness* is *single* or *multiple*. Especially in practical training, like surgical procedures, only one scenario is simulated and practiced. When replicating real-world scenarios, such as virtual laboratory environments, typically multiple scenarios are simulated.

Table 2 shows the definitions of these characteristics.

Table 2: Definition of the characteristics of the use case dimensions

Dim.	Characteristic	Definition	References
Trigger	Representability	Use case's ability to explain and communicate complex educational concepts effectively. The ability is manifested in simplification (simplifying complex ideas), interactive engagement (increasing motivation through game-like interactions), and realistic scenarios (creating immersive, accurate simulations of real-world environments for user interaction).	(Ahram et al., 2021; Bucchiarone, 2022; Dixon et al., 2020; Murphy, 2022; Solmaz et al., 2023)
	Practicability	Use case's ability to provide feasible and efficient educational solutions by transcending traditional limitations of cost, time, location (learners are unbound by geographic and time constraints), and operational constraints (VR overcome physical limitations or constraints of the real world).	(Dixon et al., 2020; Hernández-de-Menéndez, Vallejo Guevara and Morales-Menendez, 2019; Loveridge, 2020; Murphy, 2022)
	Ethical suitability	Use case's ability to uphold and address ethical considerations within educational environments, ensuring a commitment to health and safety, accessibility, and inclusion.	(Alfalah et al., 2019; Bucchiarone, 2022; Dai, Garcia, Olave-Encina, 2023, 2023)
Actors	Educator	Refers to the individual or entity responsible for delivering the educational content and experiences within the VR environment.	(Mikropoulos and Natsis, 2011)
	Learner	Refers to the individual who engages with the VR experience to learn or acquire new knowledge or skills.	
	Learning facilitator	Refers to the individual or entity that assists or guides the learning process within the VR environment.	(Meng and Yeh, 2022)
	VR scenario developer	Refers to the individual or entity that designs and creates the VR environments, experiences, and scenarios for educational purposes.	(Sunday et al., 2022a)
Richness	Single scenario	Refers to a VR use case that involves only one specific, focused educational environment or situation.	(Stella et al., 2023)
	Multiple scenarios	Refers to a VR use case encompassing various educational environments or situations, providing a broader range of experiences or contexts.	(Meng and Yeh, 2022)

4.3 Characteristics of the Education Dimensions

Educational objectives and their characteristics align with Bloom's taxonomy (Anderson and Krathwohl, 2001; Bloom, 1956). *Aimed competencies* are defined as *social-emotional*, *cognitive*, and *psychomotor* (Anderson and Krathwohl, 2001; Harrow, 1972; Krathwohl, Bloom and Masia, 1965). The *autonomy in learning* bases on SDT (Deci and Ryan, 2015) and externally imposed learning processes (Felixbrod and O'Leary, 1973). Finally, *field of study* bases on a German standard (Statistisches Bundesamt (Destatis), 2021). Table 3 provides the definitions of each of these characteristics.

Table 3: Definition of the characteristics of the education dimensions

Dim.	Characteristic	Definition	References
Educational objectives	Remember	The objective to retrieve relevant knowledge from long-term memory.	(Anderson and Krathwohl, 2001)
	Understand	The objective to have learners construct meaning from instructional messages, whether presented orally, written, or graphically.	
	Apply	The objective to use learned procedures effectively to perform exercises or solve problems.	
	Analyse	The objective to break down the material into its constituent parts, understand its interrelations, and grasp the overall structure or purpose of the subject of matter.	
	Evaluate	The objective to make judgments based on specified criteria and standards.	
	Create	The objective to assemble elements to create a coherent and functional whole or to reshape existing elements into new patterns or structures.	
Aimed competencies	Cognitive	Intellectual skills and processes involving thought, understanding, and knowledge utilization. This ranges from simple recall of information to complex tasks such as critical thinking, problem-solving, and the creation of new ideas.	(Anderson and Krathwohl, 2001)
	Psychomotor	Acquisition and refinement of motor skills and physical movement. This ranges from basic physical tasks to more complex, expressive actions that require precision, control, and highly developed motor skills.	(Harrow, 1972)
	Social-emotional	Area of learning involving emotional responses, social interactions, and development of personal values. This ranges from receiving and responding to emotions, to understanding, accepting, and adopting values and attitudes in social contexts.	(Krathwohl, Bloom and Masia, 1965)
Autonomy in learning	Externally imposed	Refers to the learning processes and strategies that are dictated by external authorities or systems, such as standardized tests, or teacher-led instructions.	(Felixbrod and O'Leary, 1973)
	Self-determined	Refers to the learning processes and strategies that are autonomously decided by the learners, based on their individual needs, interests, and goals.	(Deci and Ryan, 2015; Felixbrod and O'Leary, 1973)
Field of study	Humanities (1)	Area of study in which human society and culture are examined, including fields such as languages, literature, philosophy, and history.	(Destatis, 2021)
	Sports (2)	Area of study focusing on physical activities, health, fitness, and sports sciences.	
	Law, economics and social sci. (3)	Area of study focusing on social systems and behaviour, including disciplines such as law, economics, sociology, and political sciences.	
	Mathematics, natural sci. (4)	Area of study that covers disciplines such as mathematics, physics, chemistry, biology, and earth sciences.	
	Human medicine/ health sci. (5)	Area of study focusing on the comprehensive understanding and application of medical knowledge, encompassing general human medicine, health sciences, specialized fields within dentistry.	
	Agricultural, forestry, nutr. sci., veterinary med. (6)	Area of study focusing on agriculture, forestry, nutrition, and animal health.	
	Engineering sci. (7)	Area of study focusing on the application of scientific and mathematical principles to design, maintain, and improve structures, machines, systems, and processes across various specific fields.	
	Art, art sci. (8)	Area of study focusing on the visual and performing arts, art history, and art theory.	

The VR use cases of the 39 studies analyzed can be classified using the dimensions and characteristics of the three concepts described. Notably, two of the eight *field of studies* ((2), (6)) are not covered by the use cases. This indicates either a potential gap in the application of VR in education or in the literature sample studied. The concept matrix (Figure 6) exemplifies the description of the use cases. In the leftmost column the 39 references are listed in abbreviated Harvard style, clustered by application context. Each column on the right side is headlined by a concept discussed. The concepts are arranged hierarchically: 1) theoretical concept (e.g., VR), 2) dimensions (e.g., immersion), 3) characteristics (e.g., vividness).

Vividness/ Telepresence:
H = High,
L = Low.
Fields of study (1-8) are defined in Table 3.

			Virtual reality									Use case							Education											
			Immersion		3D environment		Sensory feedback			Autonomy in interaction		Trigger			Actors		Richness		Educational objectives						Aimed competencies			Autonomy in learning		Field of study
ID	Autor	App.	Vividness	Telepresence	Abstract	Realistic	Visual	Auditory	Haptic	Open World	Deterministic world	Representability	Practicability	Ethical suitability	Educator, Learner, VR scenario developer	Learning facilitator	Single	Multiple	Remember	Understand	Apply	Analyze	Evaluate	Create	Social-emotional	Cognitive	Psychomotor	Externally imposed	Self-determined	
1	(Alfalah et al., 2019)	Complex 3D visualization (e.g., anatomy)	H	L	X		X			X		X		X	X	X		X	X	X						X		X	X	5
2	(Banerjee et al., 2023)		H	H		X	X			X		X		X	X		X		X	X						X		X		5
3	(Stella et al., 2023)		L	H	X		X				X	X			X		X		X	X						X			X	4
4	(Zhu and Du, 2022)		H	H		X	X			X		X	X		X			X		X		X		X		X		X		7
5	(Bucchiarone, 2022)	Immersive conceptual learning (e.g., gamified learning)	H	H		X	X	X		X		X	X		X	X	X				X	X				X	X	X		7
6	(Heinemann et al., 2023)		H	H	X		X			X	X	X	X		X		X				X	X		X		X		X	X	8
7	(Jiawei and Mokmin, 2023)		H	L		X	X	X		X		X	X	X	X		X			X						X			X	8
8	(Sunday et al., 2022a)		H	H	X		X			X		X	X		X			X		X	X					X			X	4
9	Sunday et al., 2022b)		H	H	X		X	X		X		X	X		X			X		X	X					X			X	4
10	(Zhang and Lin, 2021)		H	H		X	X		X	X		X	X		X			X	X	X				X		X	X		X	8
11	(Chan et al., 2021),	Real-world replication (e.g., destinations, virt. laborities)	H	L	X		X	X		X		X	X	X	X		X			X						X			X	8
12	(Dai et al., 2023)		H	H	X		X	X		X	X	X	X	X	X			X				X	X			X			X	8
13	(Hernández-de-Menéndez et al., 2019)		H	H		X	X				X	X		X	X			X		X	X					X	X		X	7
14	(Kumlu and Ozkul, 2021)		H	H		X	X	X		X			X		X			X		X					X	X			X	3
15	(Sharma and Arora, 2022)		H	H		X	X			X		X	X		X			X		X					X	X			X	3
16	(Checa et al., 2021)	Practical skills training (e.g., surgical skills, pilot training, robotic operations)	H	H	X		X	X				X	X		X		X		X	X	X					X			X	7
17	(Gan et al., 2023)		H	H		X	X		X		X		X	X	X		X		X	X	X					X	X	X		5
18	(Hight et al., 2022)		H	H		X	X		X		X	X	X	X	X		X		X	X	X					X	X	X		7
19	(Malpani et al., 2020),		H	H		X	X		X		X		X	X	X		X		X	X	X					X	X	X		5
20	(Neira et al., 2021)		H	H		X	X		X		X		X	X	X		X			X	X					X	X		X	5
21	(Qu and Zhang, 2022)		H	H		X	X				X		X		X		X			X	X					X	X	X		7
22	(Shao et al., 2020),		H	H		X	X				X	X			X		X		X	X	X	X				X	X	X		5
23	(Vassigh et al., 2022),		H	H		X	X		X		X		X	X	X	X	X		X	X	X	X				X	X	X		7
24	(Yu et al., 2022)		H	H		X	X			X			X	X	X	X	X		X	X	X					X	X	X		5

Vividness/Telepresence:
H = High,
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Fields of study (1-8) are defined in Table 3.

			Virtual reality									Use case							Education											
			Immersion		3D environment		Sensory feedback			Autonomy in interaction		Trigger			Actors		Richness		Educational objectives						Aimed competencies			Autonomy in learning		Field of study
ID	Autor	App.	Vividness	Telepresence	Abstract	Realistic	Visual	Auditory	Haptic	Open World	Deterministic world	Representability	Practicability	Ethical suitability	Educator, Learner, VR scenario developer	Learning facilitator	Single	Multiple	Remember	Understand	Apply	Analyze	Evaluate	Create	Social-emotional	Cognitive	Psychomotor	Externally imposed	Self-determined	
25	(Dixon et al., 2020)	Safety training	H	H		X	X	X			X	X		X	X		X			X	X	X				X	X	X		5
26	(Stone et al., 2021)		H	H		X	X	X		X		X		X	X			X		X	X	X			X	X		X		7
27	(Halabi, 2020)	Environment design	H	H		X	X			X			X		X		X			X	X	X		X		X	X		X	7
28	(Solmaz et al., 2023)		H	H		X	X			X			X		X		X			X	X	X		X		X	X		X	7
29	(Han et al., 2021)	Medical examination training	H	H		X	X		X		X		X	X	X		X			X	X	X	X		X	X	X	X		5
30	(Neira-Tovar et al., 2022)		H	H		X	X		X	X			X	X	X			X		X	X	X	X		X	X	X	X		5
31	(Schuelke et al., 2022)		H	H		X	X	X	X		X		X	X	X			X		X	X	X	X			X	X	X		5
32	(Huang et al., 2023)	Language training	H	H		X	X	X		X			X		X			X		X	X	X	X		X	X		X		1
33	(Klimova, 2021)		H	H		X	X	X		X			X		X			X		X	X	X	X		X	X		X		1
34	(Loveridge, 2020)	Team coordination training	H	H		X	X	X		X			X	X	X			X		X	X	X	X	X		X	X		X	8
35	(Murphy, 2022)		H	H		X	X	X			X		X	X	X		X			X	X	X	X			X	X	X		7
36	(Netland and Hines, 2021)		H	H		X	X	X		X			X		X		X			X	X	X	X			X		X		3
37	(Meng and Yeh, 2022),	Social skills training	H	H		X	X	X			X		X	X	X		X			X	X				X	X		X		5
38	(Pandey and Vaughn, 2021)		H	H		X	X	X			X		X	X	X			X		X	X	X			X	X				5
39	(Xu et al., 2021)	Industrial process visualization	H	H		X	X	X	X		X	X	X		X		X			X	X	X				X	X	X		7

Figure 6: Concept matrix

4.4 Characteristics Inductively Derived

The papers analysed contain additional concepts with descriptive power, worth to integrate into the description. Therefore, the goal is to inductively derive further dimensions and characteristics from the studies. In doing so, the correspondence between the description and real-world implementations is increased, as all studies reflect real-world VR use cases (actually implemented). To extract and organize the dimensions and characteristics, an open coding process was performed. During this process, each researcher elaborated on the dimensions and characteristics separately. In subsequent group discussions, consensus was sought within the researcher team, considering the inductive process of labeling the dimensions and characteristics. This approach was chosen to increase the objectivity of the taxonomy development process. The following dimensions are part of the use case descriptions of the studies: *purpose*, *techniques*, *user interaction mode*, *interaction identity*, *interaction mechanisms*, and *environmental interactivity*.

Purpose: This dimension refers to the specific objectives or desired outcomes that guide the use of VR instead of other technical implementations. This dimension corresponds to VR's fundamental capability to provide immersive experiences. *Sensitivity*, as one characteristic of purpose, refers to VR applications aimed at creating deeply immersive experiences through multi-sensory engagement. *Imagination* highlights VR's role in unleashing creativity through the interactive manipulation of virtual spaces. *Interactivity* underscores the emphasis on user engagement within VR environments. Lastly, *exploration* describes the use of VR for experiential learning, allowing users to understand concepts through first-hand virtual experiences.

Techniques: This dimension reflects the array of methods VR is offering; e.g. simulating real-world events, providing immersive visualization, or constructing virtual models of physical environments. The characteristics are *simulation*, *immersive visualization*, and *virtual reconstruction*, reflecting VR's versatile capability to mimic real-world scenarios, present complex structures in a user-friendly, immersive manner, and recreate past or non-existent entities, respectively.

User interaction mode: The dimensions' characteristics are *multiuser* and *single user* scenarios. This underlines VR's versatility in accommodating multiple users interacting within one virtual world simultaneously, as well as individual users immersing in a solo virtual experience.

Interaction identity: This reflects the inherently interactive nature of VR and its ability to connect users with a diverse range of entities, e.g., *virtual objects* or *virtual* and *virtualized actors*.

Interaction mechanism: This dimension outlines the purpose of user interactions, that is *communication*, *cooperation*, or *coordination*.

Environmental interactivity: One of VR's defining features is its capacity to provide environments that users can manipulate at different levels. That can offer experiences such as *object manipulation*, *environment manipulation*, or *no manipulation* at all. Table 4 lists the definitions of the additional characteristics.

Table 4: Definition of the characteristics inductively derived

Dim.	Characteristic	Definition	References
Purpose	Sensitivity	Refers to VR applications that are designed to engage the user's senses, providing a deeply immersive experience. This could include VR experiences that incorporate not only visual and auditory stimuli but also tactile feedback.	(Chan, Bogdanovic, and Kalivarapu, 2021; Zhang and Lin, 2021)
	Imagination	VR applications intended to stimulate the user's creativity to modify real-life spaces.	(Halabi, 2020)
	Interactivity	VR applications intended to emphasize user interaction.	(Klimova, 2021)
	Exploration	VR applications designed for users to learn about different concepts by experiencing them.	(Hernández-de-Menéndez, Vallejo Guevara and Morales-Menendez, 2019)
Techniques	Simulation	A technique where VR is used to replicate real-world environments or situations (e.g., flight simulators for pilots, surgical practice for doctors).	(Gan et al., 2023; Hight et al., 2022)
	Immersive visualization	A technique where VR is used to visualize complex data or structures in a three-dimensional, immersive way (e.g., anatomy, crystal structures, architecture).	(Banerjee et al., 2023; Stella et al., 2023)

Dim.	Characteristic	Definition	References
	Virtual reconstruction	A technique where VR is used to recreate historical sites, or other entities that no longer exist (e.g., archaeology, history).	(Chan, Bogdanovic and Kalivarapu, 2021)
User interaction mode	Multiuser	Multiuser environments enable multiple individuals to enter and interact within a virtual world simultaneously.	(Neira, Castañeda and Torres, 2021; Pandey and Vaughn, 2021)
	Single user	In single-user scenarios, one person immerses themselves in a virtual world without directly interacting with other users.	
Interaction identity	Virtual objects	These are non-anthropomorphic elements in the virtual environment with which users can interact (e.g., tools, environmental features).	(Mikropoulos and Natsis, 2011)
	Virtual actors	These are computer-controlled, anthropomorphic entities in the virtual world that users can interact with.	(Zhang and Lin, 2021)
	Virtualized actors	These are virtual representations of real individuals within the virtual environment.	(Dai, Garcia and Olave-Encina, 2023)
Interaction mechanism	Communication	Refer to the exchange of information between users in the virtual environment, or between users and virtual entities.	(Mikropoulos and Natsis, 2011)
	Cooperation	Refer to users working together to achieve common goals within the virtual environment.	Bucchiarone, 2022)
	Coordination	Refers to managing dependencies between tasks performed by different users or entities within the virtual environment.	(Loveridge, 2020)
Environmental Interactivity	Object manipulation	Refers to the ability of users to interact with and change individual objects within the virtual environment.	(Yu et al., 2022)
	Environment manipulation	Refers to the ability of users to modify the overall virtual environment, not limited to individual objects.	(Checa, Miguel-Alonso and Bustillo, 2021)
	No manipulation	Refers to VR experiences where users cannot change the virtual environment or objects within it, focusing on observation or pre-defined interactions instead.	

The developed dimensions and characteristics are organized clearly in a morphological box (Szopinski, Kundisch and Schoormann, 2020) in Figure 7. This represents a possibility of describing the educational VR use cases.

Meta-Concept	**Dimension**	**Characteristics**								
Virtual reality	Immersion	Vividness	Telepresence							
	3D environment	Abstract environment	Realistic environment							
	Sensory feedback	Visual	Auditory	Haptic						
	Autonomy in interaction	Open world	Deterministic world							
Use Case	Trigger	Representability	Practicability	Ethical suitability						
	Actors	Educator	Learner	Learning facilitator	VR scenario developer					
	Richness	Single scenario	Multiple scenarios							
Education	Learning objectives	Remember	Understand	Apply	Analyze	Evaluate	Create			
	Aimed competencies	Social-emotional	Cognitive	Physical						
	Autonomy in learning	Externally imposed	Self-determined							
	Field of study	Human-ities	Sports	Law, econ. and social sci.	Math., natural sci.	Human medicine/ health sci.	Agric., forestry & nutrition sci., veterinary medicine	Engin-eering sci.	Art, art sci.	
Modalities	Purpose	Sensitivity	Imagination	Interactivity	Exploration					
	Techniques	Simulation	Immersive visualization	Virtual reconstruction						
	User interaction mode	Multiuser	Single user							
	Interaction identity	Virtual objects	Virtual actors	Virtualized actors						
	Interaction mechanisms	Communication	Cooperation	Coordination						
	Environmental interactivity	Object manipulation	Environment manipulation	No manipulation						

Figure 7: Taxonomy to delineate educational VR use cases

5. An Illustrative Demonstration: VR EasySpeech

The presented taxonomy was applied to the real-world use case "training presentations" by VR EasySpeech. The evaluation method of an illustrative scenario helps to indicate the taxonomy's applicability (Szopinski, Schoormann and Kundisch, 2019). VR EasySpeech offers VR scenarios for presentation training simulating a realistic audience (Dashöfer GmbH, 2023). The Baden-Württemberg Cooperative State University (DHBW) in Germany uses this application either as a standalone training tool for students or as an integrated component in courses (*www.dhbw.de*). VR EasySpeech works with the Pico G2 Enterprise VR glasses. The target audience are bachelor students from various higher-semester disciplines who want to improve their presentation skills. The authors of this study are actively engaged in training and testing this application.

Virtual reality. The application presents high-resolution visuals. Hence, the *vividness* is obtained as high. Students have reported that the application supports to lower the fear of public speaking and attribute this to the scenarios' realistic nature. Thus, *telepresence* is assessed as high. Consequently, a high *immersion* is observed. Due to the applications' goal (training in a realistic environment), the *3D environment* is appropriately realistic. *Sensory feedback* is primarily *visual* in line with the practice of speaking and presenting. The *autonomy in interaction* is rather low as the application offers a *deterministic world*, with three practice scenarios predefined: a meeting room, a conference room, and an auditorium.

Use case. The *trigger* of this use case is its *practicability*, as it allows students to improve their presentation skills independently and flexibly. The main *actors* are *educators*, *learners* (students) and *VR scenario developer* (VR EasySpeech developer). Since the use case includes three scenarios, the *richness* is rated as *multiple scenarios*.

Education. VR EasySpeech focuses on the *educational objectives* to both *apply* presentation skills and *evaluate* them through its integrated artificial intelligence (AI)-based assessment. The *aimed competency* is a *social-emotional* one which allows students to increase their confidence in presentation and improve their ability to interact in social contexts. Given the deterministic nature of the use case, the *autonomy in learning* is *externally imposed*, with the learning process strictly guided by the three scenarios and the embedded AI-based assessment. The *field of study* in which the use case was applied at the DHBW, was *engineering*. This was because the training was offered to engineering students.

Modalities. As VR EasySpeech allows interaction with simulated environments, the *purpose* is characterized as *interactivity* and the *technique* is defined as *simulation*. As the use case is designed for a single student practicing a presentation, the *user interaction* is defined as a *single user* interaction. The *interaction identities* are primarily *virtual actors* represented by a virtual audience. The primary *interaction mechanism* is *communication* focusing on exchanging information, either through the presentation itself or through feedback within the virtual environment. Finally, the *environmental interactivity* is defined as *no manipulation*, meaning that neither objects nor the environment can be changed. Figure 8 illustrates the taxonomy application.

Meta-Concept	Dimension	Characteristics		
Virtual reality	Immersion	Vividness (high)	Telepresence (high)	
	3D environment	Realistic environment		
	Sensory feedback	Visual		
	Autonomy in interaction	Deterministic world		
Use Case	Trigger	Practicability		
	Actors	Educator	Learner	VR scenario developer
	Richness	Multiple scenarios		
Education	Learning objectives	Apply	Evaluate	
	Aimed competencies	Social-emotional		
	Autonomy in learning	Externally imposed		
	Field of study	Engineering science		
Modalities	Purpose	Interactivity		
	Techniques	Simulation		
	User interaction mode	Single user		
	Interaction identity	Virtual actors		
	Interaction mechanisms	Communication		
	Environmental interactivity	No manipulation		

Figure 8: Applied taxonomy

This illustrative demonstration shows that the taxonomy is applicable in practice. In doing so, subjective ending conditions are fulfilled (Nickerson, Varshney and Muntermann, 2013): The taxonomy is explanatory because it helps to explain and describe VR use cases in educational contexts. Thus, the taxonomy is concise, as it consists out of four meta-concepts and can therefore be easy applied. Further, the taxonomy is extensible as new dimensions and characteristics can be easily added with the visualization as a morphological box (e.g., based on new findings of VR use cases). It is robust, as it is built up on state-of-the-art and use cases implemented. Finally, the taxonomy is comprehensive as it covers all relevant dimensions and characteristics by following an inductive (E2C) and deductive (C2E) approach (Nickerson, Varshney and Muntermann, 2013).

6. Discussion and Conclusion

The goal of this research is to offer a theory of analysis (Gregor, 2006) that is able to describe and classify VR educational use cases. The nature of the artifact chosen to offer such a theory was that of a taxonomy (Nickerson, Varshney and Muntermann, 2013). This taxonomy includes 17 dimensions and 37 characteristics derived from concepts related to *VR*, *use case*, and *education* in a deductive manner, complemented by modalities inductively derived from implemented VR use cases that are described by literature. The illustrative scenario demonstrates that the taxonomy helps precisely describe VR use cases in education. Use cases can be compared, and using an empirical approach, it may be possible in future research to explore patterns and archetypes of VR use cases in education.

The taxonomy offers both researchers and practitioners a robust tool for understanding, comparing, and discussing different types of VR use cases in education. Additionally, the taxonomy addresses the existing ambiguity around the configurations and applications of VR in education and brings attention to the subtleties and nuances inherent in this rapidly evolving field. For researchers, the taxonomy provides a systematic and consistent way of describing and analysing VR educational use cases. It serves as a foundation for further research, assisting in formulating precise research questions and hypotheses. For practitioners, including educators and curriculum designers, the taxonomy serves as a guide, assisting in the understanding, selecting, and implementing appropriate VR use cases for the specific educational context.

As the taxonomy is based on scientific literature, this work cannot generalize the presented findings without limitations. First, to address sample construction concerns (Larsen et al., 2019), conference proceedings were included in the SLR to mitigate publication bias. Second, the taxonomy covers the findings from the papers analysed. Accordingly, other dimensions and characteristics may predominate in other use cases. For example, the *autonomy in interaction* dimension lacks the constructivist world. While the open and deterministic worlds were evident in the studies, the use cases did not incorporate any constructivist approaches, where users actively shape and manipulate their environment. The inclusion of the constructivist world could reflect the shift towards lifelong learning (Qu and Zhang, 2022). Further, the dimension *sensory feedback* describes the three characteristics: *visual*, *auditory*, and *haptic*. However, this misses the olfactory and gustatory senses (Sorabji, 1971), which are either not yet integrated or not identified in the use cases of the SLR. Moreover, the *interaction identity* dimension, which currently includes *virtual objects*, *virtual* and *virtualized actors*, may need to consider the potential for virtualized objects in the future. These could be real-world objects introduced into the virtual environment using real-time scanning. Furthermore, for a proper application of the taxonomy, the implementation level of VR use cases lacks sufficient study. The analysed studies only sporadically describe how the VR use case was constructed and thus insufficient for inclusion in the actual taxonomy. Some of them mentioned data collection via 360-degree cameras (Dixon et al., 2020) or pre-built models from the Unity Asset Store (Neira, Castañeda and Torres, 2021). 3D software (Halabi, 2020) is described for modeling, and Unity 3D (Sunday et al., 2022b) or Adobe Captivate (Murphy, 2022) are mentioned as development platforms. The specific discussion of these features is currently too diffuse to be included in the current taxonomy and therefore represents an opportunity for future research. Last, as VR technology rapidly evolves, the taxonomy may require regular updates to remain relevant and applicable.

Future research should include the verification and potential expansion of the proposed taxonomy by incorporating a more extensive range of VR use cases in every field of education (Destatis, 2021). Crucially, future research should also evaluate the proposed taxonomy through its practical application to various use cases. Such real-world application and testing would offer insights into its operational efficiency, further validating or indicating necessary adjustments to the taxonomy. Based on the studies analysed, this taxonomy addresses the research gap highlighted by Zhang and Lin (2021) regarding the "(…) lack of in-depth research on the internal structure characteristics (…) of virtual learning." Won et al. (2023) also recommends "(…) identifying the unique characteristics of VR environments". Lastly, the taxonomy is a direct response to Radiantis' (2020) call "proposing a taxonomy of learning theories and other framing factors for educational VR applications is a future research task".

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Virtual Versus Reality: A Look into the Effects of Discussion Platforms on Speaking Course Achievements in *Gather.town*

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https://doi.org/10.34190/ejel.21.6.3276

Abstract: The fusion of education with the digital world is still a developing and crucial phenomenon, especially in light of the growth of metaverse applications and the lingering effects of pandemic-induced educational changes. Learning about the efficacy of platforms like Gather.town becomes increasingly important in this situation. This study explores the changing educational environment, focusing on the widely used technique of small group discussions. Our main goal is to compare the effects of such group discussions in real classrooms against the online setting made possible by websites like Gather.town, especially regarding academic performance. We assessed two separate groups of students using a highly controlled experimental method. One group engaged in traditional, face-to-face small group discussions, while the other participated in discussions within the virtual realm of Gather.town. Our research produced notable results, showing a significant difference in academic achievement between the two modes of interaction. Unexpectedly, the online environment displayed higher standards of academic success. These findings highlight the potential effectiveness of digital platforms in educational initiatives. While conventional, face-to-face dialogues still have significance, incorporating digital technologies could result in equal or better educational outcomes. In essence, this research offers insightful viewpoints to the continuing discussion concerning hybridized learning strategies in the modern educational environment. By highlighting the part played by digital platforms in influencing pedagogical practices, it highlights the potential for such approaches to benefit the future of education.

Keywords: Metaverse applications, Small group discussions, Academic achievement, Gather.town, Online education, Blended learning

1. Introduction

The COVID-19 epidemic has accelerated online and remote learning adoption, raising the possibility of utilizing virtual reality and metaverse capabilities in learning environments. Since the COVID-19 limitations, distance and online learning have become crucial tertiary education components. The metaverse offers virtual venues for student participation and learning, possibly offering special advantages above conventional online or face-to-face education techniques, as demonstrated by platforms like Gather.town. Recent years have seen a significant increase in academic participation in online and remote learning, especially due to COVID-19 constraints. Studies on traditional classroom settings and the discourses around traditional instruction, including teaching materials and teaching strategies, have been conducted in this study's context (e.g., Alghazo, 2015; Rayyan et al. 2023; Zidan, Alghazo & Clymer, 2018; Zidan & Alghazo, 2019; Alghazo & Zidan, 2019; Clymer et al., 2020; Alghazo, Jarrah & Al Salem, 2023; Abusalim, 2020). Little research has contrasted traditional classroom settings, hybrid teaching strategies, and fully online modes, highlighting various aspects of effective teaching. At the same time, academic attention has turned to the positive impact that small group discussions have on students' progress (Van Blankenstein et al., 2013). However, studies on the use of metaverse tools in education and their potential benefits on student performance are noticeably lacking. As López-Belmonte et al. (2023) argue, "[d]ue to its short history, the potential of the metaverse in education is yet to be explored" (p. 1). The current study aims to close this knowledge gap by examining the effects of small group discussions in tertiary education while contrasting traditional settings with Gather.town's online setting. The study specifically examines student academic performance in a German as a second language speaking course to identify any variations dependent on the discussion platform. This investigation aims to shed more light on the evolving educational landscape while highlighting the potential value of metaverse platforms like Gather.town in boosting learning opportunities.

Cite this article: Rayyan, M. et al., et al. 2023. "Virtual Versus Reality: A Look into the Effects of Discussion Platforms on Speaking Course Achievements in Gather.town", *The Electronic Journal of e-Learning*, 22(3) pp 63-73, https://doi.org/10.34190/ejel.21.6.3276

1.1 Gather.town

A revolutionary online platform called Gather.town simulates physical locations so that users can participate in virtual discussions and activities that closely resemble real-life interactions. Language teachers can use this platform to develop immersive language learning experiences that encourage participation and in-context language use (Zhao & McClure, 2022). It provides gamified elements and avatars that improve interaction and participation in online learning groups, making it an important tool for language teachers.

A study by Latulipe and De Jaeger (2022) comparing synchronous computer science lectures in Zoom and Gather.town found that, due to its encouragement of peer socialization, agency, and interesting interactions, students favored Gather.town. This preference highlights how it can foster group learning and student involvement. Gather.town's game-like setting and user-friendly features showed promise for boosting engagement in higher education and developing engaging virtual classrooms, according to Sriworapong et al.'s (2022) usability research.

To enhance the learning of nursing staff, Chen, Ngu, and Hou (2022) included Gather.town into the instructional game "Emergency Room." According to preliminary studies, this method improved learning efficiency, highlighting Gather.town's potential for real-world teaching. McClure and Williams (2021) highlighted Gather.town's function in self-paced learning in distance education, emphasizing how it provides exceptional possibilities to participate, personalize their learning, and forge relationships in a virtual environment.

Gather.town's game-like concept, which mimics real classroom situations and provides a useful substitute for online language learning, was emphasized by Fitria's study in 2021. When Lee et al. (2023) evaluated how students perceived teamwork on Zoom and Gather.town, they found that students preferred Gather.town because of its characteristics for social interaction, mobility, and sense of presence. Lastly, Tang, Pang, and Fung (2022) introduced Gather.town as a learning space for a laboratory module, addressing "Zoom Fatigue" and student demotivation. Their study gave preliminary results while highlighting Gather.town's potential in academic settings.

The conclusion is that, taken together, the research under examination shows that Gather.town's distinctive gamified features and immersive surroundings have enormous potential to improve engagement, collaboration, and learning in various educational contexts. These results highlight the potential of metaverse tools like Gather.town to influence the direction of online education and cooperation.

1.2 Aims of the Study

This study compares the academic results of small group discussions in conventional face-to-face settings and those on digital platforms. This study aims to pinpoint any notable variations in the efficacy of small group discussions conducted on digital platforms like Gather.town versus those conducted in actual classrooms with regard to students' academic achievements. The following research question will be addressed in order to accomplish this goal:

In what manner does the modality of small group discussion (either in a physical classroom or online through Gather.town) influence student academic outcomes?

An evaluation of the academic results of students participating in small group discussions in conventional classrooms versus those using Gather.town for comparable interactions will be done as part of a comparative study to answer this question. This study aims to add to the body of knowledge on the use of online learning tools in educational settings by exploring this research question and highlighting the potential psychological effects of these tools on student academic performance.

1.3 Significance of the Study

Our investigation takes on a contemporary dimension thanks to the introduction of Gather.town as a tool for leading group discussions. This study will pave the way for future research in this area. Prior to our investigation, it was clear that there had been a noticeable shift toward digital teaching tools, particularly as a result of the COVID-19 crisis. During the pandemic, as Reich et al. (2020) noted, there was a pressing increase in the adoption of these digital tools, underscoring the significance of understanding their efficacy. In their guide on quick transition, Hodges et al. (2020) noted that while many institutions swiftly switched to online modalities, the pedagogical impact is still under investigation. Despite this development, empirical comparisons of cutting-edge digital strategies with tried-and-true face-to-face methods are still in their infancy. Bao (2020) has also shed light on the challenges and opportunities brought about by the quick shift to digital learning, suggesting that while platforms like Gather.town hold promise, thorough research is essential to understand their complex dynamics.

2. Literature Review

2.1 Do Small Group Discussions Enhance Student Academic Achievement?

Studies in pedagogy have focused on the extent to which small group discussions affect students' academic outcomes. According to Springer, Stanne, and Donovan (1999), students who participate in these small groups usually gain a deeper understanding of the subject matter. Springer, Stanne, and Donovan (1999) found that learning in such groups not only noticeably improves academic outcomes but also student attitudes and content retention, supporting this viewpoint. Webb and Palincsar (1996) emphasize the value of collaborative learning by highlighting the role that peer engagement plays in enhancing comprehension and analytical skills. According to Cohen (1994), activities centered on group interactions lead to better academic outcomes and strengthen the sense of community among students. Kagan (1994) emphasizes the importance of structured small-group instruction, arguing that cooperative teaching strategies, in particular, are remarkably effective in increasing student achievement. In a related vein, Lou, Abrami, & d'Apollonia (2001) presented data suggesting that team-centric environments frequently outperform solo tasks in educational contexts regarding individual achievement.

2.2 A Comparison of Academic Achievement: Online vs. Face-to-Face Learning

Comparing traditional face-to-face learning with online learning in terms of academic achievement has received much attention in the field of educational research. After conducting a thorough investigation, Bernard et al. (2004) concluded that while there were differences in some factors, students' academic achievements were statistically comparable in online and traditional classroom settings. This viewpoint was supported by Means, Toyama, Murphy, Bakia, and Jones's (2009) meta-analysis, which found that students in online environments performed marginally better than those receiving direct face-to-face instruction. Allen and Seaman (2013) add to this argument when they claim that the prevalence of online education not only continues but frequently produces results that are on par with or even better than those of conventional teaching techniques.

On the other hand, despite the rapid expansion of online education, Parsad and Lewis (2008) highlight the ongoing challenge institutions face in maintaining the quality of their virtual courses. The authors Cavanaugh, Gillan, Kromrey, Hess, and Blomeyer (2004) suggested that the results of digital education might be comparable to or superior to those of traditional learning environments. While advantageous, the flexibility offered by online modules is not without its drawbacks. According to Jaggars and Bailey (2010), many students struggle with issues related to self-discipline and sustained motivation when learning digitally. On the basis of this account, Bowen, Chingos, Lack, and Nygren (2014) noted that while e-learning increases accessibility and flexibility, upholding student engagement and commitment is still a significant challenge in this paradigm of education.

The effects of incorporating mobile augmented reality learning media with a metaverse application on students' academic outcomes in Science classes were examined by Marini et al. in a separate study (2022). Seventy-five fifth-graders from Cluster I, Depok Subdistrict elementary schools participated in the study. Marini and colleagues discovered that using a metaverse app had a favorable impact on students' learning outcomes through pretest and post-test assessments. The students demonstrated greater engagement with the material, enhanced understanding, increased knowledge acquisition, and greater enjoyment in the learning process. This study highlights how augmented reality and metaverse applications can improve science education and produce more enjoyable learning environments.

2.3 Comparing Online Small Group Discussions and Face-to-Face Small Group Discussions

The choice between online and face-to-face formats for small group dialogues has attracted significant research interest in the context of student academic outcomes in the dynamically changing educational domain. In their investigation into the nuances of online discussions, Rourke and Anderson (2002) contrasted peer-led small groups with more traditional tutor-led discussions. Their research concluded that variables like moderator style and the interactive capabilities of platforms significantly influence the breadth and depth of dialogues, which in turn influences how well students understand the content.

Strijbos et al. (2006) highlighted the obvious differences in content quality and interactivity dynamics compared to face-to-face exchanges in their meticulous analysis of online dialogue content. They proposed that the mode of communication could influence both the profundity and the character of discussions.

Hrastinski (2008) examined the differences between synchronous and asynchronous e-learning interactions, delving deeply into online learning modalities. The research showed that while interactions with a temporal gap might give learners an extended reflection window, which could affect their academic success, real-time virtual dialogues may imitate the spontaneity inherent to face-to-face exchanges.

Hammick et al.'s (2007) evaluation of inter-professional education examined various pedagogical interactions and compared face-to-face and virtual dialogues. Even though their focus was on a broader range of educational outcomes, a recurring theme highlighted the influence of interaction mediums on academic outcomes, emphasizing the need for well-considered pedagogical strategies in both situations.

Numerous studies that examine how different techniques for facilitating small group dialogues affect academic success serve as a counterpoint to the growing scholarly focus on evaluating their efficacy.

Means et al. (2009) conducted a thorough meta-analysis to compare the academic outcomes of students who participated in online learning to those of students who attended traditional classroom settings. Their findings suggested that virtual learning environments gave students a slight performance advantage over direct, face-to-face instruction. Interestingly, hybrid learning environments, where digital discussions supplemented traditional instruction, were primarily responsible for the edge. This collection emphasizes that group dialogue's inherent characteristics can modulate academic outcomes when combined with various pedagogical strategies.

Dziuban et al. (2015) looked into the implications of online learning for student satisfaction, a factor that is loosely related to academic performance. Examining the psychological connection between students and teachers in a virtual environment, the research found that satisfaction levels—known as a sign of a student's commitment to their studies—were influenced by the standard and structure of online group interactions.

In essence, these academic pursuits highlight the complex relationship between small group discussions and academic achievement, highlighting the potential advantages of online discussions, particularly when incorporated into a comprehensive learning paradigm.

2.4 What is the Best Size of Groups in Small Group Discussions to Enhance Academic Achievement?

In order to maximize academic results, determining the ideal group size for small group discussions has consistently attracted attention in pedagogical studies. Although there is widespread agreement on particular ideal group sizes, most current research suggests a range of 2 to 10 participants. For instance, Lou, Abrami & d'Apollonia (2001) advocate for groups of 4-6 people. They stress that adding this element increases participation and fosters various viewpoints. This viewpoint is shared by Barkley, Cross, and Major (2014), who also warn about overly large groups. They draw attention to the danger of "social loafing" in larger gatherings, where some attendees may depend on others to carry the burden of participation and input.

However, the relationship between group size and academic results goes beyond simple math. Slavin (1996) emphasizes the idea that sometimes the collaborative nature of the task may eclipse the group's raw numerical strength. He does not, however, downplay the difficulties of handling larger groups of people. An in-depth analysis of this dynamic is provided by Webb (1991), who contends that group size and task complexity interact in a complex manner. According to Webb's analysis, while complex tasks may benefit from the varied viewpoints of a larger group, simple tasks frequently succeed in smaller groups.

In light of this body of research and to maximize academic outcomes in our study, we have purposefully decided to divide participants into groups of four to ensure compliance with the accepted standards established by existing literature.

2.5 Interim Summary

Modern research strongly emphasises the value of small group discussions in education, both offline and online. It emphasizes the complex nature of learning environments, student involvement, and the delicate balance between technology and instructor guidance, even though there is no definitive opinion on their efficacy. Online communities like Gather.town, which blend elements of real-world and virtual interactions, bring fresh viewpoints to this subject. Critical factors include task nature, instructor role, and course design. For instance, well-structured online discussions with pertinent questions can be as effective as face-to-face discussions. However, without organization, any discussion could be superficial. Interactions are impacted by technology. In contrast to synchronous platforms like Gather.town, asynchronous ones enable deeper Gather.town to strive for real-time participation. Although the growth of metaverse applications in education is exciting, understanding their full potential and difficulties requires careful research. New avenues for student engagement develop as educational practices advance with technology. The educational community must continuously research and improve these techniques for the best learning results.

3. Methodology

Participants were split into the experimental group (4 groups of 4 students, total=16) and the control group (4 groups of 4 students, total=16) according to the research's quasi-experimental methodology. The experimental group participated in group discussions using the online platform Gather.town, which offered a distinctive and interesting virtual environment for collaborative learning. Conversely, the control group participated in customary face-to-face group discussions in a classroom setting.

3.1 Participants

The study involved 32 committed undergraduate students from the University of Jordan's second-year German Speaking course. These 32 participants were divided into two sets of 16, ensuring equity and fair representation. On the Gather.town platform, experimental group members participated in online group discussions. The control group, however, participated in customary classroom discussions. With this deliberate division, we hoped to contrast traditional classroom discussions with the online discussions Gather.town facilitated. With this impartial approach, we intended to carefully examine the differences and unique effects between these discussion techniques in relation to academic accomplishments.

3.2 Course Design Overview

The German-speaking course offered by the University of Jordan's Faculty of Foreign Languages is carefully designed to improve students' linguistic journeys. Its main objective is to develop students' speaking abilities and their ability to have natural discussions in German. The curriculum strongly emphasises active student participation in dialogue exercises that simulate real-world situations and situations that might arise in daily life. This course's incorporation of in-depth role-playing exercises sets it apart from others. Students take on different personas for these assignments; for instance, some might play airline agents while others take on the roles of passengers attempting to make German flight reservations. The course also incorporates a variety of interactive platforms, such as those that simulate settings like a movie theater, bakery, or post office. Students use these platforms in a rotating fashion to ensure that everyone has interactions in which they are both a provider and a seeker. With the help of this instructional approach, students can improve their conversational skills, comprehend nuanced cultural differences, and hone their ability to take part in genuine discussions in German.

3.3 Research Design

The participants in this study were divided into the experimental and control groups using a quasi-experimental methodology. The main goal of the study was to identify any appreciable differences in academic performance between students who participated in classroom discussions in person and those who used the online discussion platform Gather.town.

3.4 Procedures

Throughout the semester, both groups took part in small group discussions. The experimental group conducted their discussions in Gather.town's digital environments, while the control group did so in a conventional classroom. The same instructor taught the course and featured the same small group discussion activities and scenarios to ensure consistency and similar external variables. To ensure students did not veer off topic, the instructor closely watched the Gather.town and face-to-face participants.

3.5 Data Analysis

The main goal of this study was to identify notable differences in academic performance between the two groups. We conducted statistical analyses using techniques like figuring out means and standard deviations. These methods played a key role in the data analysis and provided crucial insight into the effects of various teaching philosophies on student performance.

4. Results

This section presents the results to illuminate the impact of small group discussion facilitation on academic success, whether in a physical classroom or online using Gather.town.

4.1 Impact of Small Group Discussions on Academic Achievement

This section of the results carefully compares the effects of small group discussions, whether they are conducted face-to-face or through online tools like Gather.town, to those of traditional in-class instructional techniques. The principal inquiry driving this section is:

Is there a statistically significant difference, at the α=0.05 level, between the mean scores of the control and experimental groups in academic achievement attributed to the teaching method used?

Before delving into the outcomes, it's essential to revisit the research methods employed. Our conclusions were drawn from the computed average scores and standard deviations related to academic achievement for both groups. Within this study's context, academic achievement is defined as an aggregate of scores derived from class participation, assessments, and project results. To identify disparities in academic performance between the two groups, we utilized the Independent Samples Test (t-test).

4.1.1 Detailed findings

Table (1) clearly indicates a substantial difference in academic achievement scores between the two studied modalities. The traditional method yielded a mean score of 67.94, with a standard deviation of 9.85. In contrast, the group discussion method showed a more promising mean score of 79.13, with a slightly increased standard deviation of 10.70.

Table 1: Mean, Standard Deviations, and t-test (Independent Samples Test) for the academic achievement scores of the study's two groups.

Teaching Method	no	Mean	Std	t	df	Sig
Traditional	17	67.94	9.85	-3.127	31	0.004*
Group Discussions	16	79.13	10.70			

*. The mean difference is significant at the 0.05 level.

The t-value of -3.127, significant at a level of 0.004, further cements the disparities in academic outcomes between the groups.

4.1.2 Effect size

To comprehend the practical significance of our findings, it's essential to consider the effect size, using the eta squared (η^2) measure. This metric gives context to the observed differences and assists in understanding the real-world implications of our results. Using the equation:

$$\eta^2 = \frac{t^2}{t^2 + df}$$

η^2-Eta Squared (Effect size)

t - T. TEST

df - degrees of freedom

we obtained an eta squared value of 0.24. This illustrates that 24% of the variance in academic achievement scores is due to the teaching modality, with the rest being influenced by other external factors.

4.1.3 Implications of the findings

The distinct variation in academic results between the two pedagogical approaches indicates the pronounced influence of small group discussions, especially when conducted via digital platforms like Gather.town, on academic success. The noticeable increase in the mean score from 67.94 in the face-to-face small group discussions method to 79.13 in the Gather.town small group discussions emphasizes the effectiveness of this approach. Even though the statistical difference is clear, it's important to consider how these findings might apply in actual life. A larger standard deviation in the group discussion approach might indicate a wider range of student performance, necessitating further research. In conclusion, the results of this study highlight the benefits of online small-group discussions over traditional teaching strategies in terms of academic success. While keeping in mind the potential for variability in results, educators and academic institutions may see the emergence of digital platforms that support group dialogues as a valuable tool for improving student performance.

4.2 Analysis of the Predictive Power of Academic Achievement on Cumulative GPA

The secondary research query, pivotal to our analysis, aimed to determine the predictive capacity of students' academic achievement in relation to their cumulative GPA. In light of the growing emphasis on academic indicators in the realm of education, discerning this predictive linkage holds great significance for educators, academic institutions, and policy framers.

4.2.1 Methodological approach

To shed light on this relationship, we utilized a Simple Linear Regression analysis. This statistical method is instrumental in determining how much one variable (in this context, academic achievement) can serve as a predictor for another variable (cumulative GPA).

4.2.2 Interpretation

Table 2 provides valuable insights into our analysis. First, it underscores the significance of our regression model. The F-value, specifically 40.784, along with an associated significance level of 0.000, reaffirms the statistical soundness and substantial predictive capacity of our model concerning students' cumulative GPA based on their academic performance.

Table 2: Results of the Simple Linear Regression Analysis

Predictor Variable	B	Std. Error	F	Sig.	Beta	t	Sig.	Adjusted R Square
Constant	0.347	0.399	40.784	0.000*		0.869	0.391	
Academic Achievement	0.034	0.005			0.754	6.386	0.000*	0.554

*. is significant at the 0.05 level.

Furthermore, the R^2 value, measuring at 0.554, carries significant implications. This figure suggests that academic achievement, serving as the solitary predictor, elucidates a noteworthy 55.4% of the variability in students' cumulative GPAs. This finding is pivotal for educators, signifying that while academic achievement has substantial influence, other factors, constituting the remaining 44.6%, are also in play and warrant further investigation.

Of equal importance is the beta coefficient, which stands at 0.754 and demonstrates statistical significance with a t-value of 6.386 (p<0.000). This coefficient is central as it indicates that for every one-unit increase in academic achievement, there is a corresponding increase of 0.754 units in cumulative GPA. In simpler terms, this confirms a robust, positive association between these two variables, suggesting that interventions or strategies aimed at improving academic achievement can lead to marked enhancements in cumulative GPA.

In conclusion, the results of our linear regression model support the critical importance of academic achievement in predicting cumulative GPA. While there is no denying that academic performance has a significant impact, it is crucial that educators and institutions recognize that there are other factors that also play a role. These findings highlight the need for an all-encompassing educational strategy where academic success is just one element of a multifaceted approach supporting students' success.

5. Discussion

Modern educational frameworks are thoroughly examined in the investigation of the effectiveness of instructional approaches and modes, with a focus on contrasting small group discussions in both physical and virtual settings. The results of this study provide a rich basis for discussion, particularly when compared to earlier studies.

5.1 Influence of Mode of Small Group Discussions on Academic Achievement

The findings of this study support the potential effectiveness of online communities like Gather.town, particularly in facilitating small group discussions. Particularly when compared to conventional face-to-face discussions, Gather.town was observed to elicit higher academic performance. This result is consistent with Kemp and Grieve's (2014) findings, which claimed that online and in-person activities produced comparable results in terms of academic performance. Our findings, however, diverge in terms of engagement. Our study suggests that digital platforms can be just as engaging, if not more so, than face-to-face interactions, which contradicts Kemp and Grieve's (2014) finding that students felt more engaged in face-to-face discussions.

In his study, Freiermuth (2001), found that online platforms' anonymity, which can lower inhibition, was especially helpful. This observation supports our findings and raises the possibility that some students may find comfort in online environments, enhancing their academic performance. The higher levels of engagement seen in our study when compared to Kemp and Grieve (2014) may also be explained by the feeling of comfort in an online environment.

Our study's findings are also supported by the flexibility that online platforms provide. Students in flexible learning environments, such as blended learning and flipped classrooms, demonstrated better learning performance, as mentioned in the study by Thai, De Wever & Valcke (2020). According to Kemp and Grieve (2014), the flexibility and convenience of digital platforms may be a factor in the increased academic success seen in Gather.town.

However, not all online discussions ensure enhanced educational results. Choi, Land & Turgeon (2005) note that even though there were more inquiries in online discussions, the level of discussion remained unaffected. This implies that while online discussion forums can promote participation, educators must ensure the caliber of the discussions.

Bliuc, et al. (2010) noted the correlation between students' conceptions of learning, their approach, and academic outcomes in both online and face-to-face discussions while taking student approaches into consideration. In order to make the best use of tools like Gather.town, educators should be aware of students' conceptions of learning, according to our findings and those of this study.

The effectiveness of online collaborative learning (OCL) is a recurring theme in the studies. Positive correlations between different aspects of OCL were discovered by Ng, Chan & Lit in 2022, supporting our findings about Gather.town's effectiveness. Similarly to this, Guo, et al. (2022) highlight the potential benefits of combining traditional and digital pedagogies by highlighting the advantages of blended learning approaches.

However, despite the potential of digital platforms that our study and others point out, problems still exist. The challenges highlighted by Nungu, Mukama & Nsabayezu (2023) included poor internet connectivity and a lack of ICT expertise. While imagining a future where education is more digitally integrated, it is crucial to understand these limitations.

In conclusion, it's important to integrate digital tools thoughtfully even though they offer the future of education promising prospects like Gather.town. Our attention should continue to be on upholding the standard of discussions, comprehending students' conceptions of learning, and addressing the difficulties associated with using online platforms as we continue to combine traditional and digital learning environments.

5.2 Predictive Potential of Academic Achievement on Cumulative GPA

Our findings confirm that academic performance accurately predicts cumulative GPA. The observed 55.4% difference in cumulative GPA attributable to academic achievement says a lot about how they are related. This correlation is in line with Crede and Kuncel's (2008) findings, which showed a consistent pattern in student outcomes across various academic evaluations. Our findings are consistent with those of Robbins et al. (2004), who proposed that academic performance metrics, such as GPA, can serve as strong indicators of university outcomes. In a related vein, Halasa et al. (2020) documented that a variety of teaching strategies—ranging from conventional to blended and flipped modalities—yielded varying effects on student success, emphasizing the challenges in drawing comparisons between teaching strategies and outcomes like GPA. However, Richardson, Abraham, and Bond (2012) took a slightly different tack and found that while academic performance did predict GPA, other factors like study habits and competencies also had an impact, pointing to a more complex interrelation.

However, the strength of the association found in our study (Beta = 0.754) appears to be greater than that found in some earlier studies. Although the relationship between academic achievement and cumulative GPA has frequently come up, the strong influence seen in our study is particularly noteworthy and demands more in-depth investigation.

5.3 Implications and Avenues for Further Exploration

While our study clearly shows the benefits of small group discussions, it also highlights a number of questions and potential obstacles. The noticeable effect underlines the fact that, even though teaching strategies are important, other outside factors also play a critical role in shaping academic results.

In the past, factors like socioeconomic status, innate test-taking skills, and personal motivation have been investigated as potential predictors of academic outcomes (Webb, Troper, & Fall, 1995; Prince, 2004). The significant influence of socioeconomic circumstances on academic performance and involvement was clarified by Sirin (2005). In addition, Wigfield and Eccles (2000) looked at motivation, making the argument that a student's self-perception of their own abilities can have a significant impact on their academic performance. The significance of understanding academic success as a complex construct influenced by a wide range of factors is highlighted by this study.

Additionally, the emerging field of digital education offers a double-edged sword, as demonstrated by tools like Gather.town. Reich et al. (2020) identified the COVID-19 crisis as a particularly compelling reason to understand the efficacy of such online mediums. While these digital tools promise to make education more accessible, they also necessitate scrutiny of their effectiveness in comparison to traditional methods—a topic our study starts to look into.

In essence, this study highlights the expanded significance of small group discussions in academic settings and offers a sneak preview of the rapidly developing field of online learning tools. While some of our findings are consistent with previous research, others differ, particularly in terms of the degree of effect, emphasizing the complexity of the factors influencing academic success.

5.4 Limitations

There are limitations to this research. The investigation's initial focus on a single course may limit the conclusions' potential for broader application. The extrapolation of these findings to other online platforms may also be constrained due to the platform's exclusive exploration. Additionally, the small number of participants may have an impact on how robust the statistical results are. As a result, it is wise to proceed cautiously when interpreting the results of this study. It emphasizes the need for more thorough research to support and expand on the current findings.

6. Conclusion

Our main goal was to determine how small group discourse, whether it was conducted in a traditional classroom setting or online using Gather.town, would affect students' academic results. Surprisingly, the results showed that Gather.town, an online platform, has a distinct advantage over conventional face-to-face settings in encouraging higher academic achievement. Such an unexpected result casts doubt on widely held beliefs and signals a paradigm shift in how educators may view and use digital tools.

The investigation of our research question also lays the groundwork for more extensive academic ramifications. While this study specifically tracked performance within Gather.town discussions, it raises the possibility of connections between short-term academic results and longer-term metrics like aggregate GPAs in tertiary education. It raises the possibility of an alignment or correlation that calls for additional, in-depth investigation.

These results highlight the changing dynamics of contemporary education and are based on the context of our research question. They highlight the need for tertiary institutions to review and possibly recalibrate their approach to pedagogy as well as the robust potential of platforms like Gather.town. The evidence provided here could act as a catalyst for educators to rethink traditional teaching strategies, weighing the real advantages of online learning environments against established norms.

In conclusion, these findings will influence the course of pedagogical evolution as the pace of digital integration in education quickens. The focus right now is on utilizing these insights to create a learning environment that is effective, inclusive, and optimized for all students.

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Inclusive Virtual Reality Learning: Review and 'Best-Fit' Framework for Universal Learning

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https://doi.org/10.34190/ejel.21.6.3265

Abstract: The rise of Virtual Reality (VR) in educational contexts has highlighted the need to design Virtual Reality Learning Applications (VRLAs) that prioritize inclusivity, accommodating a spectrum of learner needs. Despite the surging interest, there is a noticeable gap in research that delves into the specifics of creating VRLAs that are rooted in inclusive educational theory. This research sought to extract insights and recommendations for the development of VRLAs tailored for diverse student populations. The intention was to scrutinize research focused on the inclusive design elements of VRLAs, leading to the establishment of preliminary Inclusion Guidelines for VR Learning (IGVRL). Adopting the "best-fit" framework synthesis technique, the research anchored its findings in the Universal Design for Learning (UDL) framework. UDL was developed to mold learning experiences to meet the requirements of heterogenous learners. Using UDL as a coding framework, a comprehensive literature review was undertaken, adhering to the SPIDER search strategy. The review of literature revealed distinct design recommendations that facilitate inclusive learning within VRLAs. Information was systematically categorized based on UDL's nine classifications and subsequently distilled into the preliminary IGVRL. It's pertinent to note that these guidelines, while offering a foundational perspective, necessitate further in-depth evaluations for validation. The analytical process brought to the fore several themes that UDL did not adequately encompass, such as the nuances of embodied learning, the focus on VR contents and their immersive properties, and the pivotal role of collaboration and cooperation in VRLAs. These insights underscore the further need for research in these areas. Although some facets of VR accessibility were discussed, a deeper exploration into this domain was identified as crucial, reiterating the importance of accessibility in underpinning inclusive education. The research underscores the potential of VRLAs in promoting inclusivity within educational settings and introduces the preliminary IGVRL for VRLA design, specifically targeting K-12 contexts. This paper emphasizes the continuum of research required to refine and validate these guidelines, ensuring their applicability and efficacy in diverse educational scenarios.

Keywords: Inclusion, Virtual reality, Development, Guidelines, Design, UDL

1. Introduction

In recent years, the advancement of Virtual Reality (VR) technology has generated increased interest in its potential applications within education (Kasperiuniene and Faiella, 2023; Sulistyaningrum et al., 2022). However, many studies overlook the specifics of designing Virtual Reality Learning Applications (VRLAs), focusing instead on the overall effectiveness of VR (Hamilton et al., 2021).

VR, as defined by Dörner et al., 2019, entails computer-generated, three-dimensional environments that provide users with an immersive experience in an alternate reality. This is facilitated by technologies such as Head-Mounted Displays (HMDs) and tracking systems. Such immersion permits users to interact within the virtual environment, offering potential enhancements in the utilization of media in classrooms and increasing accessibility for a range of learners (Chen and Chen, 2022; Chang et al., 2023; Roberts-Yates and Silvera-Tawil, 2019; Williams et al., 2022).

Yet, the incorporation of VR in educational settings raises ethical and practical challenges, particularly regarding the potential exclusion of certain learners (Buzio, Chiesa, and Toppan, 2017; Schäfer et al., 2023; Zender et al., 2022). Addressing these issues necessitates that VRLA development be grounded in educational theory, with a specific focus on inclusive education, as this paper intends to discuss.

Inclusion can be viewed in two ways: a "narrow" interpretation focused on special education and a "broader" perspective that considers multiple forms of inequality (Rödel and Simon, 2022a). This paper follows the broader interpretation, identifying inclusion as a continuous process that ensures equal participation by removing barriers and promoting accessibility. This perspective emphasizes collaborative learning for all students, regardless of their backgrounds and abilities (Rödel and Simon, 2022b).

2. Research Objectives

Cite this article: Wehrmann, F. and Zender, R., et al. 2023." Inclusive Virtual Reality Learning: Review and 'Best-Fit' Framework for Universal Learning", *The Electronic Journal of e-Learning*, 22(3) pp 74-89, https://doi.org/10.34190/ejel.21.6.3265

To support the inclusive application of VR in schools, it's essential to understand how VRLAs can cater to a diverse student body. This paper's objective is to provide insights and recommendations for designing VRLAs that meet the needs of a wide range of learners. This will be accomplished by analyzing research related to the inclusive design elements of VRLAs and formulating the preliminary Inclusion Guidelines for VR Learning (IGVRL) for developers and researchers. The central research question guiding this review is: How can VRLAs be effectively designed to accommodate the diverse learning styles and needs of students in order to facilitate inclusive education in schools?

3. Method

To incorporate diverse knowledge sources, including qualitative research, quantitative data, and grounded theory, the "best-fit" framework synthesis technique, developed by Carroll, Booth, and Cooper in 2011 and refined by Carroll et al. in 2013, was employed.

This method requires researchers to apply a predefined theoretical framework to literature review findings. The "best-fit" approach suggests using an existing framework or synthesizing multiple frameworks. In this study, the Universal Design for Learning (UDL) framework (CAST, 2018) was selected. Framework synthesis is effective for formulating guidelines for inclusive VRLAs, allowing the alignment of specific settings (e.g., VRLAs for K-12) with a fitting framework (e.g., inclusive education). Hence, it is frequently employed in guideline development (Flemming et al., 2019) and facilitates the merging of theory and practical findings (Booth and Carroll, 2015).

However, it's acknowledged that the "best-fit" approach's frameworks are not flawless (Cooke, Smith, and Booth, 2012). After aligning evidence with the predetermined framework, any unrepresented findings will be incorporated by adding new themes backed by evidence. The "best-fit" method is apt for this study as adopting a related framework aids in interpreting intricate data within a defined context (Brunton, Oliver, and Thomas, 2020). The steps of this method are illustrated in figure 1.

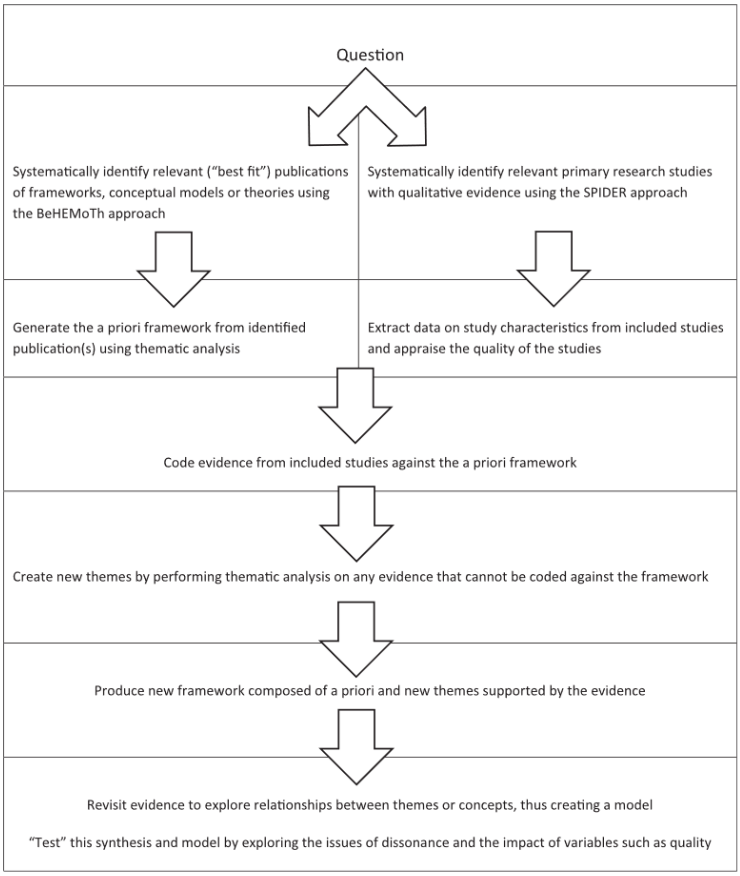

Figure 1: Best-Fit Framework Synthesis (Carroll et al., 2013)

3.1 The Universal Design for Learning Framework

The theory of UDL has roots in universal design principles from architecture, which incorporated features to make products universally accessible (Hickey, 2021). UDL emerged from efforts to address learning barriers for students with specific disabilities, eventually broadening its scope to improve access for all students (Hickey, 2021).

UDL is a framework that guides the creation of adaptive learning experiences to cater to all learners. It emphasizes diverse methods of expression, representation, and engagement, rather than a uniform solution (Meyer, Rose, and Gordon, 2014; CAST, 2018). Though not reliant on technology, UDL presents a pedagogical perspective that examines the potential benefits of technology in meeting varied learning needs (Bray et al., 2023).

Incorporating inclusive design from the onset in e-Learning tool development ensures considerations of accessibility and diverse learner engagement early in the design process (Patzer and Pinkwart, 2017; Morra and Reynolds, 2010).

The relevance of UDL to designing inclusive VRLAs lies in its understanding that accessibility and inclusive education are intertwined. There's existing literature on applying UDL in e-Learning, technology-enhanced learning, and assistive technologies (Morra and Reynolds, 2010; Cunningham and Murphy, 2018; Courtad, 2019; Poore-Pariseau, 2010; Al-Azawei, Parslow, and Lundqvist, 2017).

UDL was chosen over other models of inclusive education for its particular focus on learning content design. The framework Index for Inclusion (Booth and Ainscow, 2011) was not selected because of its focus on broader school culture, leading to categories of very low relevance to this research. Another possible model would have been the Didactic Model for Inclusive Teaching and Learning (Frohn, 2022). This model was not chosen because only 4 of its categories would have been applicable and that would have led to a lack of differentiation for this analysis.

3.2 UDL Coding Framework

The UDL guidelines, developed and published by the Center for Applied Special Technology (CAST, 2018), will serve as the foundation for the framework analysis. An overview of the framework is depicted in Figure 2.

Figure 2: UDL Guidelines (CAST, 2018)

This framework will be used to organize information extracted from the literature search into the nine categories, along with a tenth category for inclusion-related points not covered by UDL, if necessary. During the analysis, the mapped information, such as best practices, case study insights, quantitative and qualitative data, as well as pre-existing guidelines, will be synthesized into a set of guidelines for the development of inclusive VRLAs.

3.3 Systemic Review

Having the framework in advance influenced the decisions regarding how the literature search will be conducted. The chosen review strategy is a systematic review following the SPIDER search strategy (Cooke, Smith, and Booth, 2012).

3.3.1 Search strategy

An acknowledged search strategy was employed to retrieve relevant articles for qualitative and mixed-method research. The SPIDER search strategy was adopted to address ambiguities in titles and abstracts of potential articles (Cooke, Smith, and Booth, 2012). SPIDER was used to pinpoint relevant research, with search terms detailed in Table 1, adapted for each database's syntax. The focus was on K-12 education, encompassing educational processes, including inclusion, accessibility, and VR.

Table 1: SPIDER search strategy

SPIDER Tool	Search Terms
S – Sample	school OR k-12 OR k12 OR classroom
PI – Phenomenon of Interest	"education OR learning OR teaching OR curriculum AND inclusi* OR accessib* OR disab* OR UDL OR "universal design" OR divers* AND "virtual reality" OR VR OR virtual-reality
D – Design	questionnaire* OR survey* OR interview OR "focus group" OR case-stud* OR "case study" OR "case-studies" OR observ* OR experiment* OR stud* OR meta-analysis OR ethnography OR "meta analysis" OR "grounded theory" OR inquir* OR analy*
E – Evaluation	view* OR experienc* OR opinion* OR attitude* OR perce* OR belief* OR feel* OR know* OR understand* OR outcome* OR characteristic* OR impact* OR insight* OR learn* OR trend* OR pattern*
R – Research Type	qualitative OR mixed-method OR "mixed method" OR quantitative
[S AND PI] AND [(D OR E) AND R]	

Criteria for design, evaluation, and research type drew from terms in pertinent research papers, with keyword searches restricted to titles and abstracts. Only articles published post-2012 were included, coinciding with a resurgence of interest in Virtual Reality and the evolution of consumer head mounted displays. The term "learning applications" was excluded to ensure a broad dataset scope.

Given the interdisciplinary nature of e-learning and educational technologies, especially concerning inclusion, a diverse database set was chosen. The Association for Computing Machinery Guide to Computing Literature covered computing sciences, Scopus offered a broader coverage, ERIC represented educational sciences, and Taylor & Francis added more interdisciplinary papers. More databases, such as Google Scholar, were not used to limit the number of false positives and to stick to peer-reviewed studies. The selection of databases from a varied set of disciplines ensures a sufficient breadth of focus. Table 2 presents the records identified per database.

Table 2: Query results by database

Data Source	Results
ACM Guide to Computing Literature Date: 17th of August 2023	239
SCOPUS Date: 17th of August 2023	44
ERIC Date: 17th of August 2023 (Does not support the use of wildcard * Manual adjustments to the query were made)	15
Taylor & Francis Date: 17th of August 2023 (Does not support the use of wildcard * Manual adjustments to the query were made)	10
Total	308

3.3.2 *Initial screening and exclusion criteria*

From an initial count of 283 records, 13 duplicates and 12 conference reviews were removed. The remaining records were screened by title and abstract using the following exclusion criteria:

- Records unrelated to VR, e.g., those emphasizing serious games, virtual worlds, 2D-based virtual learning, or augmented reality.
- Studies where VR had only a peripheral role.
- Records not set in a K-12 environment, like higher education studies or those outside a school context.
- Records not in English or German.
- Research centered on teacher education rather than K-12 student VR use.

After applying these criteria, 15 records remained. Inclusivity in education was not an explicit screening criterion at this stage, as it was challenging to identify from abstracts alone. The subsequent framework analysis will emphasize inclusive education.

3.3.3 *Backwards snowballing*

To complement the initial search strategy and address the limited number of records, a backward snowballing technique (Wohlin, 2014) was used. From the initial 15 records, relevant references were extracted based on titles, then expanded by reviewing the introduction and background sections for citations. New references were checked for duplicates, assessed for publication date (after 2012), and screened using the prior exclusion criteria.

This approach added 24 more records, suggesting that the initial search might have missed some pertinent studies, possibly due to the specific inclusion-related terms in the SPIDER search. Insights about inclusive education can sometimes be located within broader educational findings. Using the snowballing technique effectively compensated for this limitation, bringing the total to 39 records for further analysis.

3.3.4 *Full-text eligibility*

Each identified record was examined in full to ensure its relevance beyond the title and abstract, leading to the exclusion of 21 records. Some did not meet the defined "virtual-reality" criteria, focusing on aspects like stereoscopic 3D or 2D virtual worlds. Others lacked insights pertinent to creating inclusive VRLA design guidelines, often concentrating solely on the efficacy of VR interventions without discussing application design details. Also, studies with recommendations specific to a narrow context, like language learning applications (e.g., Parmaxi, 2023), were excluded. Ultimately, 18 papers were selected for the final analysis. A summary of this process is depicted in Figure 3.

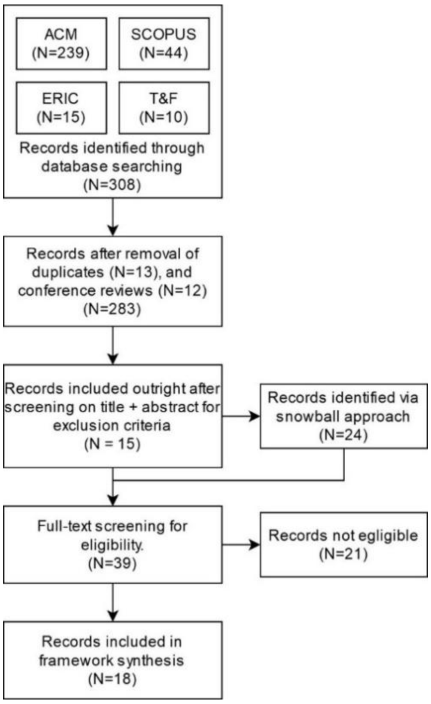

Figure 3: Flowchart of the literature search process

4. Results: The Preliminary Inclusion Guidelines for VR Learning (IGVRL)

The review's coding focused on identifying design recommendations associated with positive effects on inclusive learning, omitting broader inquiries on VR's general value in inclusive education. For example, "Increased motivation in students with learning disabilities" (Papanastasiou et al., 2019) was not included, as it didn't tie to a specific design decision. The synthesis centered on recommendations like "Expanding interaction modes to enhance embodied learning" (Thompson et al., 2018). While some observations, such as VR's capability to simulate multiple media channels (Thompson et al., 2018), may seem broad, they align with suggestions emphasizing the importance of experience fidelity and multimedia elements in VRLAs. This paper first offers tables (Tables 3-11) showing raw results based on UDL's 9 categories, then refines them into guidelines. Some findings are applicable to multiple categories but aren't repetitively listed.

4.1 Provide Options for Recruiting Interest

Table 3: Raw results for (1)

Thompson et al., 2018	• Allow learners to be an active explorer rather than a passive observer;
Cheng and Tsai, 2019	• Presence is positively linked to motivation; • Presence is linked to self-efficacy; • Task-based learning approach should be integrated to promote autonomous learning;
Chua et al., 2019	• Interactivity with VR content generates better engagement, enjoyment and potentially performance;
Papanastasiou et al., 2019	• VR allows learners to interact with virtual objects at their own pace and learn through a constructivist approach, encouraging active participation rather than passivity; • Provide realistic and interactive role-playing situations;
Yang et al., 2020	• Achieving authenticity through realistic graphic design;
Bodzin et al., 2021	• Support engagement to increase positive motivational influences on learning; • Incorporate students proactive behavior into instructions by for example including choices for the user to take that influences their learning path; • Make tasks authentic in order to promote engagement; • Incorporate narrative in learning applications to promote interest;

A dominant theme identified is the emphasis on active, autonomous, and constructivist learning scenarios (Thompson et al., 2018; Cheng and Tsai, 2019; Chua et al., 2019; Papanastasiou et al., 2019; Bodzin et al., 2021). This correlates with the UDL principle "Optimize individual choice and autonomy" (CAST, 2018). These scenarios position learners as proactive, allowing considerable autonomous individualization. The literature indicates that such scenarios prioritize active exploration, task-based learning, and high interactivity with virtual worlds.

Another notable theme is the significance of presence in boosting motivation and engagement (Cheng and Tsai, 2019; Yang et al., 2020; Bodzin et al., 2021). This corresponds with UDL's "Optimize relevance, value, and authenticity" (CAST, 2018). The literature suggests achieving this through realism in graphics and simulations, linking VR to students' real-world experiences, and integrating narratives or role-play elements (Papanastasiou et al., 2019; Bodzin et al., 2021).

The third theme, categorized by CAST as "Minimize threats and distractions" (2018), didn't provide distinct VRLAs development guidelines. The literature reiterated VR's safety compared to real environments (Fransson, Holmberg, and Westelius, 2020; Roberts-Yates and Silvera-Tawil, 2019; Papanastasiou et al., 2019), which seems more content-specific than a design guideline. More studies on VR learning and cognitive load might offer clarity.

Synthesized guidelines:

- Advocate for active exploration and problem-solving in VR, aligning with constructivist learning methods.
- Incorporate interactive elements, enabling learners to engage with the virtual environment.
- Embrace task-based learning within VR, allowing learner agency.
- Provide opportunities for choices and decisions, endorsing learner autonomy.
- Boost presence by connecting VR to meaningful real-world or engaging narratives.

- Prioritize authenticity through realistic graphics and immersive technology.

4.2 Provide Options for Perception

Table 4: Raw results for (2)

Thompson et al., 2018	• Utilize 3D visualizations for subject specific content; • Design with spatial awareness and spatial presence;
Hamilton et al., 2021	• Design with spatial understanding and Spatial visualization;
Cheng and Tsai, 2019	• Spatial presence highly related to attitudes towards learning activity;
Ritter, Stone and Chambers, 2019	• Use a mix of 360° Photos, video and 3D-modelled; • Blend (photorealistic) 3d-Models with 360° photos and videos;
Yang et al., 2020	• Supplying captions is an effective way to boost listening and reading comprehension;
Bodzin et al., 2021	• Include a wide variety of media, such as authentic imagery, text, data displays, animations, video content, audio narration; • Use multiple and varied representations to promote deeper understandings and sense-making of concepts;
Georgiou, Tsivitanidou and Ioannou, 2021	• Utilize external projection, e.g., the classroom being able to see what the VR user is doing;
Holly et al., 2021	• Ensure high levels of immersion; • User interface should be tailored to the VR world (integrated into the VR world);

A primary theme suggests VR's strength as a multimedia tool capable of offering diverse content (Thompson et al., 2018; Yang et al., 2020; Hamilton et al., 2021; Ritter, Stone, and Chambers, 2019; Bodzin et al., 2021). This corresponds with UDL's guidelines to present alternatives for auditory and visual information (CAST, 2018). Spatial understanding and awareness are underscored, being unique to immersive media (Thompson et al., 2018; Hamilton et al., 2021; Cheng and Tsai, 2019).

The literature review revealed a gap in addressing the UDL guideline "Offer ways of customizing the display of information" (CAST, 2018). Given VR's software-driven nature, opportunities exist for features like color-blind modes and audio descriptions. Further research into VRLA customization is needed.

Two supplementary themes were noted. First, the VR application UI should be directly interactive and embedded within the environment (Holly et al., 2021), enhancing immersion. Second, external projection techniques, like beamers or tablets, can make the VR experience accessible to wider audiences (Georgiou, Tsivitanidou, and Ioannou, 2021). These themes weren't directly linked to UDL guidelines but were briefly associated with perception.

Synthesized guidelines:

- Provide diverse content modalities, encompassing various media forms, 3D visualizations, 360° visuals, 3D models, and audio narratives. Aim for seamless integration of 360° content with 3D models.
- Enhance spatial awareness with interactive environments emphasizing exploration and physical navigation, including VR-integrated UI elements.
- Utilize external projection methods, allowing the larger group to view VR experiences.
- Introduce customization options addressing audio-visual and spatial components.
- Ensure the inclusion of closed captions for auditory content.

4.3 Provide Options for Physical Action

Table 5: Raw results for (3)

Thompson et al., 2018	• Create interactive and manipulatable simulation environments; • More modes of interaction enable higher embodied learning;
Cheng and Tsai, 2019	• Virtual Field trips can reduce barriers;
Papanastasiou et al., 2019	• Glove-based haptic interfaces allow for non-verbal communication;
Ritter, Stone and Chambers, 2019	• Use teleportation instead of controller-based walking to mitigate perceived motion sickness;
Fransson, Holmberg and Westelius, 2020	• Use sight, hearing and touch for interactions;
Yang et al., 2020	• Provide various modes of being able to navigate through and interact with objects in the environment;
Bodzin et al., 2021	• Provide access to locations not accessible for students with disabilities;

The UDL theme "Vary the methods for response and navigation" (CAST, 2018) underscores the value of multi-sensory interactive environments, emphasizing the integration of sight, hearing, and touch (Thompson et al., 2018; Papanastasiou et al., 2019; Fransson, Holmberg, and Westelius, 2020; Yang et al., 2020). To prevent motion sickness, varied navigation methods are essential (Ritter, Stone, and Chambers, 2019). Moreover, diversified controls can enhance embodied learning (Thompson et al., 2018) and cater to students with disabilities.

The UDL guideline "optimize access to tools and assistive technologies" (CAST, 2018) wasn't specifically addressed by the authors concerning VR tools for disabled students. Yet, VR was recognized as an assistive technology, granting experiences otherwise inaccessible to students with disabilities (Bodzin et al., 2021; Cheng and Tsai, 2019). The design emphasis shifts to how VR makes experiences accessible rather than VR's intrinsic accessibility.

Synthesized guidelines:

- Utilize diverse interaction modalities, including speech, gaze controls, haptic feedback, and controller inputs, facilitating a multi-sensory environment.
- Introduce alternative navigation options, like teleportation, to counteract motion sickness.
- Design VR environments that render experiences accessible to students with disabilities, such as virtual excursions to non-accessible sites.
- Integrate or enable compatibility with assistive technologies to ensure broad accessibility within the VR learning platform.

4.4 Provide Options for Effort and Persistence

Table 6: Raw results for (4)

Thompson et al., 2018	• Technology-enabled forms of collaboration and communication; • Ongoing feedback to the learners integrated into the application; • Allow learners to be an active explorer rather than a passive observer; • Collaborative work faciliates peer-learning by way of clear role division and asymmetrical tasks;
Papanastasiou et al., 2019	• Promote flexible, open and collaborative learning; • Provide realistic and interactive role-playing situations; • VR allows learners to interact with virtual objects at their own pace and learn through a constructivist approach, encouraging active participation rather than passivity;
Ritter, Stone and Chambers, 2019	• Embed feedback mechanisms, such as voice-over, in the design of the learning environment;

Southgate et al., 2019	• Networked IVR produces collaboration and deepens learning;
Fransson, Holmberg and Westelius, 2020	• In order for teachers to integrate different levels of challenge, they need to be able to produce and edit content for the VR application;
Yang et al., 2020	• Implement task-based assignments for students; • Achieving authenticity through realistic graphic design;
Bodzin et al., 2021	• Incorporate students proactive behaviour into instructions by for example including choices for the user to take that influences their learning path; • Implement Rapid feedback systems; • Tasks should strike the right challenge-skill balance; • Make tasks authentic in order to promote engagement;

The UDL guidelines delineate four themes for effort and persistence. The first, "heighten salience of goals and objectives" (CAST, 2018), suggests emphasizing goals in VR learning through graphic design or realism for engagement (Papanastasiou et al., 2019; Yang et al., 2020; Bodzin et al., 2021).

The second theme, "Vary demands and resources to optimize challenge" (CAST, 2018), emphasizes flexible tasks, self-guided learning, and proactive behaviors (Thompson et al., 2018; Papanastasiou et al., 2019; Yang et al., 2020; Bodzin et al., 2021). There's an emphasis on teacher customization (Fransson, Holmberg, and Westelius, 2020; Bodzin et al., 2021), indicating the potential need for authoring tools for educators.

The third theme, "foster collaboration and community" (CAST, 2018), is addressed by authors discussing VR's capability for collaboration (Thompson et al., 2018; Papanastasiou et al., 2019). They propose networked VR for shared learning spaces (Ritter, Stone, and Chambers, 2019).

Lastly, "increase master-oriented feedback" (CAST, 2018) recommends automated feedback for learners, as discussed by various authors (Thompson et al., 2018; Ritter, Stone, and Chambers, 2019; Bodzin et al., 2021).

Synthesized guidelines:

- Emphasize goals through authentic narratives in learning experiences.
- Encourage flexible and proactive task exploration, allowing learners to dictate their learning path.
- Offer configuration tools for educators to customize learning application content, ensuring they are user-friendly.
- Design cooperative tasks for both VR and non-VR participants.
- Develop networked VR learning applications supporting multi-user cooperation.
- Integrate automated feedback systems for real-time learner insights.

4.5 Provide Options for Language and Symbols

Table 7: Raw results for (5)

Thompson et al., 2018	• Multi-media simulation to address multiple channels of media reception; • Learners are prompted to gesture during problem solving; • Non-verbal communication with peers;
Papanastasiou et al., 2019	• Use avatars to enable students to develop social skills through communicating with avatars;
De Vasconcelos et al., 2020	• VR serious game for children with intellectual disabilities incorporated multiple means of representing language to improve literacy skills, such as: spoken instructions, written words, syllabic separation and pronounciation;
Fransson, Holmberg and Westelius, 2020	• Offer different languages instead of just English; • Avatars should have faces and the ability to gesture;

In the context of UDL guidelines for language and symbols, the findings align with two out of five categories, with the remaining three being context-dependent and not necessarily relying on the implementation of features or design considerations for VRLAs. "Clarify vocabulary and symbols," "clarify syntax and structure," and "support decoding of text, mathematical notation, and symbols" (CAST, 2018) were not explicitly addressed by the reviewed literature, thus implying a need for these to be researched further for suitability in VR.

The first theme addressed is “Illustrate through multiple media” (CAST, 2018). Beyond multimedia usage, there's discussion on the importance of accommodating diverse learner needs and learning styles through varied media and representation of language (Thompson et al., 2018; De Vasconcelos et al., 2020). The second theme, “promote understanding across languages” (CAST, 2018), indicated a need for multiple language options and emphasized non-verbal communication in VR through gestures and avatars (Thompson et al., 2018; Papanastasiou et al., 2019; Fransson, Holmberg, and Westelius, 2020).

Synthesized Guidelines:

- Offer optional linguistic aids for both text and spoken words within applications.
- Employ varied media to cater to diverse learner receptivity and provide alternative means for language reception.
- Ensure application availability in multiple languages.
- Develop avatars capable of emoting and using body language and gestures.

4.6 Provide Options for Expression and Communication

Table 8: Raw results for (6)

Thompson et al., 2018	• Learners are prompted to gesture during problem solving; • Non-verbal communication with peers;
Papanastasiou et al., 2019	• Use avatars to enable students to develop social skills through communicating with avatars;
Vishwanath et al., 2019	• Using VR for content-creation as a means of expression;
Fransson, Holmberg and Westelius, 2020	• Avatars should have faces and the ability to gesture;
Yang et al., 2020	• The virtual body should be similar in appearance or functionality to the individuals own body;

Expression and communication encompass three themes, with two identified in the literature review. "Use multiple media for communication" (CAST, 2018) relates to student communication methods during learning, primarily in VR via body language, gestures, avatars, and physical interactions, offering non-verbal alternatives to verbal communication (Thompson et al., 2018; Papanastasiou et al., 2019; Fransson, Holmberg, and Westelius, 2020; Yang et al., 2020). While avatars have been addressed in prior guidelines, potential undiscovered communication methods suggest the need for further research on non-verbal communication in VR.

The next theme, “use multiple tools for construction and composition” (CAST, 2018), is mentioned with reference to students creating content like 360° videos (Vishwanath et al., 2019). However, the emphasis on student-generated content was limited in the reviewed records, indicating the need for further research into user-generated content in VRLAs for more comprehensive guidelines. The last theme, “build fluencies with graduated levels of support for practice and performance” (CAST, 2018), was not addressed and should be a subject for future studies regarding scaffolding with VRLAs.

Synthesized Guidelines:

- For networked VR applications, incorporate network voice communication.
- Enable avatars with expressive faces to enhance communication and consider incorporating non-verbal communication methods.
- Allow students to create or import content into learning applications where appropriate.

4.7 Provide Options for Self Regulation

Table 9: Raw results for (7)

Thompson et al., 2018	• Creative positive interdependence in collaborative applications as a means for learners to reflect their contributions; • Clear rules & roles to optimize joint and individual effort;
Roberts-Yates and Silvera-Tawil, 2019	• Experiential learning to facilitate imagination, creative thinking, emotion activation, reflection;
Yang et al., 2020	• Observing classmates performance in VR application enables self-assessment;
Luo et al., 2021	• Consider automated assessment options within the application;

The UDL Guidelines for self-regulation include three themes, but only one was extensively addressed in the literature: "Develop self-assessment and reflection" (CAST, 2018). The other two themes, “Promote expectations and beliefs that optimize motivation” and “facilitate personal coping skills and strategies” (CAST, 2018), were briefly discussed by Thompson et al., who highlighted the significance of clear role distributions in optimizing VR learning engagement (2018). Although motivation and certain benefits, such as fostering confidence and reducing test anxiety, were discussed (Cheng and Tsai, 2019; Roberts-Yates and Silvera-Tawil, 2019), no direct ties to specific VRLA design choices were identified. Research to connect VRLA design features to student attitudes and self-perceptions is recommended for future exploration.

Regarding "Develop self-assessment and reflection", the literature suggests that observing peers in VR can encourage self-assessment and reflection (Thompson et al., 2018; Yang et al., 2020). Moreover, the experiential nature of learning promotes reflection (Roberts-Yates and Silvera-Tawil, 2019), and the potential for automated assessment in VRLAs has been suggested (Luo et al., 2021). The exact implementation of automated assessments requires consideration, emphasizing the need for further research. Some of these findings relate to previous guidelines, which will not be reiterated to avoid redundancy.

Synthesized guidelines:

- Assign clear roles or goals to guide learners, especially in multi-user VRLAs.
- Explore automatic assessment methods to provide learners with insights into their performance.

4.8 Provide Options for Comprehension

Table 10: Raw results for (8)

Thompson et al., 2018	• Authenticity of simulation allows for more well-rounded understanding of the subject;
Cheng and Tsai, 2019	• Heightened Sense of presence increases learning outcome;
Papanastasiou et al., 2019	• Transfer of emotional and social skills in VR applications to real situations;
Tilhou, Taylor and Crompton, 2020	• Connect to background knowledge by connecting contents of the VR application to ways of pre- or post- discussion in the classroom;
Bodzin et al., 2021	• Embed supports connecting learning content to prior experiences students have; • Provide supportive guidance in the form of advice, feedback, prompts and scaffolding to deepen learning; • Provide guided exploration or metacognitive support elements such as badges or points;
Holly et al., 2021	• Highlight the goal of the simulation before entering so the students dont feel lost in the simulation, for example through a pre-defined quest-list with clear task instructions;
Luo et al., 2021	• Consider adding scaffolding to the VR applications;

VRLAs can "activate or supply background knowledge" (CAST, 2018) through methods such as grounding the learning experiences in classroom discussions (Tilhou, Taylor, and Crompton, 2020) or by embedding supports that connect learning content to prior experiences within the VR (Bodzin et al., 2021).

To "highlight patterns, critical features, big ideas, and relationships" (CAST, 2018), it is vital to provide authentic VR experiences with a high degree of presence, as this leads to a more comprehensive understanding of the subject (Thompson et al., 2018; Cheng and Tsai, 2019). Clarifying the central goal or "big idea" of the simulation before beginning is another recommended method (Holly et al., 2021).

Regarding guiding "information processing and visualization" (CAST, 2018), the literature suggests incorporating guided exploration and scaffolding, such as metacognitive support elements like badges or points, and providing a pre-defined quest-list before entering the simulation (Bodzin et al., 2021; Holly et al., 2021; Luo et al., 2021). Additionally, delivering guidance, advice, feedback, and prompts within the learning application is crucial (Bodzin et al., 2021).

However, strategies to "maximize transfer and generalization" (CAST, 2018) are scarcely discussed. Although the transfer of emotional and social skills in VR to real situations is noted (Papanastasiou et al., 2019), it doesn't yield new guidelines beyond existing ones on social and cooperative aspects of VRLAs.

Synthesized guidelines:

- Develop authentic virtual environments for a comprehensive understanding of the subject.
- Integrate pre- and post-simulation activities within the application's design.
- Embed context that relates to learners' prior experiences, allowing modifications by teachers or aligning with standard curricula.
- Offer guidance, feedback, prompts, and scaffolding to aid exploration within virtual environments.
- Incorporate metacognitive elements like badges, markers, arrows, and highlighting.
- Clearly define the simulation's goal for students at its outset.

4.9 Provide Options for Executive Functions

Table 11: Raw results for (9)

Thompson et al., 2018	• Clear role division helps planning and strategy development;

The UDL guidelines for this section yielded limited findings in the literature review. One study highlighted cooperative learning in VRLAs, noting a clear division of roles facilitated "planning and strategy development" (Thompson et al., 2018; CAST, 2018). Other general observations include potential enhancements in working memory and attention for individuals with traumatic brain injuries through VR applications (Papanastasiou et al., 2019). Collaborative Virtual Environments supported communication among children with ASD (Papanastasiou et al., 2019). Additionally, a connection between presence and self-efficacy was identified (Cheng and Tsai, 2019). However, these findings don't specify VR features or design decisions. Comprehensive research on all UDL guidelines for executive function is warranted for more detailed insights.

5. Discussion

The literature review and subsequent framework synthesis have yielded preliminary guidelines for developing inclusive VRLAs (preliminary IGVRL) and highlighted future research avenues and gaps in Universal Design for Learning (UDL) within VR education. While the preliminary IGVRL offer insights for VRLA developers, they are not exhaustive. Some findings from the literature are not sufficiently addressed, and the methodology employed has inherent limitations, emphasizing the preliminary nature of these guidelines. More expansive evaluation and testing are required.

5.1 Unaddressed Findings and Themes

Embodied learning and presence (Thompson et al., 2018; Cheng and Tsai, 2019; Holly et al., 2021) is one significant theme not adequately encapsulated in the UDL. While it could be connected with multimedia usage or physical action, its distinctiveness in VR learning is not sufficiently recognized. These findings underscore the need for future research on inclusive embodied learning and how it relates to this set of guidelines.

The importance of cooperation and collaboration has been acknowledged (Thompson et al., 2018; Papanastasiou et al., 2019; Southgate et al., 2019), but its treatment within the framework is mainly under the banner of sustaining effort and persistence. Inclusive education literature often stresses cooperation's role in fostering inclusivity and enhancing social competencies. Thus, comprehensive research on VR cooperation and collaboration, including design and technological requirements for multi-user VR, is necessary.

Another recurring theme, not wholly represented in the guidelines, concerns the nature of VR content. Suggestions range from experiences fostering perspective-taking (Vishwanath et al., 2019; Hamilton et al., 2021) and cultural sensitivity (Brown et al., 2021) to exploratory applications anchored in instructional design and constructivism (Georgiou, Tsivitanidou and Ioannou, 2021). As critical as the method of VR application deployment is the content chosen. Therefore, analyzing VRLA types from an inclusive education standpoint is a relevant future research area.

Addressing VR accessibility features is essential. While some were mentioned within the framework's categories, a more in-depth exploration is needed. Existing guidelines focus on VR games (Heilemann, Zimmermann, and Münster, 2021), but they weren't within the scope of this synthesis. As accessibility underpins inclusive education, further research into VR accessibility guidelines is crucial.

Lastly, the UDL framework doesn't entirely encompass other core inclusive education concerns: anti-discrimination, gender equality, and cultural inclusion (Rödel and Simon, 2022b). Some authors broached these subjects (Vishwanath et al., 2019; Brown et al., 2021), indicating the need for a comprehensive review dedicated to these topics and subsequent guideline development.

5.2 Limitations

The review's primary limitation was its search strategy, which aimed to identify items with an explicitly inclusion-oriented focus. Yet, many results were false positives, with few papers explicitly discussing concepts related to inclusion. This suggests that the inclusion related keywords didn't provide sufficient value in filtering the results, while also enabling the possibility of missing relevant papers simply because they did not use explicitly inclusion theory related keywords. Backward snowballing was employed to mitigate this limitation, however it cannot be said that this resulted in a truly comprehensive list of results. Broader search terms and the utilization of more databases is advisable for future research.

The review's emphasis on school and K-12 settings was another limitation. Although the focus was VRLA design for schools, findings related to higher education outnumbered those from K-12. It's essential to explore how insights from higher education can inform K-12 VRLA design. Future research should consider diverse search strategies to address this gap, making findings from other educational contexts relevant for K-12.

Additionally, using the "best-fit" framework method for synthesizing findings meant that no quality assessment of the included studies was conducted (Carroll et al., 2013). Thus, the guidelines should be viewed as preliminary insights rather than definitive recommendations. Future research should aim to enhance, evaluate, and validate these guidelines to ensure their validity and reliability.

6. Conclusion and Future Research

Using the "best-fit" framework synthesis method based on the UDL framework, initial guidelines for inclusive VRLAs in K-12 settings were identified. This set is called preliminary IGVRL. These guidelines serve as a starting point for further research and the development of VRLAs in study settings. Instead of offering a complete set of guidelines, this review marks the beginning of an extended research endeavor, presenting foundational categories from the literature and highlighting various research gaps to be addressed. The preliminary IGVRL represent a first answer to the question of how to effectively design VRLAs to accommodate diverse learning styles and needs of students in order to facilitate inclusive education in schools. Future research should focus on refining research questions to explore the design, cognitive aspects, and inclusive features of VR learning applications. Identified topics include investigating the impact of audio-visual customization, locomotion-systems, assistive technologies, non-verbal communications, user-generated content, scaffolding, and automated assessment on student attitudes and self-perception. Additionally, there is a need for research on metacognitive support elements, learning transfer, executive function, inclusive embodied learning, collaboration guidelines, and an analysis of genres and types of VR learning applications, particularly with an emphasis on accessibility.

Acknowledgement

The article processing charge was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 491192747 and the Open Access Publication Fund of Humboldt-Universität zu Berlin.

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Virtual to Reality: Understanding the Role of Metaverse as a Pedagogical Strategy

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https://doi.org/10.34190/ejel.21.6.3219

Abstract: The use of the metaverse in education has gained increasing attention as a potential supplement to traditional teaching methods. This study aimed to investigate the impact of experiential learning on students' intent to use metaverse learning platforms and to explore how the metaverse can support these approaches. The study included participants from three countries and used metaverse scenes, such as a restaurant or Hong Kong scene, to complete learning tasks and interact with Non-Player Characters (NPCs) to complete assessments over a semester. The results of a correlational analysis showed that pedagogical factors had a greater impact on students' intent to use the metaverse for educational purposes than technical factors, which was unexpected. However, the study also identified challenges in adapting content to match the needs and skills of students who may not be familiar with games, as well as using the metaverse for more advanced pedagogical approaches, due to limitations in integrating content. Based on the findings, recommendations for educators, designers, and researchers are provided to enhance the effectiveness of metaverse-based education. Overall, the results of this study suggest that the metaverse can be a valuable addition to traditional teaching methods.

Keywords: Metaverse, Pedagogical strategies, Experiential learning, Virtual reality education, Immersive learning environments, Game-based learning

1. Introduction

Experiential learning is originally defined by Kolb (1984) as a process in which knowledge is created through the transformation of experience. This approach can be supported by authentic learning, where classroom knowledge is applied in real-world scenarios such as learning about waste in a restaurant or pollution in a city street (Wong, G. W. C., Wong, P. P. Y., and Chong (2022). Authenticity includes incorporating feedback, realism, and diverse student preferences (Farrell, 2020) and may be conducted in the metaverse, a form of virtual environment, frequently implemented with virtual reality (VR) technology. The term "metaverse" refers to a virtual space where users interact with digital objects, characters, and other users (Dwivedi et al., 2022). The metaverse facilitates engaging learning through interactions with characters and objects (Calvert and Abadia, 2020; Kye, et al., 2021). Such interactions may increase students' intent to use the technology, making the process more memorable (Sartaş and Topraklkolu, 2022).

The metaverse is described by Kye et al. (2021) as a smart virtual environment with location-based effects, information recording, a reflection of the real world. Hwang and Chien (2022) elaborate how information might be recorded and transferred more efficiently by employing intelligent virtual agents. Users access the metaverse via desktop computers, mobile devices, and specialized hardware, in addition to virtual reality. While the metaverse is an idea, platforms are developed so that anyone can join and participate. Decentraland, Fortnite, and Minecraft, as mentioned by Owusu-Antwi and Amenuvor (2023), provide immersive digital environments or virtual worlds where users can join, create avatars, interact with others, and engage in various gaming activities. Studies have investigated potential engagements, social exchanges, and applications of the metaverse (Dwivedi et al., 2022). While metaverse platforms are frequently designed for social interactions, they can be used for purposes like education.

Metaverses in education have been noted for topics such as excavations, athletics, safety, and language learning (Yang, Ren and Gu. (2022); Sartaş & Topraklkolu, 2022). Sartaş & Topraklkolu (2022) claim that while metaverse

Cite this article: Wong, P.P.Y. et al., 2023. "Virtual to Reality: Understanding the Role of Metaverse as a Pedagogical Strategy", *The Electronic Journal of e-Learning*, 22(3) pp 90-110, https://doi.org/10.34190/ejel.21.6.3219

apps might boost motivation and involvement, more active tasks and storytelling are needed. Cost and effort to set up the virtual environments are also constraints. There's also the issue of cognitive overload, where processing multimedia in educational contexts can place greater demands on working memory than its available capacity (Mayer, 2014). In the metaverse, this challenge is particularly pronounced for beginners, who may experience cognitive overload due to the overwhelming array of controls and options, as noted by Makransky et al. (2019). While VR and metaverses hold promise for enhancing learning experiences, more research is needed to fully understand their potential, particularly their impact on experiential learning. For instance, realistic VR may be costly and difficult to scale to classes that require more sophisticated simulations and scenarios, which can hinder the ability to engage in concrete experiences or reflections as required by experiential learning (Makransky et al., 2019). On the other hand, metaverse concepts such as scene integrations, virtual agents, and authoring tools may allow for content customization (Nah et al., 2022). Thus, the purpose of this study is to investigate how the metaverse could be effectively utilized in an educational setting, considering the different ways it could be applied in various fields of study, receiving student input, and examining the difficulties and constraints associated with deploying metaverses in educational contexts.

In our context, the educational metaverse is a virtual learning environment for students to do educational tasks, talk to each other, take tests, and virtual characters or objects. It can be used in a synchronous in-class setting, or in an asynchronous out-of-class setting, where students access learning materials on their own. The educational metaverse may be supported by pedagogies like the flipped classroom and problem-based learning pedagogy to improve students.

2. Theoretical Background

Virtual reality is a mix of hardware and software to produce an immersive sense of being in a different world (Biocca and Delaney, 1995). Presence, as defined by de Regt, Plangger, and Barnes (2021), is the sensation of being physically present in a virtual environment, a measure of how the user feels present within the VR setting. This encapsulates the authenticity and the subjective reality experienced by the user, distinguishing it from mere graphical fidelity or technical immersion. The process of interpreting an experience is known as reflection. If an individual can connect information in a virtual environment to real life, then reflection is successful (Hamby, Brinberg, and Daniloski, 2017).

Virtual worlds can employ narratives or stories to induce presence and reflection (van Laer, Feiereisen and Visconti (2019). This method, known as narrative transportation, is used in education for virtual field trips and serious games (Markowitz et al., 2018). Wong, G. W. C., Wong, P. P. Y., and Chong (2022) discovered that adopting a virtual platform to permit students to roleplay as real estate brokers boosted student involvement in a real estate transaction simulation.

Dwivedi et al. (2022) categorize the metaverse into four distinct yet interrelated dimensions: an environment that spans realistic to unrealistic realms, interfaces ranging from simple 3D to immersive VR, complex interactions beyond mere conversation, and social value that redefines the metaverse's societal implications. This multifaceted virtual space is not only a collection of digital enhancements, as Zhang et al. (2022) highlight, but also a convergence of augmented and virtual realities, evolving from early virtual communities to today's sophisticated platforms that offer rich, multisensory experiences and user-generated content within an expansive digital economy.

Shin (2022) further suggests that by weaving presence, reflection, and emotion into its fabric, the metaverse can foster a deeply engaging virtual experience that is both immersive and emotionally resonant. Leveraging state-of-the-art graphics techniques, metaverse developers construct environments that merge lifelike 3D settings with interactive elements such as NPCs and avatars. This blend of real and virtual components provides a deeply immersive and engaging user experience in the metaverse (Zhao et al., 2022).

2.1 Previous Studies: Experiential Learning and Metaverse

Previous studies affirm that learners can actively engage in experiential learning by simulating real-life situations within the metaverse's scenes, allowing them to practice skills and apply knowledge in a safe and controlled environment. This can promote practical skills development, for example through virtual field trips, which transport learners to different locations without physically being there (Farrell, 2020; Markowitz et al., 2018). Game-based learning can also be further incorporated with steps like role-play, rules, and resources into educational activities to create an immersive and engaging experience (Mochizuki et al., 2021), to maximize the effects of virtual reality presence and reflection.

The metaverse's capability to facilitate experiential learning is deeply linked with the concepts of presence and reflection. Presence in virtual environments, as defined by de Regt, Plangger, and Barnes (2021), allows for authentic engagement with simulations akin to real-life scenarios. Meanwhile, reflection, the process of interpreting an experience to connect virtual environments to real-life applications (Hamby, Brinberg and Daniloski, 2017), is integral to this learning process. By designing the metaverse with task-based systems employing realistic scenes and specific metaverse tools, educators can create content that fosters both presence and reflection. This design strategy enhances experiential learning by improving conceptualization and engagement, aligning with previous studies that have found efficacy in virtual field trips and game-based learning in achieving practical skills development (Farrell, 2020; Mochizuki et al., 2021).

Besides the adoption of pedagogy, a mechanism to blend an e-learning framework into the metaverse is also required. One framework that can be utilized is the blended-learning RASE framework by Churchill, King, and Fox (2016). The RASE framework consists of four key components: Resources (knowledge or content to fulfil the learning), Activity (tasks required to complete), Support (where students can get help), and Evaluation (how to assess if students are successful) - that can be adapted to the specific needs and requirements of the metaverse environment. The RASE framework can be complemented by an instructional design framework, such as ADDIE (Analysis, Design, Development, Implementation, and Evaluation) to give structured approach to creating instructional materials and programs (Branch, 2009).

Overall, it is crucial to evaluate students' intent to use the metaverse for educational purposes based on various factors, such as enjoyment, ease of use, perceived utility, and prior understanding or perception of the metaverse (Fussell and Truong, 2022). In this context, "intent to use" can be defined as a user's willingness to continue using a technology or system for a specific purpose, such as learning (Davis, 1989). It is well established that factors like perceived usefulness, ease of use, social influences, facilitating conditions are important factors to predict intent to use (Davis, 1989;).

2.2 Research Question Development

While educational metaverses have the potential to create enjoyable learning experiences (Kye, et al., 2021), it is important to consider how they fit into overall learning objectives and how they can be used to support relevant educational materials and assessments (Krotoski, 2010). However, the effectiveness of metaverses for learning is still uncertain due to the lack of research on the topic. For example, Kye et al. (2021) describes the use of simulation technology to link abstract visuals to concrete objects in context of the real world. These simulations can be enhanced using intelligent non player characters to aid decision-making (Hwang and Chien, 2022). However, evidence of learning adoption with metaverse concepts, such as adaptable scenes (Nah et al., 2022) is lesser known. Further, according to, the implementation of methodologlical and pedagogical models within the metaverse is lesser known, particularly in a learner centred environment (Zhang et al., 2022). A multi-disciplinary approach is needed to develop effective strategies for incorporating metaverse technology into the curriculum.

From these considerations, the research questions are:

RQ1: How can metaverse technology be adapted and integrated into experiential learning to support student learning in the curriculum?

The factors defined by Fussell and Truong (2022) about a virtual environment's ability to invoke intent to use, can be largely grouped into two, where aspects like ease of use and enjoyment can be combined into technological factors while others like usefulness and interesting placed under pedagogy. These two groups (technological and pedagogical) can then be used to influence learning satisfaction, leading to students wanting to continue to use it for their learning experiences, described as "intent to use".

RQ2: To what extent do technological and pedagogical factors affect students' intent to use the metaverse for educational purposes?

2.3 Hypothesis Development

The underlying framework of educational metaverse technology is game-based learning, which can be further supported by experiential learning. The effectiveness of this approach in promoting student learning outcomes depends on factors such as usability, utility, and prior understanding or perception of the metaverse (Fussell and Truong, 2022).

H1: The metaverse technology can support experiential learning pedagogy, through elements of concrete experimentation and reflection to support numerous learning pathways.

In virtual reality education technology adoption, specifically on the metaverse, the success of new technology can depend on a variety of factors, such as perceived utility and usability (Fussell and Truong, 2022). However, pedagogical strategies that are most effective when integrating technology into metaverse platforms are not yet well defined. Without a clear understanding of these strategies, it may be challenging to incorporate metaverse technology into educational curricula. Despite this uncertainty, prior research has consistently shown that both technological and pedagogical factors can impact students' intent to use virtual reality for educational purposes (Fussell and Truong, 2022). As such, it is important to assess how these factors influence students' adoption of the metaverse platform, to evaluate the effectiveness of pedagogical strategies and their ability to support student learning.

H2: Pedagogical factors, such as the perceived usefulness and effectiveness of experiential learning in metaverse technology, will positively influence student learning in using the platform for educational purposes.

H3: Technological factors, such as perceived ease of use, enjoyment, performance expectancy, and attitude toward use, will positively predict students' intent to use the metaverse for educational purposes.

Overall, it is expected that both technical and pedagogical factors affect a student’s intent to use the metaverse. Based on the above, Figure 1 outlines our research model.

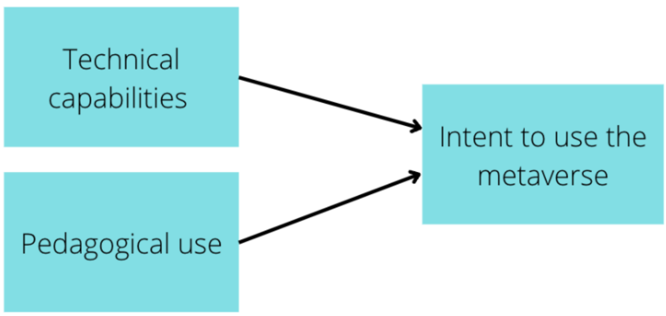

Figure 1: Research model

3. Research Method

This study employed a mixed approach by combining quantitative and qualitative methods to comprehensively understand participants' experiences with the metaverse, evaluate the effectiveness of its design, and identify areas for improvement. The main decisions for choosing a mixed method were:

- Research Question Scope: This study investigates how metaverse technology supports experiential learning and the factors affecting students' intent to use it. A mixed methods approach enables quantitative evaluation of student usage and qualitative insights into their engagement.
- Student Engagement and Usage Intent: To understand student engagement with metaverse technology and their intent to use it, the study combines quantitative data (from surveys) with qualitative feedback (from interviews and observations), ensuring a thorough exploration of these areas.
- Diverse Hypotheses Testing: The hypotheses cover both quantifiable elements (such as ease of use) and subjective aspects (like perceived effectiveness). Mixed methods are used to test these variables, providing a well-rounded analysis.

By combining quantitative survey data and qualitative insights from quest-based learning sessions, the study aimed to provide a comprehensive evaluation of the metaverse's integration into experiential learning within the curriculum.

3.1 Participants

The participants in this study were students from higher education institutions in Hong Kong and Thailand. To ensure effective integration of metaverse technology into pedagogy, classes were selected based on instructors' prior experience in incorporating the use of social learning technology in their classrooms, such as social media for facilitating discussions. These instructors were expected to have a certain level of familiarity with the use of new educational technology, which allowed for more effective control and management of the pedagogy. The samples of the respondents are shown in Table 1. It should be noted that the number of participants was based on the size of the classes.

Table 1: Participants of the study

Group No.	Type	Level	Scene	Participants	Topic	Country	Mode
1	Sustainability	Undergrad	Hong Kong, Restaurant	35, 17-19 years, mixed	Waste and traffic pollution	Hong Kong	Async
2	Sustainability	Masters	Hong Kong, Restaurant	20, 22-25 years, mixed	Waste and traffic pollution	Hong Kong	Sync
3	Sustainability	Undergrad	Sci-fi City	27, 17-19 years, mixed	Sustainable development goals	Thailand	Async
4	Finance	Undergrad	United States	34, 17-19 years, mixed	Great depression (Economic History)	Hong Kong	Sync

3.2 Metaverse Experiences

In the context of this study, two groups in Hong Kong (No 1 and 2 in Table 1) engaged in immersive learning sessions that took place in a restaurant and a virtual Hong Kong city. These sessions were designed to explore the topic of waste management and pollution, specifically focusing on the dilemmas faced by different stakeholders and the information surrounding environmental damage.

In the sustainability class conducted in Thailand (No 3 in Table 1), the focus was on sustainable development goals (SDGs). Due to limitations in lesson time and technological availability, the students were not directly placed in multiple locations. Instead, a generic "sci-fi-like" environment with windmills and greenhouse buildings was utilized to represent a green city. This allowed students to explore various aspects of the SDGs, such as migration, poverty, gender, and the environment.

For the economics class (No 4 in Table 1), the metaverse was used to simulate time travel and delve into the topic of the Great Depression. Non-player characters (NPCs) were designed to portray different perspectives and experiences, including the impacts on farmers, business owners, and regular citizens. This enabled students to engage with the historical context and gain a deeper understanding of the economic theories associated with the Great Depression.

The groups selected from sustainability and economic history classes were particularly well-suited for this study due to the abstract nature of their disciplines. These fields often benefit from visual and experiential learning methods to fully grasp complex concepts and large-scale implications (Luna-Nemecio, Tobón, and Juárez-Hernández, 2020). The metaverse's immersive environment provided a visual context that could make abstract ideas more concrete and understandable.

3.3 Assessment and Measures

3.3.1 Pedagogical approach

In this study, we implemented an authentic learning framework by Farrell (2020), focusing on diverse experiences and personalized challenges for students. We incorporated Churchill, King, and Fox (2016) Resource, Activities, Support, and Evaluation (RASE) framework to strategize these components for the metaverse, an e-learning platform (see Table 2). A central aspect of the learning experience was 'performance', encouraging active participation in the scene and task completion (Sarıta and Topraklıkoğlu, 2022). The metaverse's features were maximized, including authoring tools, to infuse a wide range of content and Non-Player Characters (NPCs), enabling learners to define their learning path and challenge level. NPCs played varied roles from content delivery to fostering social influence, stimulating reflection, and feedback (Oh et al., 2023).

Table 2: E-learning model based on authentic learning (Churchill, King, and Fox (2016); Farrell, 2020)

Category	Resource, Activities, Support, Evaluation (RASE)
Performance	Utilizing metaverse components like NPCs for task completion and learning engagement.
Varying Experiences	Exploring diverse metaverse settings for adaptive and experiential learning.
Challenges	Tackling metaverse tasks autonomously with supportive guidance for skill application.
Feedback	Receiving real-time response from metaverse interactions to inform learning adjustments.
Reflection	Assessing decisions and feedback within the metaverse to deepen self-understanding.
Collaboration	Engaging with virtual agents to enhance teamwork and communicative abilities in the metaverse.

In this study, designing learning experiences such as setting rules and roles within the metaverse became essential, particularly as students would engage through avatars in a third-person perspective. To facilitate this, we employed the game-based learning model by Mochizuki et al. (2020) for its emphasis on interactive, game-based learning and its focus on social learning.

- **Roles**: Learners take on defined roles within the metaverse and complete related tasks, actively engaging with the content and enhancing their learning through direct participation.
- **Rules**: Learners engage with the metaverse through rule-guided quests and tasks that focus and enhance engagement.
- **Gameplay**: An interactive and exploratory design prompts learners to navigate scenes, interact with NPCs, and accrue points via quizzes.
- **Interconnectedness**: The metaverse illustrates the interplay between different scene elements, fostering a comprehensive grasp of the topics.
- **Problem Situation**: Scenarios within the metaverse depict real-world challenges, enabling learners to tackle complex issues in a virtual setting.
- **Resources**: NPCs are strategically placed to act as knowledge hubs, offering various types of information to enhance the learner's understanding, with each selection prompting a distinct response and contributing to a richer educational experience.
- **Social learning**: The metaverse facilitates social learning by enabling learners to engage with NPCs for problem-solving and idea exchange. While direct collaboration isn't featured, the presence of peer avatars in this multiplayer environment promotes observational learning and increased activity.

The learner experience (summarized on Figure 2) would consist of:

Onboarding (10 minutes):

- Learners are briefed on the metaverse learning approach and the Classlet platform via direct instruction and an informative video.
- They install the Classlet application and use a specific code to access the designated metaverse learning environment.

Quest-based Learning (30 minutes):

- Inside the metaverse, learners meet a quest giver who provides them with interactive tasks to be completed by engaging with various NPCs.

- Each NPC interaction challenges the learners to solve problems or answer questions, with immediate feedback provided to facilitate learning progression.

Reflection and Discussion (Post-session):

- Following the interactive session, learners engage in a reflective discussion, often led by an instructor, to articulate their learning experiences.
- This reflective phase is designed to help learners assimilate the knowledge gained and understand the application of their experiences.

This learning experience resembles a cyclic learning experience within the context of experiential learning and is expected to enhance decision-making skills and foster continuous improvement (Figure 2). By incorporating non-player characters (NPCs) to provide feedback, learners can engage in an iterative process of experimentation and reflection. Through concrete experiences, learners make decisions and receive guidance from NPCs, enabling them to analyze the outcomes and refine their decision-making abilities. This approach facilitates active engagement, hands-on learning, and the application of new knowledge to future situations, aligning with the principles of experiential learning (Kolb, 1984).

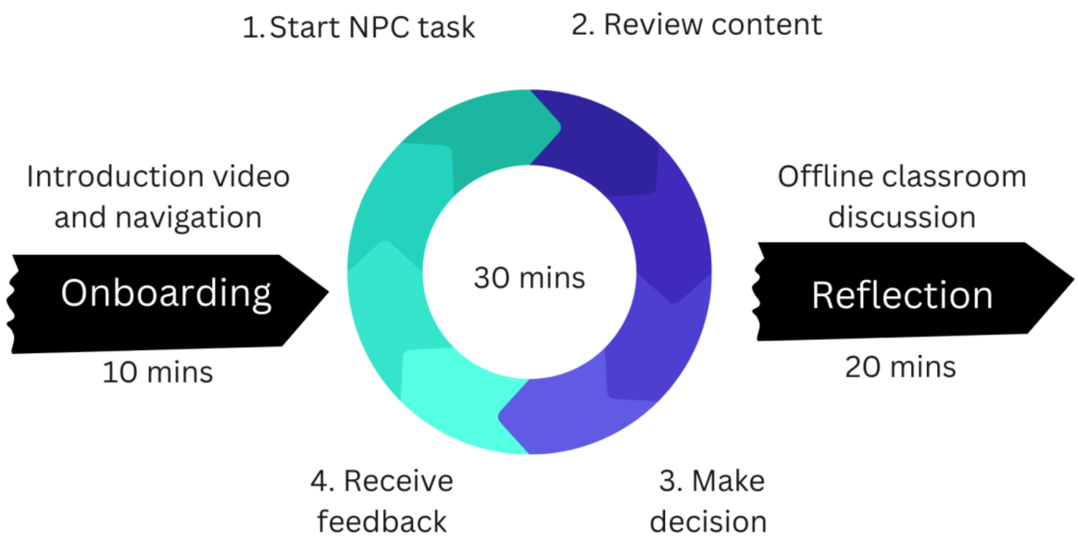

Figure 2: Onboarding process for the metaverse platform

3.3.2 Scene setup (technological)

To set up the scene used for this study, we leveraged a simplified, quiz-like approach for delivering knowledge rather than a comprehensive narrative framework. This was primarily achieved through the design of non-player characters (NPCs), which were created with a specific set of informational requirements. Content was delivered through a user interface that drives description and question as shown in Figure 3. These include:

- **Description**: Each NPC comes with a unique description that provides context and background, helping to situate learners within the metaverse and enhance their understanding of the NPC's role.
- **Question**: Each NPC presents a question related to the learning material, which challenges the learner's understanding and promotes active engagement with the content.

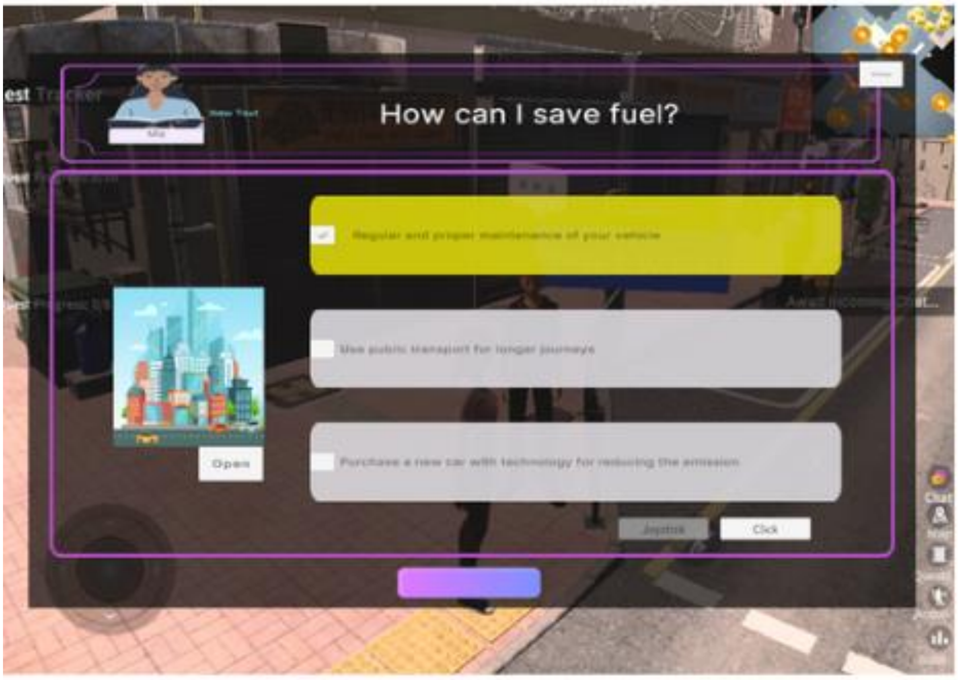

Figure 3: The user interface for a multiple-choice question

- **Options**: For every question, there are three possible answers, out of which only one is correct. This design encourages critical thinking and decision-making skills.
- **Clues**: For each answer option, there is a corresponding clue provided (see Figure 4). This assists learners in deciphering the correct answer and facilitates deeper understanding of the content.

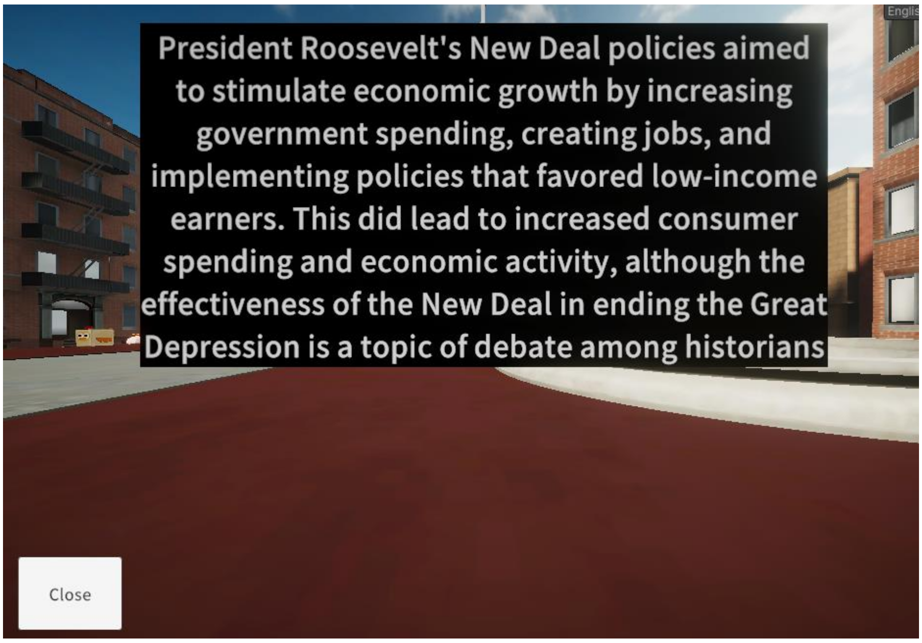

Figure 4: Clues for a multiple-choice question

- **Responses**: Based on the learner's chosen option, the NPC provides a specific response. These responses are designed to give immediate feedback, reinforcing correct understanding and addressing misconceptions.

- **Point System**: A point system is implemented where learners earn one point for a correct answer and zero for a wrong answer. This gamified approach fosters a sense of achievement and motivates learners to fully engage with the learning process.

For this study, we sourced educational content from a range of public data sources like websites and forums. After carefully curating and structuring the material, we formatted it according to the requirements of the metaverse platform. The content was then uploaded to the chosen metaverse platform, making it accessible for learners in the digital learning environment.

The metaverse platform utilized in this study was Classlet (https://soqqle.com). Classlet is an application designed for the metaverse, offering users an interactive and immersive learning experience. It employs game- and scenario-based virtual scenes to engage learners in various educational activities. The platform provides authoring tools that enable the creation of realistic and diverse environments, allowing users to complete learning tasks and make decisions within these virtual settings. Through these activities, learners can earn points and achieve objectives, fostering an engaging and interactive learning experience. The platform allows users to browse a semi-open world (constrained within an area), where they could browse a map, track their quests and interest with non-player characters in the scene (Figure 5).

Figure 5: Generic view of the metaverse platform for great depression

For demonstration in this study, we have set up a demo scene, which can be accessed at https://soqqle.com/demo/demofp.html. Upon visiting the site, it will automatically direct to the Great Depression scene. To initiate the quest, simply tap on the quest giver (Sheep), and the NPCs required for completing tasks will become available in the scene. It is important to note that the Classlet platform is continuously being improved. Therefore, when accessing the demo, it is expected to be more user-friendly compared to the experiment, as several bugs would have been fixed by then.

3.3.3 The Survey. Predicting student intent to use the metaverse.

To assess the learning outcomes of students in relation to the metaverse, surveys were administered at the end of each session, using a Likert scale ranging from 1 to 5. The surveys aimed to explore students' experiences with the metaverse and their intentions to continue using it for their learning. The study aimed to uncover the relationship between independent variables and the dependent variable, as well as any patterns or trends in the data that could shed light on factors influencing users' intent to continue using virtual reality for learning. Previous research by Fussell and Truong (2022) informed the survey design, providing an enhanced perspective of the Technology Acceptance Model tailored to the unique pedagogical and technological factors of Virtual Reality in education. This extended TAM model captures critical elements such as the immersive nature of VR and its interactive capabilities, which are pivotal in understanding students' intentions to adopt such dynamic learning tools.

The survey consisted of eight questions, divided into two categories (technological and pedagogical factors) representing the independent variables. Four questions focused on the technical aspects of the Metaverse system, assessing the aesthetic quality, technical functioning, ease of use, and accessibility/usability of the resource. Examples included evaluating visual appeal, performance, and user proficiency in navigating the system. The remaining four questions pertained to the pedagogical implications of the metaverse, gathering feedback on enjoyment, perceived impact on learning and performance, usefulness, and engagement. Additionally, participants were asked about their willingness to use the metaverse system in the future if given the opportunity, which we will also refer to as their intent to use the metaverse. The questions were adapted from previous research by Davis (1989) and Farrell (2020), examining the effectiveness of metaverse technology in supporting student learning. The averaged technology and pedagogy variables were used as independent variables, while the intention to use the metaverse was designated as the dependent variable in the analysis.

To analyze the collected survey data and explore the association between technological and pedagogical factors and students' intention to use the metaverse for education, several statistical procedures were employed. Cronbach's alpha was used to assess the reliability of the technology and pedagogy attributes. Pearson's correlation analysis examined the relationships between the independent variables and the dependent variable, while Shapiro's test and Spearman's rank correlation coefficient assessed the normality and validity of the data. A linear regression analysis was then conducted to determine significant predictors of the intention to use the metaverse, using JASP software (https://jasp-stats.org/).

In this study, ethical considerations included informed consent through a clear statement on the survey, ensuring participant understanding and voluntariness. Additionally, students were briefed in class using PowerPoint slides, where the goals and nature of the immersive learning activity were explained in detail. We ensured data confidentiality and participant anonymity, and designed metaverse content to be educational and non-threatening, such as interactive scenarios on waste management and agriculture with semi-cartoon style, non-intimidating 3D models. This approach aimed to provide a safe, engaging learning environment without distressing content.

4. Results

4.1 Use of Metaverse

Instructors utilized the metaverse platform as previously described, which allowed for the integration of real-world applications and game-based learning scenarios. This approach facilitated a diverse range of learning experiences across disciplines. In total, our content packs contained 13,627 words, encompassing descriptions, questions, options, and responses. The words were distributed as follows: Group 1 and 2 used 5,570 words; Group 3 used 3,620 words; Group 4 used 4,437 words. The average word count per participant was 159 for Group 1, 181 for Group 2, and 164 for Group 3. Differences between groups did not surpass the 20% threshold, indicating no significant variance in word count across the groups.

We conducted an online survey at the end of the sessions and received 162 responses. Students were asked to provide three things they liked and three things they felt were opportunities for the metaverse learning experience (Table 3). These responses were collected via an open input text field, which gave students the freedom to express their views on what they liked and what they considered as opportunities within the metaverse learning experience. Typically, 'opportunities' are understood to be areas with potential for enhancement, growth, or development. Selected illustrative quotes from the likes and opportunities are shown on Table 3.

Table 3: Illustrative quotes from post-session surveys

Type	Likes	Opportunities
Aesthetics (Technology)	The design of the environment in the game is so nice that it is trying to show us the street of US at that time, and we can have a better understanding of it These cartoon characters are cute. It will increase my motivation to learn.	The appearance is still lacking in comparison to other game as I play Genshin impact which has similar feature but breath-taking scenery.
Functional (Technology)	First-person game can help immersing into the scenario.	Too many bugs (cannot not close the answering page), confused about the use of the system and too many humans in the system. it is little bit confused when i was controlling the character as there are not clear instructions about what can we do for the next step
Ease of use (Technology)	Easy to control, Npc is easy to find and kind of fun way to learn	I do not know what my progress is (i.e. how much I have already answered). New to us, too advance, need consultant to guide The interface itself is not very smooth and may just cause more stress for people trying to access the information on it.
Fun (Technology)	Games always make class more fun and enjoyable. Its idea is innovative, it covered some additional acknowledgements, the interaction is fun.	Not interesting/beneficial to study since phone's monitor is smaller, also not interesting by reaching the NPC and receive information (although not boring than sit in classroom)
Usable /Access (Pedagogy)	Students are free to try out anything in the game which is very free. Players can try to answer any questions without barriers.	It is little bit confused when i was controlling the character as there are not clear instructions about what can we do for the next step
Improves learning (Pedagogy)	Encourage students to learn more other than lecture notes like the background information provided in every question We get to know more about real global environmental issues which we sometimes ignore or do not clearly notice unless we suffer high temperatures and nature disasters as well as man-made disasters.	The interaction between npc and the player could be more active. More “wrong answer options” should be set in the multiple-choice options.
Useful (Pedagogy)	I appreciate the activities that have to be done in groups because they can help each other plan the event. Not lecture based, self-discovery, and new perspective of learning. Can increase the memory of knowledge through playing the game	I’d rather get to the point when learning subjects, a video would be fine as well, however I see zero value in using a metaverse
Interesting (Pedagogy)	The approach is different from traditional methods of education which might work better for some people. It is more interesting than learning from words, I can learn more information than class and I will feel no stress when learning	not interesting/beneficial to study since phone's monitor is smaller, also not interesting by reaching the NPC and receive information (although not boring than sit in classroom)

4.2 Inferential Statistics

The sample size of 162 (the survey results) was considered appropriate for the analysis conducted in this study. The reliability of the scores was tested using Cronbach's alpha (α) and resulted in a value of 0.930, indicating that the dataset is suitable for correlational analysis. A Pearson's correlation (Appendix B) was calculated to examine the relationship between a student's intent to use the metaverse and various technology and pedagogy attributes. The results showed that the most significant predictor of intent to use the metaverse was how interesting the technology was ($r = 0.798$, $p < .001$), followed by how it improves student learning ($r = 0.702$, $p < .001$). Aesthetics and the functions of the metaverse had the lowest correlations ($r = 0.375$, $p < .001$ and $r = 0.547$, $p < .001$).

Additionally, T-T plots were used to assess the normality of the data, which appeared to be normalized. However, Shapiro's test revealed that the data for technology ($p=0.002$) and pedagogy ($p<0.001$) were not normally distributed. Despite this, the Pearson's correlation coefficients were still significant, indicating a strong relationship between the variables.

To further strengthen the analysis and to provide a robust result, we also calculated the Spearman's rank correlation coefficient. The results (Appendix A) showed that the correlation between intent to use the metaverse and technology attributes (rho = 0.601, $p<.001$) and intent to use the metaverse and pedagogy attributes (rho = 0.763, $p<.001$) were both statistically significant. Similarly, the correlation between technology and pedagogy attributes was statistically significant (rho = 0.732, $p<.001$). These results indicate that there is a moderate to strong correlation between the independent variables (technology and pedagogy attributes) and the dependent variable (intent to use the metaverse) regardless of the correlation measure used.

A linear regression analysis was then conducted with pedagogy as the independent variable and intent to use the metaverse as the dependent variable. The analysis was run using JASP software and a significance level of 0.05 was used. The assumptions of linear regression were checked and met, including linearity, homoscedasticity, and independence of errors. The results showed that pedagogy significantly predicted intent to use the metaverse ($\beta = 0.934$, $p < .001$) with an R-squared value of 0.623, indicating that 62.3% of the variance in intent to use the metaverse can be explained by pedagogy. Additionally, the Root Mean Squared Error (RMSE) value of 0.706 indicates that the model has a good fit with the data. It is relatively low compared to the standard deviation of the dependent variable (intent to use the metaverse) of 1.135, indicating that the model can predict the intent to use metaverse with good accuracy. The overall regression model was statistically significant ($F(2,162) = 65.166$, $p < .001$). Based on these results, it can be concluded that pedagogy is a strong predictor of intent to use the metaverse, with each unit of pedagogy rating contributing to 0.934 for intent to use.

5. Discussion

5.1 The use of Metaverse Learning Strategies (RQ1)

In the context of VR, participants in this study engaged in experiential learning through the stages of Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation, with a focus on VR-specific concepts.

- Concrete Experience: Participants immersed in virtual environments, engaging in hands-on experiences. Metaverse technology enabled real-time feedback, enhancing engagement and presence.
- Reflective Observation: Participants reflected on metaverse-based activities, evaluating actions and connecting virtual experiences to real-life applications.
- Abstract Conceptualization: Participants developed conceptual insights within VR, relating experiences to theoretical principles and considering the metaverse's educational impact.
- Active Experimentation: Participants explored alternatives in VR, engaging in hands-on experimentation. Although they applied skills and iteratively refined strategies, the 30-minute quest-based learning limited evidence of repeated trial and error. Further exploration in extended sessions may reveal deeper insights.

Experiential learning was found to be the easiest to implement since it only requires putting students in a situation and letting them explore. Participants also liked it because many of them like immersion and freedom to go through scenes at their own leisure. Overall, we present the metaverse-based experiential learning model below in Figure 6.

Figure 6: Metaverse-based experiential learning model

Active experimentation in the metaverse presents unique challenges in observing and evidencing successful learning outcomes. The level of realism and individualization required might vary drastically depending on the learning objectives. For instance, sending a student back to 1930 to study the Great Depression raises questions about the required authenticity of that period. Increasing individualization, such as offering access to diverse settings like a farm, a business, or a bank, can enhance learning but might be constrained by the additional effort and cost to develop such intricate environments.

Moreover, the way information is conveyed within the immersive environment must be carefully considered. Should students learn through videos relevant to the scene, engage with characters in active learning stories, or experience a blend of both? The choice of scene types and levels of immersion can profoundly affect understanding and engagement, which might explain why some participants were unclear about the goals or directions.

No specific differences were observed in the use of the metaverse between Thai and Hong Kong cultures, and statistical analysis did not reveal any significant distinctions. This uniformity in engagement may be attributed to the overarching collectivist values prevalent in both societies, which influence how users interact with virtual objects, environments, and shared goals within these immersive platforms, as suggested by Awanis, Schlegelmilch, and Cui (2017).

No differences were observed in the use of the metaverse across various academic disciplines, degree levels, and delivery modes, reflecting its broad applicability and effectiveness in education. This finding resonates with Shin's (2022) insights on the metaverse's potential to integrate emotions, embodiment, and presence, which likely contributed to the platform's adaptability and consistent engagement levels noted in our study.

Overall, the use of a metaverse platform as a learning strategy proved to be effective in achieving the desired learning goals in both Hong Kong and Thailand. The incorporation of simulations of real-world situations and game-based learning allowed students to engage in immersive experiences that were directly relevant to the subject matter at hand. For example, students had the opportunity to assume the roles of characters traveling back in time to the Great Depression or working in a restaurant to explore concepts related to food waste. These experiences were facilitated using avatars and interactive elements such as clicking on items and interacting with non-player characters (NPCs). To ensure alignment with the learning objectives, specific game-like rules and quests were created, requiring the completion of certain tasks and interactions. When designing lessons within the metaverse, careful consideration was given to assessment methods, information delivery, and the appropriate narrative structure that best supported the intended educational outcomes.

Technological features

The metaverse platform used in this study has demonstrated its potential for supporting a range of pedagogical methods, including problem-based learning and flipped classroom approaches. The platform's authoring tools allow for the creation of user-generated scenes, setting it apart from other VR solutions and providing opportunities for customization and tailored learning experiences. In this context, we would articulate that an educational metaverse can set itself apart from other VR solutions or game-based solutions by providing the ability for users to actively participate in the creation and customization of virtual environments and learning experiences. The use of authoring tools empowers educators and learners to design and develop their own virtual scenarios, incorporating specific learning objectives and content relevant to their educational goals.

In terms of process and operational use to integrate the metaverse platform, the creation of each content pack required two to three weeks of preparation and research. Similarly, designing and deploying each 3D scene took about three weeks. This process included developing the assets, integrating them into the Classlet metaverse engine, and optimizing these assets. Optimization involved tasks such as reducing the polycount of 3D models for smoother performance and tagging the Non-Player Characters (NPCs) to prepare them for content mapping.

Notably, Classlet utilizes a keyword tagging system to link the NPCs within a scene to relevant learning content that is uploaded to the server. This system ensures that each NPC in the metaverse is effectively tied to the educational material, facilitating the learning process within the immersive 3D environment.

Some participants also expressed some concerns and challenges related to the metaverse learning implementation. Some participants found the questing system to be limited and expressed difficulties in monitoring their own progress. They also mentioned that not all students were familiar with using mobile game platforms, highlighting the need for instructors to provide guidance and support. To address confusion and improve the user experience, the inclusion of visual signals, such as waypoints, could help students navigate and stay motivated to fulfil their learning objectives (John et al., 2020).

The comparison of metaverse graphics to popular mainstream AAA games, as mentioned by participants, highlights a known challenge in serious games (Starks, 2014). It is important to consider that the positioning and explanation of the platform at the beginning of the learning experience can influence participants' perceptions. While the metaverse platform may not have the same level of graphical fidelity as AAA games, its primary focus is on educational content and learning outcomes. To assist students in comprehending and harnessing the educational benefits of the metaverse, teachers must provide them with structured and easily comprehensible instructions, accompanied by necessary technical support (Krotoski, 2010).

Furthermore, there is potential for leveraging generative AI technologies like Generative Pre-trained Transformer (GPT) models to further enhance the interaction between players and non-player characters (NPCs). GPT is a deep learning model that has been pre-trained on a large corpus of text data and can generate human-like text based on the given input. This can be helpful to generate dialogue or scenarios so that the experience can depend less on scripted dialogue. However, more research is needed to understand the implications and implementation of such processing models.

The Classlet metaverse platform utilized in our study provided a secure learning environment through a private code-based access system, ensuring that only students with the code, distributed during class, could join the specific scenes. Additional security can be added by implementing email whitelisting, but this would increase administrative effort, presenting a trade-off for institutions to consider.

Acknowledging the limitations of metaverse learning strategies, it becomes evident that replicating real-world experiences in the metaverse poses significant challenges. Realism, particularly in subjects that require physical interaction, remains a hurdle. While immersive virtual reality using head-mounted devices can enhance the experience, as Lan (2020) notes, they may be cost-prohibitive for widespread implementation. Additionally, equitable access to these technologies is a major concern, with performance varying based on the user's device; not everyone has access to high-powered machines and devices. In addition to these technological constraints, there is a considerable effort involved in developing detailed learning scenarios and transforming existing educational content into game-based formats. This process can be time-consuming and resource-intensive, presenting another layer of complexity in the effective implementation of metaverse learning strategies.

Despite these limitations, the metaverse holds considerable potential for educational innovation. It presents opportunities that traditional learning environments may not offer, such as the creation of personalized learning pathways and alternate realities that respond to student actions, allowing learners to see the consequences of their choices in a controlled environment. Furthermore, the integration of advanced technologies like AI has the potential to enhance these virtual environments, facilitating more dynamic and interactive experiences.

H1 Conclusion: The assertion that metaverse technology can support experiential learning is partially substantiated. The stages of concrete experience, reflective observation, and abstract conceptualization were successfully facilitated by the metaverse, as demonstrated by the students' engagement. Active experimentation, however, was hindered by the virtual environment's limitations in realism and the capacity for iterative, variable scenarios. Future studies will attempt to further this aspect with learning pathways and artificial intelligence integration.

5.2 Intent to use the Metaverse for Learning (RQ2)

Pedagogy-related factors predicted intent to use better than technical components, with a β coefficient of 0.934 and an R-squared value of 0.623. This shows that our metaverse for cross-disciplinary courses and flipped classroom style increased students' interest and enjoyment in learning. The overall regression model was statistically significant ($F(2,162) = 65.166$, $p < .001$), supporting the hypothesis that pedagogy influences students' metaverse use. Our findings also suggest that metaverse pedagogy-based strategies like the flipped classroom can improve learning outcomes and student engagement.

It was interesting that the regression analysis showed that pedagogy-related factors (e.g., perceived utility) had a greater impact on students' willingness to use the metaverse for instructional purposes than technical factors (e.g. ease of use). This was surprising because many metaverse or virtual reality education research focuses on technological factors like presence activation (van Laer, Feiereisen and Visconti (2019); de Regt, Plangger, and Barnes (2021). Pedagogical aspects may be more important than technical factors because intrinsic motivation, such as the desire to learn, may be more influential (Lavoué, et al., 2021). Nonetheless, it is also possible that even greater immersion or performance in the metaverse platform, as technology improves, may yield higher results, like a higher effect size beyond 0.646 which was recorded in this study.

This finding suggests that intrinsic motivation, such as the desire to learn, may be more influential than the technical features of the platform. According to Bandura (1986), individuals are more intrinsically motivated when they perceive they are competent and have more control. Participants in the study reported that they could browse in a relaxed way and retrieve more information than they otherwise couldn't in a classroom. Using a goal-based system in the platform, such as requiring to complete a number of multiple-choice questions also allows for increased motivation. This means that educators should aim to create learning environments that foster students' sense of competence and control, that can challenge them appropriately, and provide clear feedback. This is consistent with Farrell's recommendation of authentic learning (2020).

In addition, presence and immersion in virtual reality can also contribute to creating learning purpose and meaning, as well as enhancing students' emotions and embodiment. The metaverse platform offers a depth of experience that traditional classrooms cannot provide, allowing students to explore and experiment with a range of scenarios that are not possible in a physical setting. This depth of experience can also lead to deeper reflection and personal meaning-making, as students are able to connect the classroom knowledge to real-life situations. For example, being in a restaurant to interview owners and kitchen staff about food waste helps to put the learning content into context. Shin (2022) suggests that the metaverse has the potential to connect emotions, embodiment, and presence together, providing a more holistic learning experience. Therefore, incorporating the use of VR and metaverse platforms into education can not only increase motivation, but also enhance the overall learning experience for students.

Despite the use of presence and immersion, some students reported that the process of obtaining information through the platform was inefficient and slow. Incorporating narratives into the metaverse platforms can potentially improve learning efficiency. By incorporating narratives, the learning process can become more targeted and straightforward, as it is guided by a story direction. For example, in the language learning class described above, the use of a story helped to engage students and provide a clear goal for their learning. This is consistent with research that suggests narratives can enhance learning by providing structure, context, and meaning (Schank and Abelson, 1994). Therefore, the use of narratives in VR and metaverse platforms can be a potential solution to address the issue of learning efficiency.

Finally, the benefits of using the metaverse for learning can be linked in part to the employment of metaverse authoring tools. These tools allow instructors to convert existing curricula into dynamic, immersive scenes, that can be shared across varying cultural and geographic classes. The dynamic nature of the scenes also allowed the customization of goals, through the setup of quests and non-player characters, which enhanced scaffolding

(Zimmerman, Bandura and Martinez-Pons (1992). These authoring tools are available through a web portal to assist teachers manage content (Nah et al., 2022). In our study, students re-used scenarios across countries, therefore fostering a global and interconnected mindset.

H2 Conclusion: The study confirmed that pedagogical factors have a strong influence on students' engagement and intention to use the metaverse for learning, as indicated by the robust statistical support from the regression model.

H3 Conclusion: Technological factors, while initially engaging, were less influential than pedagogical elements in determining students' sustained intent to use the metaverse, suggesting that effective learning strategies are paramount for long-term engagement.

5.3 Significance: An Adaptive Framework for Metaverse Learning Environments

In this study, a framework for metaverse learning was developed, providing a structure for educators and learners to create immersive educational experiences. This framework allows for the design and development of virtual scenarios that align with educational objectives. It includes various pedagogical methods, such as problem-based learning and flipped classroom approaches, suitable for different educational settings. The framework's use of authoring tools enables the generation of specific content, crucial for tailored learning experiences. Operational processes, including the creation of 3D assets and optimization for the Classlet metaverse engine, are core aspects of this framework. These elements support the implementation of metaverse learning and encourage consistency and efficiency in developing metaverse environments. Its broad applicability and adaptability make it a significant contribution to the academic community, providing a method for integrating immersive technologies in educational contexts.

5.4 Limitations

This study collected data from several classes due to the lack of metaverse research on various subjects. This study's 162 participants were sufficient, however inconsistent teaching methods may have affected the results. To overcome these obstacles and reinforce our findings, future research should use a larger sample of classes organized by similar topics and broader teaching methods. This would demonstrate how the metaverse can teach various subjects and approaches. Additionally, it is important to highlight that the data obtained in this study are self-reported and that no control group was employed.

Despite the aforesaid restrictions, our study's Cronbach Alpha was satisfactory, indicating data reliability. However, additional study is needed to understand how serious games affect learner engagement and to design successful ways for promoting uptake and use of these instructional tools.

6. Conclusion

In conclusion, our study contributes to the metaverse in education literature by affirming the potential of immersive learning to increase student engagement through a cyclical process of experiential learning. The use of the metaverse in education effectively supported the stages of Concrete Experience and Abstract Conceptualization, aligning with the experiential learning theory. However, limitations in realism within the virtual environment slightly curtailed the extent of Active Experimentation.

Addressing our research questions, we found that:

- RQ1: Metaverse learning strategies foster experiential learning, evidenced by the active engagement of students within virtual environments. This engagement supports the hypothesis that metaverse strategies can enhance concrete and abstract learning experiences.
- RQ2: Pedagogical constructs had a more substantial impact on the intent to use the metaverse for learning than technical factors, emphasizing the importance of instructional design. This reinforces the hypothesis that pedagogical considerations are paramount in the adoption and effectiveness of educational technologies like the metaverse.

The study's limitations include the variability of teaching methods across classes, reliance on self-reported data, and the absence of a control group. Although the sample size was sufficient, future research would benefit from a larger, more uniform sample to solidify findings. Despite these issues, data reliability was confirmed to be satisfactory.

By integrating game-based elements and authentic simulation environments, our research contributes to the body of literature by providing empirical evidence supporting varied roles and dynamic rules within the metaverse. Despite the benefits, we note instances of cognitive overload, indicating the need for careful design considerations to prevent distractions and enhance focus. In response to the study's findings, future research will focus on the relationship between gaming familiarity and academic achievement in metaverse learning.

The subsequent research agenda should explore:

- The relationship between gaming familiarity and academic achievement in metaverse learning, to discern how prior gaming experience influences educational outcomes.
- Strategies to mitigate cognitive overload in metaverse educational settings, aiming to balance interactive and educational elements.
- The role of artificial intelligence in personalizing learning experiences within the metaverse, which could revolutionize the interactivity and adaptability of virtual learning environments.

Overall, our study underscores the necessity of a strong pedagogical foundation in designing educational metaverse applications, advocating for a thoughtful balance between engaging content and educational rigor.

Conflicts of Interest Disclosure

Daniel Shen, a co-author, holds stock in Classlet. Despite this, the authors have rigorously adhered to objective and critical analysis throughout the research process. The findings and conclusions presented are the result of an independent and unbiased evaluation of the data.

Acknowledgement

This study was funded by Lingnan University, Hong Kong (Teaching Development Grant, Project Code: 102716).

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Appendix A

Correlation Table

				Pearson			Spearman		
			n	r	p	VS-MPR†	rho	p	VS-MPR†
Intent	-	Avg Tech	163	0.626 ***	< .001	$2.050 \times 10^{+16}$	0.601 ***	< .001	$4.162 \times 10^{+14}$
Intent	-	Avg Pedagogy	163	0.787 ***	< .001	$3.613 \times 10^{+32}$	0.763 ***	< .001	$1.834 \times 10^{+29}$
Avg Tech	-	Avg Pedagogy	163	0.776 ***	< .001	$1.077 \times 10^{+31}$	0.732 ***	< .001	$4.889 \times 10^{+25}$

* p < .05, ** p < .01, *** p < .001

† Vovk-Sellke Maximum *p* -Ratio: Based on the *p*-value, the maximum possible odds in favor of H_1 over H_0 equals 1/(-e *p* log(*p*)) for *p* ≤ .37 (Sellke, Bayarri, & Berger, 2001).

Appendix B

Linear regression of technology, pedagogy and intent

Model Summary - Intent

Model	R	R^2	Adjusted R^2	RMSE
H_0	0.000	0.000	0.000	1.135
H_1	0.789	0.623	0.613	0.706

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
H_1	Regression	129.862	4	32.466	65.166	< .001
	Residual	78.715	158	0.498		
	Total	208.577	162			

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients						
Model		**Unstandardized**	**Standard Error**	**Standardized**[a]	**t**	**p**
H_0	(Intercept)	3.724	0.089		41.901	< .001
H_1	(Intercept)	0.266	0.245		1.087	0.279
	Avg Tech	0.044	0.100	0.035	0.441	0.660
	Avg Pedagogy	0.934	0.100	0.763	9.385	< .001
	Offline? (Yes)	-0.111	0.120		-0.925	0.357
	Group? (Yes)	-0.080	0.124		-0.646	0.519

[a] Standardized coefficients can only be computed for continuous predictors.

Descriptives				
	N	**Mean**	**SD**	**SE**
Intent	163	3.724	1.135	0.089
Avg Tech	163	3.319	0.892	0.070
Avg Pedagogy	163	3.630	0.927	0.073

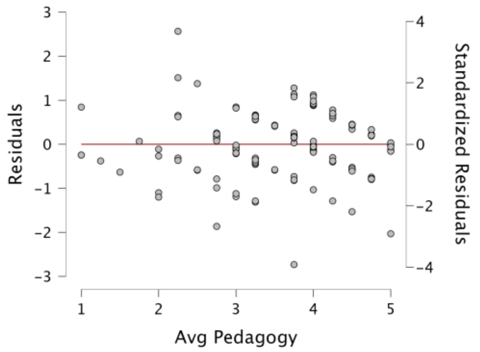
Residuals Statistics					
	Minimum	**Maximum**	**Mean**	**SD**	**N**
Predicted Value	1.156	5.157	3.724	0.895	163
Residual	-2.732	2.566	4.768×10^{-18}	0.697	163
Std. Predicted Value	-2.868	1.600	-2.084×10^{-16}	1.000	163

Residuals Statistics

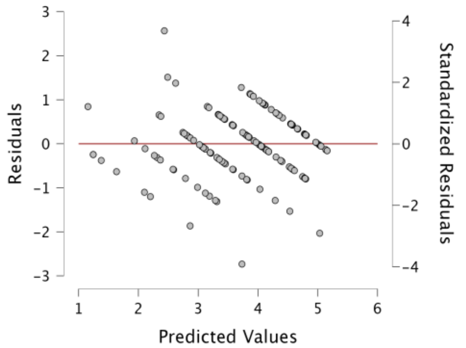
	Minimum	Maximum	Mean	SD	N
Std. Residual	-3.936	3.718	4.805×10^{-4}	1.004	163

Residuals vs. Covariates

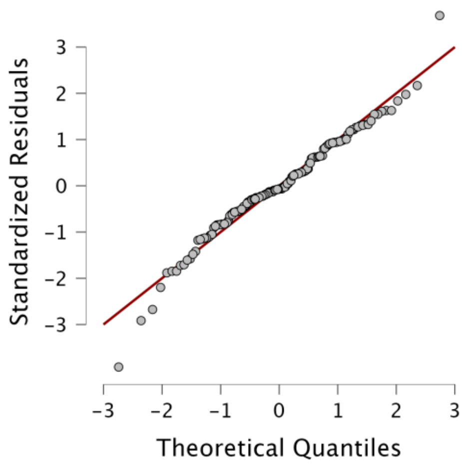
Residuals vs. Avg Pedagogy



Residuals vs. Predicted



Q-Q Plot Standardized Residuals



Virtual Reality in Social Work Teaching - Two Approaches to 360° Videos and Collaborative Working

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https://doi.org/10.34190/ejel.21.6.3225

Abstract: The use of virtual reality and 360° videos has been little researched so far, especially in social work studies and teaching. The reasons for this are the low prevalence of VR headsets in social work courses and the fundamental technological deficit in social work, which means the lack of clear causal chains within it. Professionals must adapt their practical knowledge to the individual framework conditions and problem situations depending on the case situation and field of work. In contrast, in simulation-based approaches, as used in the teaching of many rather object-oriented courses of study, fixed sequences of action usually lead to success. At the same time, 360° videos, with suitable didactic framing, can be used to convey case studies in an immersive manner that can then be continued individually, methodically developed and reflected upon. In the" Teilprojekt XR", two approaches to the use of VR headsets were designed, the first enables remote collaboration, the second offers a chance for analysis and reflection using 360° videos. The first approach is Collaborative work using VR headsets, which is intended to be an addition to communication with existing video conferencing systems. It has the potential to counteract the previous challenges associated with zoom technology and create more proximity. The first few evaluation results (n=11) on the methodological implementation of collaborative work with VR headsets suggest that this approach can bring added value to students. However, getting started with VR headsets is challenging for students and only a few have taken up the offer so far. The integration of 360° videos in education has potential for social work, as the high degree of realism and immersion can improve the link between theory and practice. Students can thus obtain realistic insights into practical examples already during their studies and professionally reflect on their own perspective in the situations. The use of 360° videos using VR headsets has been tested and established in teaching in four seminars so far. The students experience the simulated case situations from the subjective perspective of the different protagonists and can thus more easily put themselves in their individual perspective. Didactically, these observations are professionally framed by teaching content taught in advance, group work in small numbers as well as a collaborative analysis and reflection within the seminar group. The results of the evaluation (n=60) of the integration of 360° videos into teaching are promising and show a clear potential for university didactics. A flow experience and an experience of presence were confirmed by the students when working with the 360° videos. Furthermore, the students reported that the methodological extension supported their comprehension of the course materials and validate the usefulness and advantages of using 360° videos during the seminars.

Keywords: Virtual reality, Social work, 360° videos, VR group work, Immersion, Theory-practice transfer

1. Introduction

This article deals with the relevance and implementation of virtual reality [VR] in social work teaching and presents two concrete approaches and findings of the use of VR headsets in this teaching. Specifically, based on existing applications, this article will show the extent to which both approaches provide added value for the teaching of social work. The first approach focusses on VR headsets as an alternative to video conferencing systems for collaborative group work. The second approach centres on the use of VR headsets to integrate 360° videos into lessons in order to strengthen the theory-practice transfer. In the course of the paper, 360° videos are understood as a spherical video format that combines conventional video technology with the characteristics and properties of virtual reality (Rosendahl and Wagner, 2023, p.3).

In part-time and online-supported study programmes, forms of remote collaboration are often used with the help of video conferencing systems and online learning platforms (Weinberger, et al., 2020, p.230). Due to software limitations, there are sometimes major differences between presence-based and online-based discussions (Hejna, et al., 2022, p.224). At this point, working in virtual reality can be an alternative and enrich discussion processes.

In social work as a practice-based profession and an academic discipline (IFSW 2014), theory-practice transfer is a fundamental challenge in teaching. So far, this challenge has been addressed using various forms of self-activation (for example case work as well as role playing and planning games), observation and exploration (for

Cite this article: Averbeck, F., et al. 2023. "Virtual Reality in Social Work Teaching - Two Approaches to 360° Videos and Collaborative Working", *The Electronic Journal of e-Learning, 22(3)* pp 111-123, https://doi.org/10.34190/ejel.21.6.3225

example practice visits), practice phases of the students and reports by practitioners (guest lectures) (Matthies, 2020, p.59). These methods can be supplemented with the help of the possibilities of 360° videos and expanded with new methodological approaches. The first implementations of the second approach showed positive results in the presence and flow experience, and the students also reported that the 360° videos contributed to a better understanding of the teaching content and an active engagement with it.

The "Teilprojekt XR", which is part of the "H³-Projekt", addresses precisely these two challenges. Within the project, the use of VR headsets in social work teaching is being tested and evaluated, with the goal of expanding university didactics by means of new approaches and methods. By connecting with the part-time study programmes "BASA-online" and "maps", these can be tested directly within established online-supported study programmes.

First, the second chapter outlines the growing state of research on the use of virtual reality and VR headsets in higher education and summarises findings on 360° videos in teaching and on collaborative work. In addition, central terminology is outlined. In the third chapter, the two approaches using virtual reality and VR headsets are presented in more detail. Finally, results of the implementation in the seminars are presented (Chapter 4). These provide information about the consequences and benefits of the project approaches (Chapters 4.1 and 4.2).

2. Definition of Terms and State of Research

Due to the increasing digitalisation of both living and working environments, new competence profiles are required to participate actively in society. Social processes and the world of work increasingly become more interdisciplinary and collaborative in the future. As a result, future professionals must gain confidence in using digital media (Lermen, 2017, p.342). One aspect of these changing living and working environments may be virtual spaces in the future, which could play an increasing role in the lives of many people. In the area of teaching, these can represent a supplement and enrichment for established teaching formats (Zhang, et al., 2022, p.1).

In the following, definitions of the central terms used in this article will be given and a brief overview of the state of research will be presented.

Virtual Reality (VR)

Virtual reality is a three-dimensional computer-generated environment that creates an immersive, multi-sensory and user-centred experience (Langer, 2020, p.20). Virtual reality is usually experienced through VR headsets, which are worn on the head and place displays directly in front of the user's eyes (Grimm, et al., 2019, p.170).

Immersion represents a state of perception created by the allocation of the user's attention to the medium and its content (Langer 2020, p.42). It is a phenomenon of experience and not a characteristic of a device, and the degree of immersion depends on the content of the media presented, the preparation and the fit (Kerres, Mulders and Buchner, 2022, p.314-315). Immersion creates a feeling of involvement and presence, so that the users get the feeling of being in the middle of the presented or mediated environment. Immersion shows parallels to the flow experience, which can also arise in VR applications and is closely linked to optimal challenges (Kerres, Mulders and Buchner, 2022, pp.317-318).

Virtual reality can create a great sense of illusion of place and presence, which might have a strong impact on emotional responses and empathy (Christofi, Hadjipanayi and Michael-Grigoriou, 2022, p.2). For example, many studies show that a strong sense of presence fosters realistic user behaviour (Diemer, et al., 2015; Parsons and Rizzo, 2008). This creates the opportunity to generate experiences within a safe framework and with few resources, which can nevertheless generate realistic cognitive and emotional reactions (Della Libera, et al., 2023, p.1). In principle, positive effects can be assumed in the interrelationship between the experience of presence and flow and the learning effects, since immersion creates a stronger experience of presence and this can have an effect on the experience of flow and the learning effects (Zinn and Ariali, 2020; Pirker and Dengel, 2021).

The state of research on virtual reality in educational contexts has been growing steadily over the last decade due to the increasing availability of software and hardware (Zhang, et al., 2022, p.1). Different trends can be identified depending on the subject area. In a survey of available applications (n=136) for higher education teaching from 2021, it was shown that the proportion of applications for more object-related courses (biology, astronomy and engineering) was highest there at 41% (Radianti, et al., 2021, p.128). The study cited did not include any applications targeting social work courses (Radianti, et al., 2021, p.128).

Currently, it can be used to create action sequences that can be practised, to analyse situations and to represent elements that are not visible in reality (for example radiation, magnetism). Virtual learning environments are often created in the form of simulations in which sequences of action can be reproduced and practised. This can save resources and provide safe testing grounds (Calandra, et al., 2022, pp.3-4).

Collaborative work

Collaborative processes in social interactions are an essential building block for knowledge acquisition (Bandura, 1977; Lave, 1991), as is the acquisition of shared knowledge through feedback loops (Foelsing and Schmitz, 2021, p.114). Collaborative work is fundamentally characterised by the fact that the participants work together to acquire knowledge and thus anchor and deepen the acquired knowledge, for which social exchange and active participation are essential as success factors (Foelsing and Schmitz, 2021, p.114).

Particularly, in the context of the corona pandemic years, the need for online communication has increased, along with the challenges of remote collaboration. Video conferencing systems are mostly used for this purpose, which, compared to face-to-face communication, make it more difficult to feel physically close and present. Verbal and partly non-verbal articulations of the counterpart can be perceived, but a deficit remains in the area of experiencing sociality (especially in group conversations). This deficit manifests itself in the absence of elements of turning towards and away from the other person and of eye contact, which are essential to the flow of a conversation and regulate it naturally (Kerres, Mulders and Buchner, 2022, p.319). This can have an impact on communication processes (Wei, Jin and Fan, 2022). Increased fatigue, known as zoom fatigue, can occur due to a lack of closeness to the other person and changes in non-verbal communication (Fauville, et al., 2021, p.11). Reasons for the development of increased fatigue include:

- Cognitive load due to the feeling of constant visual contact and the resulting perceived lack of social distance
- The perceived restriction of movement through the frame of the camera image
- Cognitive load due to constant analysis of non-verbal signals and permanent self-monitoring of one's own expression (Bailenson, 2021; Rumpf, Bühringer and Mühlig, 2021, cited in Hejna, et al., 2022).

Collaborative work within virtual reality allows a more immersive and natural environment than traditional video conferencing systems (Fromm, Mirbabaie and Stieglitz, 2020, p.11), which can lead to more considerate, empathetic, less aggressive behaviour and increased communication quality (Wei, Jin and Fan, 2022). According to Smith and Neff (2018), verbal and non-verbal communication behaviours in VR applications and face-to-face situations are quite similar when communication partners are embodied as avatars (Smith and Neff, 2018, p.10). The psychological relationship between users and avatars creates a sense of social presence (Della Libera, et al., 2023, p.12), which can have positive effects on collaborative work phases. These advantages over traditional video conferencing systems were confirmed in a qualitative study on the work of small groups with different living and working locations in brainstorming processes (Fromm, Mirbabaie and Stieglitz, 2020, p.13).

360° videos

360° videos represent a video format that makes it possible to capture a situation or an environment in the full 360° visual spectrum. A three-dimensional effect is achieved by filming in stereoscopic shots, i.e. using at least two lenses placed at eye distance. Three-dimensional and preferably high-resolution images enhance the effects of immersion and the experience of presence in 360° videos (Stelzmann, Toth and Schieferdecker, 2022, p.198).

Research on 360° videos in teaching is still at an early phase, but is growing steadily (Ranieri, et al., 2022, p.1204). In a meta-study by Pirker and Dengel (2021), over half of the 64 included studies showed a positive effect of learning with 360° videos. In particular, factors such as an increased experience of presence, positive effects on perception, increased engagement, better conveyance of emotions and better conveyance of empathy were found (Pirker and Dengel, 2021, p.83). Improved knowledge acquisition, a comprehension-enhancing experience, increased motivation and improved performance were also found in some of the studies (Pirker and Dengel, 2021, p.83). With the help of 360° videos, immersive learning environments can be created that make it possible to directly experience the simulated case situations (Veber, Pesek and Abersek, 2023, p.3). In this context, studies have shown that 360° videos are able to generate emotional reactions (Della Libera et al. 2023, p.3). This opens up new ways and strategies to promote empathy in social work studies (Rambaree, et al., 2023, p.2).

The results show that 360° videos can play an important role in social work education. In order to be able to establish and widely use them in university teaching, it is necessary to develop and test suitable concepts and prepare teachers in the use of the new technologies (Wiesche, Schäfer and Sträter, 2023, p.22).

3. Two Approaches for Social Work Education

When developing possible approaches for the use of virtual reality and VR headsets in social work studies, various points of contact arise.

The project is linked to online-supported and in-service study programmes, so that approaches to remote teaching seem to make sense, even independently of the corona pandemic. Due to the existing disadvantages of video conferencing systems, there is a great need for alternatives.

The technology deficit based on the reality of working with people in their very individual problem and life situations. This causes the lack of causal chains, i.e. simple cause-effect relationships, so that social workers have to constantly adapt and individualise their own methodological implementation (Hörster, 2021, p.119). This means that simulation-based applications cannot be used well. Students should therefore not memorise concrete sequences of action, but rather develop a feeling for how they can encounter clients in practice. At the same time, the theory-practice transfer in social work studies - as described - is a general challenge that has so far been met by means of various methods, such as role-playing. At this point, the potentials of higher immersion, emotion transfer and representation of inaccessible work and situation contexts can be used for teaching.

Based on these considerations, two project approaches were developed: firstly, collaborative work using VR headsets and secondly, improving theory-practice transfer with the help of 360° videos for teaching.

In the context of the project, Meta Quest 2 headsets are used, which are advantageous for collaborative work due to broadly based, free software solutions. In addition, they can be used as so-called standalone headsets without additional hardware. This means they can be lent out at a low threshold and at the same time are characterised by a justifiable price-performance ratio. In order to ensure data protection as comprehensively as possible for the students, project-related accounts are used on the headsets. This prevents the requirement to provide personal information during the account creation process.

3.1 Collaborative Work

In the design of online-supported and part-time study programmes, remote group work phases cannot be avoided, as the students usually do not live close enough to meet in person. In some cases, they have to work in small groups on common tasks over periods of one to several semesters. At this point working in virtual rooms can be an alternative.

The students receive VR headsets and the necessary accessories for use in the home environment. For this purpose, an extensive pool of instructional videos was created to help students familiarise themselves with the VR headsets. In addition to the instruction videos, a separate course room is available on the learning platform (OpenOlat) so that informal exchange and mutual support possibilities are guaranteed. After an initial introduction to the VR headsets (approx. one hour) and possible workspaces (the application "Horizon Workrooms" is recommended), the students can borrow the VR headsets and work with them in the virtual spaces. Initially, fewer headsets were lent out than expected and even headsets that had already been lent out were little used. Likewise, few students participated in the evaluation of the offer. Feedback from the students indicated that this was mainly due to a lack of confidence in using the hardware and software independently. For a more in-depth introduction to Virtual Reality and VR headsets, students can now take part in an introductory course over two days of 2.5 hours each.

Within the introductory course, the following topics are worked on with the students:

- Social work and basics and developments of virtual reality
- Comparison of the advantages and disadvantages of digital and virtual collaboration
- Testing and organising cooperation in small VR groups
- Exploring and testing social VR applications
- Application and development of methods within the virtual space
- Practical transfer of the acquired knowledge to social work

To ensure low-threshold access to virtual reality and the associated hardware and software, the introductory event is characterised by playful and explorative learning (Figure 1: Testing within an introductory event). Participants should primarily be able to pursue their own interests in a self-directed manner, but always with professional guidance, and thus open up to VR technology. Accordingly, the students can build up the necessary confidence for independent use and try out various software offers (Figure 2: Testing of Horizon Workrooms by students).

Figure 1: Testing within an introductory event

Figure 2: Testing of Horizon Workrooms by students

The stock of VR headsets for student rental consists of 20 VR headsets and is supplemented by additional accessories, for example different head mounts to increase comfort, spacers for wearers of glasses and special keyboards that can also be used in virtual reality. The group work tasks are determined by the respective teacher. Students are free to combine working with the VR headsets with other methods of remote collaboration, for example using the headsets only for brainstorming and discussion phases.

3.2 360° videos for Teaching

For the theory-practice transfer, internships, role plays, reflection and case analyses, among others, are used in social work studies (Matthies, 2020, p.59). The use of 360° videos represents a new approach to creating authentic learning situations in which action can be tested in realistic case constellations (Davidsen, et al., 2022, pp.2-3). Existing seminars are supplemented with 360° videos, whereby the planning and design of the case studies, the script and the didactic implementation take place in close cooperation with the teachers. Figure 3: Creation of 360° videos and didactic implementation illustrates the process:

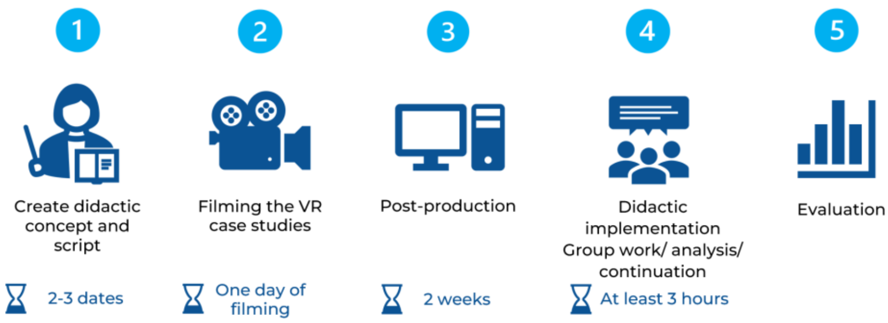

Figure 3: Creation of 360° videos and didactic implementation

This process makes it possible to create 360° videos specially designed for the respective seminar so that the teaching content is presented in a suitable didactic framework. With the 360° videos created, two purposes from the literature are taken up: on the one hand, the observation and presentation of learning content and, on the other hand, immersive videos to support theory-practice transfer (Rosendahl and Wagner, 2023, p.26; Barnidge, et al., 2022; Ros, et al., 2021; Theelen, van den Beemt and den Brok, 2020).

The developed 360° videos and the didactic framework make it possible to create individual learning processes, as there is no predefined image section, but all directions of view are possible due to the 360° all-round view (Rosendahl and Wagner, 2023, p.32). In order to make it easier for the students to take on roles and perspectives later on and to promote immersion, the situations are usually filmed from the different perspectives of the protagonists. In this way, students "experience" the communication situation of the case study from the perspective of their role (Figure 4: Small group work - viewing of 360° case studies). The adoption of perspective might have a high explanatory value in the context of learning from the model, as it places a strong emphasis on feelings and a reference to the affective personality structure (Kron, 1993, p.264).

Figure 4: Small group work - viewing of 360° case studies

So far, the videos have been used in four different seminars within the Bachelor's and Master's degree programmes. The following depiction is an example of the didactic implementation in the seminar "Crises and Critical Conversations". In this seminar of the Bachelor's programme, the videos are used to introduce situations from supervision.

- Plenary introduction
- Small group work - viewing of 360° case studies
- Collegial consultation on the respective roles & case studies
- Small group work - analysis & methodical extension of the case studies
- Group presentations in plenary - Case analysis/methodical continuation (Figure 5: Case analysis in plenary)
- Final reflection & evaluation

Figure 5: Case analysis in plenary

This process requires at least four hours of time, so that the viewing and processing phases are not calculated too tightly. Two half days or a full seminar day have proven to be an optimal framework. In this instance, an in-depth case reflection can be conducted by transferring the case studies into a plenary discussion and systematically examining them through a methodical analysis of one's personal viewpoint. For the case work with the 360° videos, handouts with information on the background and the roles of the actors are available in each case, so that the contents of the videos can be placed in context (Figure 6: Handout).

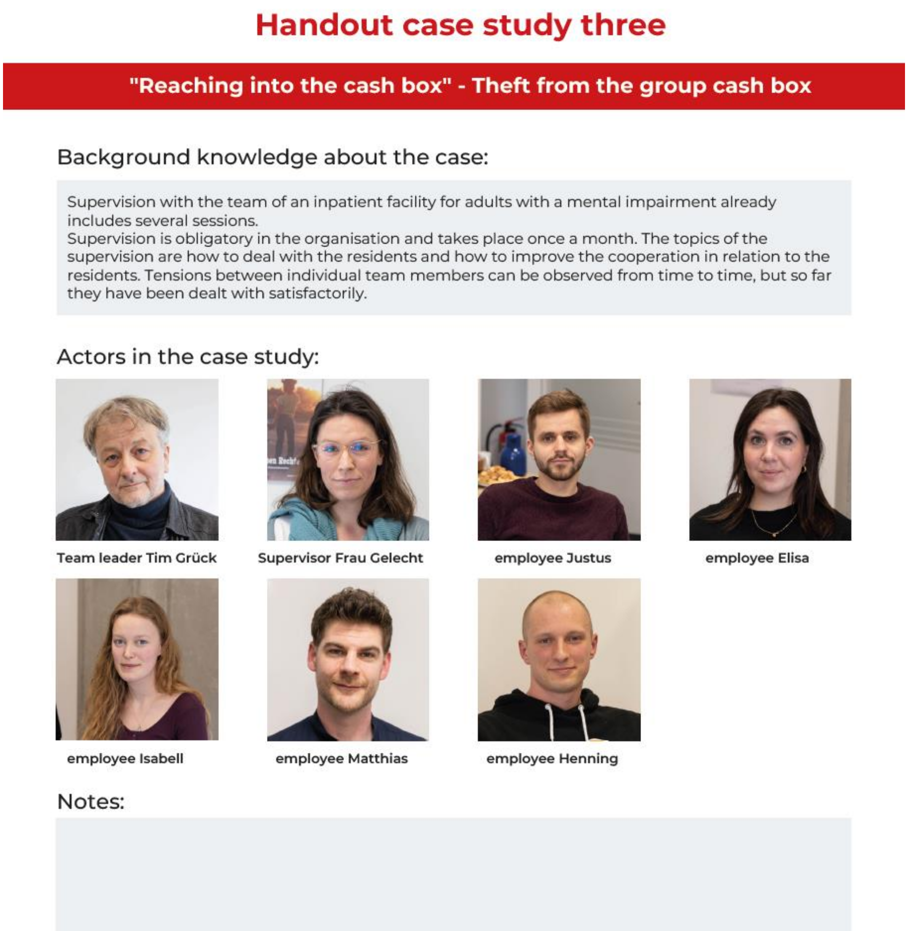

Figure 6: Handout

4. Evaluation

The evaluation of the project is process-oriented and is carried out internally (Merchel, 2019). Different questionnaires were developed for the evaluation of the two approaches, whereby on the one hand validated existing survey instruments were taken up and on the other hand own items were added.

4.1 Collaborative Work

The questionnaire for the approach of collaborative work was created in order to specifically capture the students' insights, needs, problems and challenges and to be able to make adjustments during the course of the project. On this occasion, the framework conditions were surveyed with five items (for example: "The online materials were well comprehensible in terms of content"), the work phases with eight items (for example: "Would you like to use VR headsets for remote group work again in the future?”), the influencing factors with 14 items (for example: "Did you feel very tired after the VR group work?") and additional positive and negative comments were evaluated through four open questions. The items were developed specifically for the agile evaluation of the approach and are thus not based on valid questionnaires. The questionnaire can be accessed via the following link: https://fh-muenster.sciebo.de/s/wqTMX2Pgk0VNNWU.

The evaluation of collaborative work in small groups is limited so far, as only eleven complete responses are available. Despite the small database, which does not allow any general conclusions to be drawn, initial results should be presented here.

The framework conditions were rated positively on a scale of 1 (not at all true) to 6 (completely true) overall (n=9) with M=5.78 (SD=0.44), with the hardware provided (n=11 M=4,91 SD=0,94) and the prepared online materials for explanation (n=9 M=5,22 SD=1,39) being rated particularly positively and also the embedding in the seminar essentially positively (n=10 M=5,30 SD=1,57). The work phases were evaluated overall as followed (n=11 M=3,73 SD=1,75), which represents a rather mixed evaluation and is also reflected in the verbal feedback when the VR headsets were returned. The most positive evaluation was given to the contact within the group work (n=11 M=5,73 SD=0,47) and the general satisfaction according to the interaction and communication with the help of the VR headsets (n=11 M=4,64 SD=1,75). Whether the VR headsets improved collaboration within the group was rated negatively (n=11 M=2,82 SD=1,25), as well as whether the VR headsets facilitated communication with the group (n=11 M=3,00 SD=1,61). Among the influencing factors, the focus on the virtual world was rated clearly positively (n=10 M=5,30 SD=0,95) and the user-friendliness positively (n=11 M=4,09 SD=1,76). Negative factors such as feeling unwell (nausea, dizziness) during use (n=11 M=2,18 SD=1,17), exhaustion after VR group work (n=10 M=3,60 SD=1,17) and irritation of the eyes after VR group work (n=10 M=2,40 SD=1,17) occurred to some extent among the students, although the feedback here is more in the area of "tends not to apply".

The evaluation results of the collaborative work can be classified to the extent that they depend on the conceptual integration of the VR headsets into the teaching context (Hejna, et al., 2023, p.316). In the context of the integration applied here, the students were able to use them without instructions and direct support from the teachers to accompany the seminars. Accordingly, the conceptual integration in the teaching context was completely absent, which can explain the negative results. In the small group work, which was conducted using VR headsets, the teachers did not participate in the work phases in the VR environment, which could be a negative influencing factor as well (Speidel, et al., 2023, p.9). When deciding whether to use VR headsets within group work, students find it advantageous to be able to concentrate well in the VR environment.

The evaluation results of the collaborative work enable conclusions to be drawn for the further conceptual development of the approach. Better dovetailing with the respective seminars, acceptance by the teachers and their support can have a positive impact on VR group work.

4.2 360° Videos for Teaching

The questionnaire for the 360° videos is constructed upon validated questionnaires (Schwinger, Kärchner and Gehle, 2021; Vorderer, et al., 2004; Rheinberg, Vollmeyer and Engeser, 2003) and is based on a 7-point Likert scale (1=Does not apply at all;7=Applies completely). Within the questionnaire, the flow experience as a whole is surveyed, taking into account aspects such as the occurrence of apprehension and the fit of the experience with a total of 16 items (Rheinberg, Vollmeyer and Engeser, 2003). The experience of presence is recorded more comprehensively, so that statements can be made about the students' immersion; the following topic blocks are asked with six items each (Vorderer, et al., 2004):

- Attention (ATT)
- Spatial Situation Model (SSM)
- Spatial Presence - Self Location (SPSL)
- Spatial Presence - Possible Actions (SPPA)
- Involvement (INV)
- Suspension of Disbelief (SoD)
- Domain Specific Interest (DSI)
- Visual-Spatial Imagery (VSI)

For this purpose, the quality of the 360° videos created is surveyed with the help of eleven items (Schwinger, Kärchner and Gehle, 2021), the user-friendliness of the VR headsets and the software used with four items, the embedding in the course with two items, possible nausea (motion sickness) with two items and the overall assessment of the use in the course with three items. At the conclusion of the questionnaire, students are able to answer four open questions for additional positive and negative feedback, as well as suggestions for improvement. The questionnaire can be accessed via the following link: https://fh-muenster.sciebo.de/s/wqTMX2Pgk0VNNWU.

The evaluation results of four implementations in different seminars provide initial insights into the added value of using 360° videos in education. The evaluation focuses particularly on the two phenomena of presence and flow experience, as these are presented in the literature as the main aspects in the context of immersion and added value compared to conventional media. A total of 60 students (n=60) fully participated in the evaluation.

The students evaluate the flow experience immediately after the application in the seminar with a mean value of 5.11 (SD=0.81), so that it can be assumed that the integration of the 360° videos has a positive influence on this. This positive influence is reinforced by the challenge fit scale (1= low, 4= just right, 7= high) in the questionnaire of flow experience, according to which the fit in the "just right" range is 3.93 out of 7 (SD=0.59). The experience of presence is rated as strongly present overall with M=4.82 (SD=0.52), detailed in the respective sub-areas:

- Attention (ATT) M=5.73 (SD=0.86)
- Spatial Situation Model (SSM) M=5.93 (SD=0.65)
- Spatial Presence - Self Location (SPSL) M=4.94 (SD=0.99)
- Spatial Presence - Possible Actions (SPPA) M=3.47 (SD=1.19)
- Involvement (INV) M=5.28 (SD=0.85)
- Suspension of Disbelief (SoD) M=5.10 (SD=0.64)
- Domain Specific Interest (DSI) M=3.62 (SD=1.36)
- Visual-Spatial Imagery (VSI) M=4.46 (SD=1.35)

It is noticeable that the values for the spatial situation model (SPSL) and the attention allocation (ATT) are the highest. This indicates a pronounced focus of attention on the content, as well as a clear presentation of the spatial environment and case situation, so that it is perceived as comprehensible.

Two areas, the interactivity of the videos (SPPA) and the area-specific interest (DSI), are rated rather negatively. In particular the aspect of interactivity is understandable in the negative evaluation, since there is no possibility of interaction within the videos, apart from the possibility of pausing or fast-forwarding and rewinding. In the area-specific interest, it becomes clear that the students only partially have previous points of reference and interests in the new technology of VR headsets. Nevertheless, it can be confirmed that the 360° videos create an overall sense of immersion and, in some aspects, that this experience is very pronounced. The degree of immersion of the playback medium can have a significant impact on learning motivation and success (Rosendahl and Wagner, 2023, p.28).

The students' overall assessment of the statements on integration into teaching (M=6.0, SD=0.96), stimulation to engage with the content (M=6.13 SD=0.87), embedding in the course (M=6.07 SD=1.04), promotion of understanding (M=6.18 SD=0.87) and the closeness to reality of the environment (M=6.10 SD=0.83) was extremely positive and encouraging for further implementation. However, a total of six students also felt physical discomfort to be "rather true" to "completely true", which corresponds to the occurrence of the motion sickness phenomenon in about one tenth of the students.

Based on the evaluation results, it can be concluded that 360° videos and viewing them through VR headsets is an added value to social work education. By embedding the 360° videos, students can, among other things, expand their empathic and emotional skills (Rambaree, et al., 2023, p.14) and experience a direct connection between theory and practical examples.

5. Discussion

Within the contribution, two approaches were presented with which, through the use of virtual reality and 360° videos, the teaching of social work can be enhanced and expanded. The findings on collaborative work using virtual reality are still very limited and only provide small exploratory insights into the hurdles and opportunities of this approach for online-based study programmes. At this point, an implementation in regular teaching could be an opportunity to enrich and support a whole seminar with the help of virtual reality. Since this is associated with an increased effort on the part of the teachers and has not yet been implemented, it is not yet possible to present any in-depth findings. Only the self-learning and work phases of groups could be supplemented so far and were accepted partly well and partly rather cautiously.

In contrast, there are more comprehensive evaluation results for the 360° videos, which, with a sample size of 60 participants, show initial advantages in the area of immersion, learning motivation and theory-practice transfer. The advantage of the realistic depiction of case studies in 360° videos also became clear, which was also considered by Della Libera, et al. (2023, p.12) and Gazzelloni, et al. (2023, p.124).

The main limitation of 360° videos is the lack of interactivity, as the students are purely observers of the situation (Tarantini, 2023, p.217) and the didactic design must therefore be based on this aspect, for example by following up the videos with role plays. However, the role of the viewer can be quite different from watching regular 2D videos due to the panoramic view, which provides various perspectives and views of the scenario (Ferdig, Kosko and Gandolfi, 2023, p.4; Rosendahl, Müller and Wagner, 2023, p.795; Roche, Rolland and Cunningham, 2023, pp.44).

The 360° videos provide a learning experience in which the students are able to improve their empathic competences. By adopting the first-person perspective of the actors, students can better empathise with them (Chao, et al., 2021, p.15). The high motivation potential as well as interest and commitment of the learners attributed to the 360° videos (Rosendahl and Wagner, 2023, pp.29-30) could be confirmed in the evaluation. In further research, learning-based outcomes could be collected in a control group design to complement the previous findings. This could provide further insights into the added value of the approach.

The pedagogical and didactic potential of creating 360° videos has not yet been fully exhausted, as the production of these is carried out entirely by the project and the teachers. Besides, the students have not yet been involved in video conception processes. Here, the learners could become more involved by independently conceptualising or creating the 360° videos in group work, which can lead also to the generation of knowledge through social interaction (Funk and Schmidt, 2023, p.308). The creation of the 360° videos becomes possible and practical for the seminar context through the availability of, meanwhile, cheaper cameras and VR headsets (Ionescu, et al., 2021, p.17).

6. Conclusion

The two approaches presented for the implementation of virtual reality and VR headsets in social work teaching can be formulated as a recommendation for action for pedagogical study programmes, taking into account the findings of the evaluation.

For a transfer of the approach to remote collaborative working, the previous findings can be summarised in five points:

- A comprehensive instruction pool is recommended, as the instructions freely available online are not always tailored to the needs of the students.
- In addition to VR headsets, special keyboards and different head mounts should also be offered so that comfort during the work phases is as high as possible.
- The VR headsets should be a voluntary offer, as their use may cause discomfort for a few students, which should not lead to exclusion.
- A detailed introductory session enables the students to help themselves after a short time and to have internalised the operation and the technical possibilities for the most part.
- Collaborative work with VR headsets should only be a supplement to existing video conferencing systems.

The evaluation results on 360° videos for teaching confirm the already suspected added values of teaching content in the subject areas of methodological analysis, reflection on communication processes, perspective taking and the application of methods based on 360° videos as a starting example. Six recommendations for action for transfer can also be formulated here:

- Cooperation with the teachers of the seminars is essential for a didactically meaningful implementation of 360° videos.
- A high technical quality of the media created enhances the immersion and thus the experience of presence in the 360° videos.
- The duration of the 360° videos should not exceed the limit of three minutes per sequence, as this can increase waiting times during the execution and reduce attention.
- One supervisor for five VR headsets is optimal.
- To minimize waiting times, it is recommended that there be one set of VR headsets for every two students.
- If the VR headsets are used several times in the seminar, the supervision effort decreases over time, as the students quickly learn to use them independently.

The project's findings demonstrate that the implementation of virtual reality and VR headsets in teaching, especially in social work, is still in early stages, but it's worth experimenting with new methods in this area. Especially in the area of theory-practice transfer, these can create added value for the teaching of pedagogical professions.

Within the framework of the project, a new perspective for the creation and use of 360° videos has emerged. In cooperation with the software prototype "Paneo-VR" by "Mixality", a new series of 360° videos should be produced that are interdependent and should offer different scenarios based on a decision tree. For this purpose, the 360° videos are equipped with interaction elements (for example dialogue field), so that one can select different reactions and continuations of the situations. This new approach is intended to enable teachers and students to use VR headsets with self-learning resources, which, compared to conventional seminar implementations, can provide more flexibility, self-organisation and decision-making opportunities. The independent choice of interactions can enable students to gain individual experiences in the scenarios and thus enrich the discussions and analyses based on them (Langer, 2020, p.111). As a conclusion, the developed approaches will be transferred to higher education institutions as part of the "BASA-online" higher education network, so that they can be tested and, if necessary, anchored in higher education institutions.

Acknowledgements

The "Teilprojekt XR" of "H³-Projekt" is funded by the "Stiftung Innovation in der Hochschullehre" of 08/21-12/25. The projects goal is the development of new methodological approaches with the help of VR headsets for social work and the transference of the results to the university landscape.

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Virtual Gathering Platforms in Academic Teaching: Potential and Applications

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https://doi.org/10.34190/ejel.22.3.3263

Abstract: The COVID-19 pandemic resulted in a rapid shift towards online learning where educators and students had to quickly adapt to new digital formats. However, the core aspects of community building and social interaction that are essential to traditional classrooms became challenging to maintain. To address this issue, we were interested in testing Virtual Gathering Platforms (VGPs) *Topia* and *WorkAdventure* to see how effectively they could be adapted to various academic teaching and learning settings. These examples of Extended Realities (XR), adopted from the 2D metaverse, aim to improve communication and interactivity in a fun and engaging way, allowing users to create immersive worlds for socialising, and collaborating. Using Technological Pedagogical Content Knowledge (TPACK), Technological Self-Efficacy (TSE) and distributed scaffolding frameworks as a guide, we created adaptable templates of both platforms that not only introduced users to how they work, but also included features flexible enough to suit various academic disciplines and promote social engagement and collaborative learning. We then implemented a case study and invited university educators teaching international courses to adapt the templates and assess them within their own learning settings. In addition, it was important for us to use the on-boarding sessions as a focal point. Here, we introduced the templates through multiple resources and offered one-to-one support to develop their use within chosen learning scenarios which ranged from an icebreaker activity to an online student resource centre. Observations then documented the adapted templates being used with students in these settings, and feedback regarding user perceptions of the platforms and the support strategies used was gathered. The study reveals the complex interplay between user experiences, support strategies, and educational frameworks, emphasising the need for adaptable and collaborative approaches to optimise these platforms in higher education.

Keywords: Online learning, Gamification, Virtual gathering platforms, Community building, Social interaction, Collaborative platforms, The metaverse, Teacher support, Digital competencies, Extended realities, Technological pedagogy

1. Introduction

Understanding the impact of emerging technologies in education is crucial for meaningful advancements in teaching and learning practices (Oliveira et al., 2019). This paper explores Technological Integration (TI), defined as the incorporation of technology into educational settings to support educational objectives (Consoli, Désiron & Cattaneo, 2023). Within this framework, Extended Realities (XR), like virtual and augmented reality (Mann and Wyckoff, 1991), have emerged as transformative tools, and metaverse environments in particular, have demonstrated promise in educational contexts, addressing challenges such as maintaining community and collaboration in online settings. However, examples regarding simpler formats, namely 2D metaverse technologies, are less prominent. Therefore, by drawing on the example of Virtual Gathering Platforms (VGPs*),* a 2D virtual gamified interactive meeting space (Le, MacIntyre and Outlaw, 2020), this paper bridges these existing research gaps by exploring user perceptions and approaches to these platforms, identifying relevant support structures that enhance their use.

In doing so, we aim to contribute to the evaluation of VGPs in alignment with Technological Pedagogical Content Knowledge (TPACK), Technological Self-Efficacy (TSE), and distributed scaffolding frameworks, and to identify areas for future research. With these goals in mind, this paper will first delve into the methodology employed to assess VGPs, followed by an analysis of user perception and support strategies. The study employed a single case study approach using a "triangulation," (Flick, 2007, p.43) data collection method which included observations, interviews, and surveys, thus providing a more detailed comparison on the varied insights into this under-researched area.

Cite this article: Foster, S., Barth, L. and Chaudhry, Z. 2024. "Virtual Gathering Platforms in Academic Teaching: Potential and Applications", *The Electronic Journal of e-Learning, 22(3)* pp 124-140, https://doi.org/10.34190/ejel.22.3.3263

2. Literature Review

2.1 The Education Metaverse Post COVID-19 Pandemic

Even before the pandemic, many universities had established networks and initiatives to promote digitalisation and technical competencies among the university community (Song, 2023), suggesting an already existing focus on digital engagement and skills development (Caena and Redecker, 2019). Yet when the pandemic began and university campuses had to close, new challenges emerged and lecturers had to quickly find solutions by transferring to fully digital formats (Kara, 2021; Fauzi, 2022). Whereas already established online course management systems such as *Moodle* provided a centralised platform for delivering course content, video conferencing software like *Zoom* and *MS Teams* became essential for hosting virtual meetings, classes, and events (Leporini, Buzzi, and Hersh, 2023). These platforms also allowed for features to support continued engagement which not only helped maintain academic continuity but opened further possibilities of social interaction in purely online settings.

This ultimately aided research into collaborative learning through XR of which, due to its recent in fruition and interest, the metaverse will be focussed on. The concept of the metaverse is said to have originated in the 1990s through the works of Neal Stephenson (Ball, 2022) and the first well-known metaverse, virtual world platform *Second Life,* was developed by San Francisco-based firm Linden Lab in 2003 (Orland, 2021). Its aim is online social connection where the user logs into a non-downloadable software replicating a three-dimensional world. To navigate through this, they are represented as an avatar and can access various forms of social media, browse content with other visitors and chat or send messages (Au, 2008). These metaverses are primarily used for multiplayer gaming like *World of Warcraft* and *Fortnite*, however they have also transferred to the education sector and used for virtual classrooms, labs, and training simulations (Kye, et al. 2021). Several studies in this area have already investigated the advantages of these technologies and their potential in creating a more dynamic learning environment that engages students. For example, Zheng, Jun and Di (2022) states that the metaverse can motivate and engage learners because of their immersive and game-like qualities. This is further supported by Jovanović and Milosavljević (2022), who concluded that the metaverse allows for a more entertaining experience of otherwise dry topics making students more motivated and accepting of the subject. In addition, a metaverse can give access to various resources from all over the world and facilitate simulations of experiments that would otherwise be inaccessible or dangerous. For example, Kshetri (2022), noted that the simulation of real environments is not only able to replicate practical exercises, but students feel safe when immersed in them.

However, research into the challenges of metaverse technology cannot be ignored, especially with relation to technical limitations, software requirements and a lack of regulation and security concerns. (Ahmad, et al., 2022). When discussing the potential of metaverse in future teaching and learning scenarios, Onu, Pradhan and Mbohwa (2023) concluded that the technology needed to create and access metaverse environments remains challenging and expensive. In addition, there is still a lack of pedagogical content or class material available for metaverse technologies, limiting educators and students and preventing opportunities to standardise these platforms. Furthermore, there are strong concerns about privacy which Qiu, García-Aracil and Isusi-Fagoaga (2023) highlights as the main issue as with any online environment. This can prevent educators and students feeling comfortable sharing their personal information and engaging in online activities. There is also a compelling case made by Badger, et al. (2023) on how being immersed in virtual worlds can affect students' actions, heightening the risk of cyber bullying and inappropriate behaviour.

Overall, despite its analysis in educational settings, there is limited research into educator's perceptions and their approaches to using this software in their teaching (Downie. et al., 2021). It has been argued that the more positive teacher's perceptions are to the metaverse, the more successful their use in the teaching and learning process, leading to a more developed integration of these technologies (Sunardi. et al., 2022). However, Frith (2022) has argued that more case studies are needed to examine its potential in facilitating learning outcomes before it can become an educational tool. Therefore, by identifying this gap, this study aims to track their integration from a teacher perspective. Namely, to initiate support for educators to adapt metaverse software to their courses, observe this adaption and collect feedback. From there, we can identify practical approaches for metaverse-based teaching and learning and consider how to design resources that aid student learning and develop technical competencies for teachers.

2.2 The 2D Metaverse and VLPs

There is the common view that the metaverse exists through a 3D interface where users meet within an immersive VR environment (Gallagher and Forman, 2021). However, formats on a smaller, 2D scale have also been utilised by various educational institutions as an alternative for current video conference meetings (Larsen, 2022). Allowing people to interact more naturally in these 2D environments attempts to bridge the gap between real-life and virtual interactions. One example are VGPs, where users create an avatar to navigate within a 2D virtual map (Maclntyre and Outlaw, 2020). They mimic many features of real-life interactions and are integrated with spatial technology which connects other users via audio, video, and a chat function when their avatars are close together. When the user moves away, the video stops and the sound mutes. Unlike a video conference call, users are not forced within a single conversation, giving users more fluidly between conversations as speakers or listeners (Kshetri, 2022). In addition, these virtual worlds can be customised depending on the needs of the users, whether it be a virtual office or online event, various platforms offer templates that can be adapted. In his topology of metaverses, Kshetri (2022) highlighted that virtual gathering technology is decentralised and numerous examples of this software exist, many of which becoming established during the COVID pandemic. After researching various examples, five platforms have been selected (Fig.1) alongside our general definition of the metaverse introduced in section 2.1 of this paper.

	Gather	**Wonder.me***	**WorkAdventure**	**Topia**	**Definition of Metaverse**
Features					
Interactive Elements and features	Personalised avatars, collaboration tools: digital whiteboard, emoticons, and reactions. Broadcast and Follow Me feature.	Partially customisable profile pictures as avatars, emoticons, Pop-up icebreaker questions. Broadcasting is available.	Completely customisable avatars. Pop-up split screens with interactive tools, emoticons, and reactions. Moderators can send global messages to all users	Simple monotone figures as avatars. Pop-up messages, maps, and other media applications. YouTube links can be integrated. emoticons and other reactions can be sent	Highly rendered, completely customisable avatars. Collaborative designing and prototyping of models in a virtual environment, social interaction tools available
Customisation	Can embed whiteboards, customisable objects, *Google* Docs, *Microsoft* Docs and PDFs	Only background and profile pictures are customisable	Possibility of embedding external websites, learning management systems etc. Objects completely customisable.	Possibility of linking external websites, learning management systems, live streams etc. Objects and environment both completely customisable.	In a large virtual environment, customisation of all elements possible, possibility of embedding different commercial and non-commercial websites.
Data Security	SOC 2 Type II certified, not GDPR complaint	GDPR complaint	Can be fully secure when self-hosted	Partially GDPR complaint	Not completely GDPR complaint
User Capacity	Free Plan: Up to 10 users Paid Plan: Up to 500 users	Up to 500 users	Free Plan: Up to 15 users Paid Plan: Unlimited number of users	Free Plan: Up to 10 users Paid Plan: Between 20 and 200,000 users	Unlimited number of users
Commercial aspect	Online meetings, collaborative work and team building activities (escape rooms)	Online meetings	Open source, everything accessible	Buying and selling NFTs and Map Templates, promoting online events	Can be fully used for commercial purposes

*No longer in operation as of April 2023

Figure 1: Virtual Gathering Platforms

In contrast to the 3D metaverse, the features of VGPs have the potential to promote online collaboration due to their social nature and capacity to integrate exchange through a variety of communication channels. In addition, they house the gaming mechanisms that not only supports university learning strategies but fits the technical awareness and receptiveness of the current student demographic. This can be reinforced by pedagogical perspectives on collaborative learning and how these platforms have the potential to further enhance it. For example, Gabbert's five basic elements of collaborative learning (Gabbert, Johnson and Johnson 1986) includes positive goal interdependence, verbal interchange, effective communication, individual accountability and group reflection and processing. This also can be further supported with Roodt, de Villiers and Joubert (2012) who linked the importance of collaborative learning with the current university student demographic, the *Net* and *Z Generations*. They have more of a preference for group and peer learning because of their responsiveness and affinity towards multi-media, gaming, and social media technologies. Therefore, students could benefit from teachers using game-based learning as a pedagogical concept. In addition, it can be argued that VGPs could work well within university settings, because course content follows a blended learning approach that requires more independence from the learner. Currently, Virtual Learning Environments (VLEs) and Massive Open Online Courses (MOOC) are the most well-known ways of combining blended and flipped classroom approaches and these platforms could also be integrated into these learning techniques in a more personalised way. For example, they can be accessed at any time which can help build learners' self-confidence and autonomy and learner relationships can still be developed outside of classroom hours. The flexibility of these programs and their capacity to integrate various online tasks and tools could also increase goal-orientation and more personalised learning objectives.

The decision on which platform to use should be based on the intended purpose of the virtual environment and the features that best align with the goals of the users. As evident from the comparison in Fig. 1, *WorkAdventure* and *Topia* were preferred choices due to their simpler features and functions. For one, *WorkAdventure* has the advantage of being self-hosted, making it completely data secure. Conversely, *Topia*'s simplicity and quick set-up makes it suitable for collaborative sessions or team meetings, while *WorkAdventure*'s customisation capabilities cater to more complex virtual events or interactive experiences. However, for educators and students to put their trust into using VGPs and integrate them successfully and efficiently has its challenges. Firstly, Kshetri (2022) noted that many of these VGPs require an advanced network and computing infrastructure. For example, the video chat is a necessary component for the experience, which requires extremely low latency as users move around and connect to each other. Therefore, fears in achieving a stable connection and making sure the system functions effectively could prevent universities from wanting to work with this technology. Furthermore, in a study conducted right before the pandemic by Amhag, et. al. (2019) which investigated university teacher's use of digital tools and need for digital competence, it was concluded that teachers were not primarily using digital tools for pedagogical purposes. This claim is further supported by various OECD surveys that assessed teachers' engagement in online learning activities as being rather limited and the sudden switch to online teaching during COVID-19 highlighted the difficulties educators faced to integrate and process this phenomenon effectively (Minea-Pic, 2020). Therefore, research into suitable frameworks that could be adopted to support educators in integrating 2D metaverse pedagogies will offer a valuable insight into potential on-boarding methodologies that can be used and evaluated in this study.

2.3 TPACK, TSE and Distributed Scaffolding Frameworks

As society became further embedded with technology in the 1990s, it was crucial to adapt competency models and frameworks to form a technological perspective, analyse aspects of digital tools used by educators and assess the needs of digital competence in higher education. Those important to note are TPACK (Mishra and Koehler, 2006) and TSE (McDonald and Siegall, 1992). The TPACK model includes three knowledge domains (pedagogical, technical, and content), and the interaction between these domains measures the effectiveness of teaching with digital tools. For example, effectiveness can be recognised through the teacher being able to use a specific software and integrate that technology into an educational purpose so it can be used together with their didactic knowledge on a subject area within their own teaching practice (Koehler, Shin, and Mishra, 2012). In favour of this framework, Koehler, et al. (2014) underlines that it is essential for educators to also recognise interactions between pedagogical, technological, and content knowledge as there is no single technological solution that can solve every teaching and learning situation. Since its introduction, a variety of methods to assess educator's TPACK, including interviews, open-ended questionnaires and observations have been created (Koehler, et al., 2014). However, it must be noted that, the TPACK model has also faced criticism by Ruthven (2014) who highlighted its lack of precise definition and the difficulties in distinguishing the different domains which can therefore result in contradictions determining user effectiveness.

In comparison, the theoretical methodology TSE, adopted by McDonald and Siegall (1992), was intended to describe feelings towards the ability to adopt new technology and therefore has been purposely left vague to work across several technical spheres. The concept extends from Bandura's self-efficacy theory (Bandura, 1997) which refers to how confident individuals feel when managing certain tasks. For example, those with higher TSE have more confidence using a particular form of technology and are more likely to better engage with and benefit from it, whereas those with lower TSE may face challenges in using the same technology which could negatively impact their learning experience and performance (Gomez, et al., 2022). To better assess these TSE levels, four factors were identified: prior experience, modelling, social persuasions, and physiological factors (Pfitzner-Eden, 2016). However, Pfitzner-Eden (2016) also noted that there are additional precursors that can also be associated and influence a high or low TSE rate. For example, it can be argued that age and gender as well as external factors such as having access to adequate resources are better forecasters than TSE itself. For instance, recognising prior experience is typically a better predictor of task performance, but these factors should not be over-relied on and other variables that can affect TSE on performance-based outcomes should be identified and considered. Overall, when linking these frameworks to VGPs and their use in university settings, it can be argued that the models of TPACK and TSE are relevant tools. However, it would also be interesting to clarify whether these frameworks best apply to the effective utilisation of these technologies in university teaching and learning contexts or if other variables are more influential in determining which support strategies should be employed.

In the context of developing an educator's digital competence through the TPACK and TSE frameworks, distributed scaffolding has been chosen as a pedagogical support mechanism because it involves similar factors. It is a teaching strategy developed by Puntambekar and Kolodner (1998) which provides an ongoing system of support that involves multiple resources, tools, and technologies to increase learning and performance. For example, modelling, is also a common scaffolding tool. Studies have shown that when learners observe successful demonstrations of a task, such as by an instructor, and are subsequently provided with opportunities to practice and demonstrate their own abilities, for instance by using technology independently, their self-efficacy beliefs regarding technology are enhanced (Smith, 1994) This is further supported by previous studies on self-directed learning and its impact on learning experiences through communication technology and the Internet (such as MOOCs and online courses) (Kim, Lee, and Park 2019). When defining scaffolding, there are five common components: A common goal between learner and educator, an ongoing diagnosis of task performance, adaptive support, active learner interactions and a transfer of responsibility to the learner to complete the task (Stone, 1998). These have been orchestrated into the pedagogical support planned for this study.

3. Problem Statement and Research Objectives

This project was initiated to explore the broad question of the usefulness of VGPs and their impacts on university teaching-learning environments, hypothesising that they might improve social interaction. As the research progressed, this inquiry was refined into two specific objectives:

- To explore the advantages and disadvantages of community platforms in university learning and teaching environments
- To identify useful support tools that will help students and teachers use them effectively.

These objectives were chosen based on the research highlighted in the literary review. For example, this technology, especially in 2D format, presents opportunities for immersive teaching and learning experiences due to their features which encourage online community building and support collaborative learning strategies (Zheng, et. al. 2022). However, while studies (Kye et al. 2021, Jovanović and Milosavljević, 2022, Kshetri, 2022) acknowledge this potential, challenges such as technical limitations, privacy concerns, and the lack of pedagogical resources to integrate these tools remain (Ahmad, et al., 2022, Onu, Pradhan and Mbohwa, 2023, Qiu, et. al. 2023, Badger, et al. 2023). Moreover, there is limited research on educators' perceptions and approaches to using 2D metaverse software in educational settings, demanding further investigation into its integration and impact from a teacher perspective (Downie et al., 2021, Frith, 2022). Due to these limitations, it was decided to use open research questions that are answerable with a small sample and fits the qualitative, exploratory research methodology that we wanted to employ. Focusing on the "advantages" and "disadvantages" of these platforms from both a student and educator perspective, also allows us to evaluate the practicality of VGPs in university teaching-learning environments and their potential to improve social interaction.

Regarding the second research goal and the kind of support structures needed to successfully implement these platforms, frameworks such as TPACK and TSE, as mentioned in the literary review (Mishra and Koehler, 2006, McDonald and Siegall, 1992), were used as a guideline in creating support and valuable guidance for educators integrating this technology into teaching. TPACK emphasises the interaction between pedagogical, technical, and content knowledge domains, while TSE addresses educators' confidence in adopting new technology. These frameworks are therefore also relevant for organising the support and data collection in this study, facilitating a holistic understanding of technology integration in educational settings. Additionally, distributed scaffolding complements TPACK and TSE by providing adaptive and interactive support tailored to participants' needs (Kim, et al., 2019). A combination of these structures was used to not only understand how teachers employ *Topia* and *WorkAdventure* within their existing courses and explore whether the perceptions of educators and students align with them, but also to see if these frameworks actually apply to these platforms or the university learning-teaching context.

4. Methodology

To answer our research questions, a single case study (Yin, 2009) format was chosen to fit the inductive and exploratory design of the research method. This was so the use of *WorkAdventure* and *Topia* could be compared in one real-life university context and the patterns or differences between these platforms could be better identified. In addition, data was gathered using a variety of sources and outlets including observations of the platforms in use, one-to-one interviews with the university educators and immediate feedback taken from students through a survey.

4.1 Data Collection and Analysis

It was important for us to investigate the use of the platforms in ways that did not disturb regular class business which is why targeted, and purposeful sampling was arranged and the sampling resulted automatically from the students had already enrolled to these courses. What is important to note is that two specific online classes were purposely selected because the student groups were international and therefore offered a lot of different participants that had not yet met in person. This allowed us to better explore the aspects of social collaboration within these platforms and whether initial meaningful connections between online participants could be created. In addition, to allow better comparability for potentially varying adaptions of the template made by the educators, evaluation questions were formulated to account for this influence to isolate and analyse other factors that might affect educational outcomes, particularly the focus points of the VGPs. This included "navigation," "collaboration" and "preference for future use."

4.1.1 Sampling

A total of four university educators and 35 students were selected in the sample. The key demographics of each participant are displayed in table (Fig. 2) which highlights the wide variety of study participants who were sampled.

Number	Role	Location	Platform
T1	Teacher	Weimar, Germany	*Topia*
T2	Teacher	Zadar, Croatia	*Topia*
T3	Teacher	Berlin, Germany	*WorkAdventure*
T4	Teacher	Ilmenau, Germany	*WorkAdventure*
S1	Student	Ilmenau, Germany	*WorkAdventure*
S2	Student	Ilmenau, Germany	*WorkAdventure*
S3	Student	Ilmenau, Germany	*WorkAdventure*
S4	Student	Ilmenau, Germany	*WorkAdventure*
S5	Student	Weimar, Germany	*Topia*
S6	Student	Weimar, Germany	*Topia*
S7	Student	Weimar, Germany	*Topia*
S8	Student	Weimar, Germany	*Topia*
S9	Student	Weimar, Germany	*Topia*

Number	Role	Location	Platform
S10	Student	Weimar, Germany	*Topia*
S11	Student	Weimar, Germany	*Topia*
S12	Student	Weimar, Germany	*Topia*
S13	Student	Weimar, Germany	*Topia*
S14	Student	Weimar, Germany	*Topia*
S15	Student	Weimar, Germany	*Topia*
S16	Student	Weimar, Germany	*Topia*
S17	Student	Weimar, Germany	*Topia*
S18	Student	Weimar, Germany	*Topia*
S19	Student	Weimar, Germany	*Topia*
S20	Student	Zadar, Croatia	*Topia*
S21	Student	Zadar, Croatia	*Topia*
S22	Student	Zadar, Croatia	*Topia*
S23	Student	Zadar, Croatia	*Topia*
S24	Student	Barcelona, Spain	*Topia*
S25	Student	Barcelona, Spain	*Topia*
S26	Student	Barcelona, Spain	*Topia*
S27	Student	Barcelona, Spain	*Topia*
S28	Student	Barcelona, Spain	*Topia*
S29	Student	Barcelona, Spain	*Topia*
S30	Student	Barcelona, Spain	*Topia*
S31	Student	Barcelona, Spain	*Topia*
S32	Student	Barcelona, Spain	*Topia*
S33	Student	Barcelona, Spain	*Topia*
S34	Student	Barcelona, Spain	*Topia*
S35	Student	Barcelona, Spain	*Topia*

Figure 2: Study participants

The teaching experience of the university educators who led the courses ranged from less than one year to more than ten years. Furthermore, most of them reported that they had an "adequate" technical ability meaning that they had some technical knowledge and experience with digital learning tools and could use them to facilitate learning in established scenarios. However, it is important to note that almost all of them had heard of *Topia* or *WorkAdventure*, but had never used them before, making this study their first interaction with VGPs.

4.1.2 Data collection methods

The university educators were first informed about the purpose of the study which was to explore the advantages and disadvantages of VGPs *WorkAdventure* and *Topia* in university learning and teaching environments and identify useful support tools that will help students and teachers use them effectively. This was achieved by introducing specially designed templates from each platform for them to adapt and use in their courses. The single case study was organised into four phases throughout the 2023 summer semester period.

Phase 1: Two starter-kit templates with embedded "How to" resources were sent to each university educator. Here, they were expected to navigate through the template and access the resources by themselves. They could then get a feel for the platforms and choose which template they would like to work with.

Phase 2: One-to-one on-boarding sessions with an educational technology assistant. Here the university educators could get hands-on support to edit their template to a chosen learning scenario that fitted their course aims.

Phase 3: An observation of the learning scenario where the university educator used their edited template in a particular lesson activity. Students involved were first given a 5-minute introduction to the platform with access to technical assistance during the learning activity. The observation was followed by an immediate 10-minute survey with the students.

Phase 4: A post-observation 30-minute interview was conducted with the university educator which collected personal feedback and experiences using the template.

We combined observation, interview, and questionnaires to explore the advantages and disadvantages of VGPs, *WorkAdventure* and *Topia*, and identify useful support in using these platforms. Due to the nature of the study and the variety of participants, one methodological approach was simply not enough and so a "triangulation," (Flick, 2007, p.43) method that enhanced the validity and reliability of findings was adopted. Sampling people for interviews and situations for observation can offer new ways of comparison to better verify the results and increase the robustness of the conclusions drawn. In addition, each method adds unique perspectives and data types to the study. For example, the observations of the adapted template in use by the university educator in a real-life university context provided detailed insights into actual behaviour and practices interacting with the technology, adapting it to their courses, and integrating it into their teaching methods. This contextual understanding therefore helped interpret the responses from the questionnaires and interviews more accurately (Flick, 2007). The questionnaires gathered answers from both closed-ended questions from a 5-point Likert scale and open-ended questions to capture broader trends and patterns on participants' perceptions of the platform's usability, interactivity, and impact to learning. Furthermore, the interview questions were adapted from criteria that focussed on the participants TSE and level of confidence and competence in using the template for their didactic situation. This included, ease of use, clarity of instruction, quality of resources, level of support and user control. By combining these methods, a more comprehensive understanding from a range of perspectives on the advantages, disadvantages, and usability of the VGPs in university settings could be determined.

5. Results

In this section, the results have been divided into two subtopics; the first addresses the user perception of *WorkAdventure* and *Topia* from both students and teachers, whereas the second evaluates the effectiveness of the various support strategies that were integrated. Consequently, this arrangement not only highlights all the different perspectives on the virtual gathering platforms from the study participants, but evaluates how these findings align with the TPACK, TSE and distributed scaffolding frameworks.

5.1 User Perception

For the first subtopic, results have been drawn from answers to the same questions taken from both the student survey and the post-observation interviews from the university educators. This allowed us to gain a better understanding of the advantages and disadvantages of *Topia* and *WorkAdventure* in university teaching and learning settings from a broad user perspective.

5.1.1 Experience level with VGPs

In the survey, the 35 participants were asked about their previous experience with VGPs (Fig.3). Of which, 16 were classed as "intermediate users" meaning that they had some experience but not extensive use with VGPs, either using them once or a few times before. There were also 16 participants categorised as "novice users," those that have little to no experience with these platforms and had never heard of them or used them before. Finally, there were 3 participants who regarded themselves as "experienced users" and had frequently used VGPs.

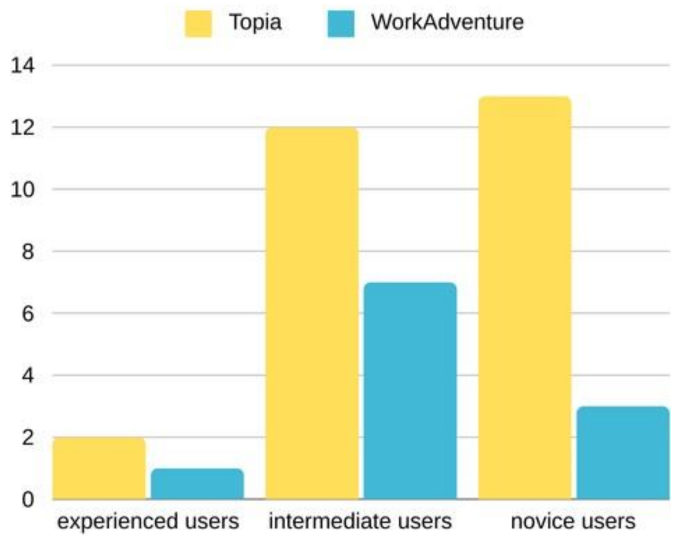

Figure 3: Survey results: "What is your previous experience with VGPs?

5.1.2 Ease of navigation and communication

Results of the survey indicated that just over half the participants, 19 altogether, rated the navigation and communication as "easy" or "very easy" and therefore had a high ease of using these platforms (Fig.4). 11 participants scored navigation and communication as "somewhat easy" and the other 4 participants had a low ease navigating around the platforms and communicating with other participants indicating that this was either "difficult" or "very difficult" to achieve.

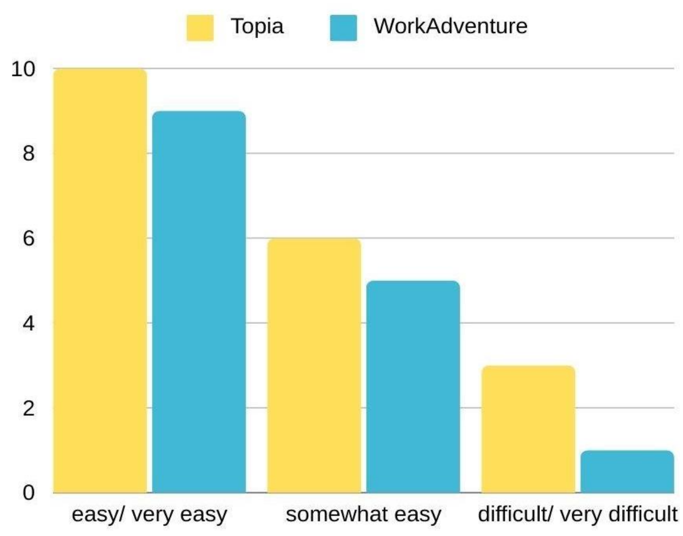

Figure 4: Survey results: "On a scale of 1-5, how easy was it to navigate around the platform?"

5.1.3 Effectiveness of the platforms for collaboration and learning

For supporting collaboration, 9 participants rated these platforms to be either "effective" or "highly effective" (Fig.5). 17 participants rated the platforms more moderately as "somewhat effective" and 11 participants rated them as either "ineffective" or "very ineffective" for collaboration, teamwork and supporting learning activities. However, when it came to using the adapted template in their chosen learning scenario, responses from the university educators were more critical with two rating their template as unsuccessfully supporting their learning scenario.

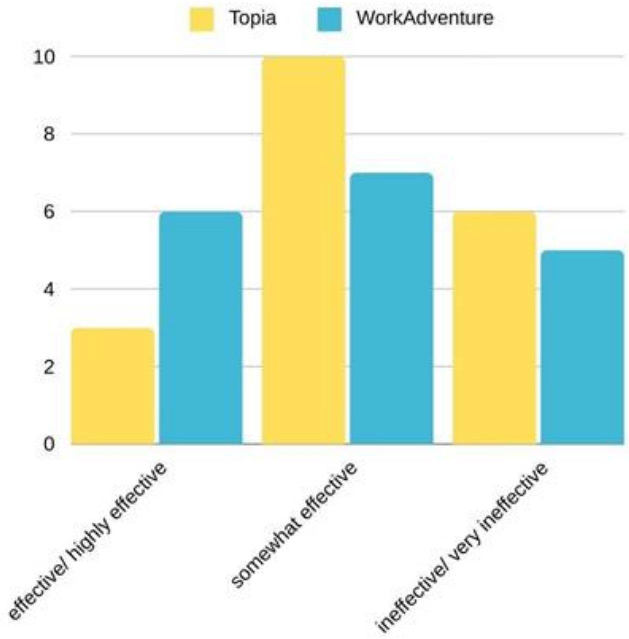

Figure 5: Survey results: "On a scale of 1-5, how effective was the platform in supporting your collaboration and teamwork with other students? / On a scale of 1-5, how easy was it to communicate with the other participants in the platform?"

5.1.4 Positive experiences

Participants who identified specific features of *WorkAdventure* and *Topia* that positively affected their learning experience included T2's comment that the platforms are "easy to use" and the way of navigating and talking to other participants and the simulation of a "real life" video game is motivating. For example, T4 commented that "students were more engaged and relaxed," a condition that could not be replicated with other video conferencing software like *Zoom*. S12 and S19 emphasised "the customisable avatar" as a positive feature. S17 wrote "It was nice and playful to walk around and talk to people." This was further supported by S16 who added "navigating like in a video game was very interesting and brought the team closer to each other." In addition, S19 stated that "real life simulation helps overcome the long-distance barrier.", and S21 remarked that "It was a lot of fun" meaning a more personal and enjoyable experience.

In addition, many students felt that having the platform interface as a storage space for all work material was very useful and has a lot of potential for a variety of learning situations. For instance, S34 highlighted that "having all the sources in one platform and having team-mates to talk to is useful while working on something", and S15 liked "using different features (audio, video, links to *Miro* board, etc.)" within one platform. This aspect was also mentioned by S4 who attributed the "one-step storage place for all the work material" as a positive feature.

Another positive feature noted by the university educators was the "follow me" option which allows users to follow the movements of others like a guided tour. "When I asked my students to follow me and I showed them the rooms available in *WorkAdventure*, it turned out to be playing hide and seek […] The students are more relaxed and I had the feeling that they are enjoying it," highlighting the increase in engagement compared to a regular video conference meeting.

5.1.5 Negative experiences

Regarding the limitations, participants who identified specific features of *Topia* and *WorkAdventure* that negatively affected their learning experience noted that usability could be slow at times with buffering problems and other connection issues with the internet browser. For example, T1 wrote that there were "too many technical issues." S25 wrote "I had quite a few problems with loading the platform, it was buffering constantly" and S26 mentioned that they had "connection issues." S23 also described the experience as "glitchy" and S10 noted that "people experienced difficulties with audio."

Furthermore, many participants noted the time needed to get used to the platform beforehand, emphasising the importance of clear user instructions and on-boarding of the platform before the learning scenario takes place. For example, S15 said "it needed a bit of time to get used to." This was further reciprocated by some of the university educators who emphasised the amount of time needed to adapt the templates if they encountered problems and needed to troubleshoot. T3 mentioned "due to problems with linking the sources I had to invest some more hours to fix it." S16 also described the initial experience as "chaotic" and S28 emphasised "I spent more than ten minutes at the beginning to understand how it works." S19 recommended that "before letting students use *Topia*, it is better to give them some tips or make some tutorials integrated into the system."

Moreover, the nature of the spatial technology which connects the users was also criticised. For example, even though the user area of the templates was big enough to avoid conversations overlapping, there was little regulation for students to interrupt other conversations if they wanted to. S31 picked up on this stating "people joining within a discussion is quite interrupting." S28 also added "When wanting to talk to someone, you would always hear and see everyone else as well." This was further supported by S14 who remarked "there were too many people talking at the same time." However, it must be noted that some participants saw the advantages. For example, S24 viewed "the freedom to leave a conservation" as a positive feature.

Some of the university educators felt that there was no obvious way to offer feedback to the students on whether their instructions could be heard or not. For instance, T1 tried using the broadcast feature and realised that the participants could not give feedback. T2 also commented "the broadcasting tool is not so good as one does not know if the other hear you or cannot respond to you." Therefore, there were limitations to how the whole group could be coordinated.

5.1.6 Preference for future use

Despite these experiences, 19 participants expressed an interest in using VGPs in future teaching and learning situations with 9 participants somewhat interested, and 7 participants not interested and unlikely to use them again (Fig.6). Generally, participants felt more motivated using them compared to other online learning settings highlighting their potential. For example, S9 described it as "a great concept" for teaching and learning experiences and S10 saw it as "promising for group work." S21 also highlighted that they "would love to use it again" and S28 remarked "with more time and more precise interactions, it would be perfect." T3 also showed interest if there was an opportunity to increase the user limit, stating that they would like to use these platforms for courses with larger student groups. This was further reinforced by T4 who said, "the platform has potentials to be used in teaching," but also highlighted that "the most difficult thing is to find the time to prepare the scenario that will fit the needs of the class." Others were more sceptical with T2 highlighting the technical problems outweigh the possibilities and is "not so suitable to coordinate a whole group" or use in complex teaching projects. T1 also expressed it caused "more stress than fun" and was "unlikely" to use it in future.

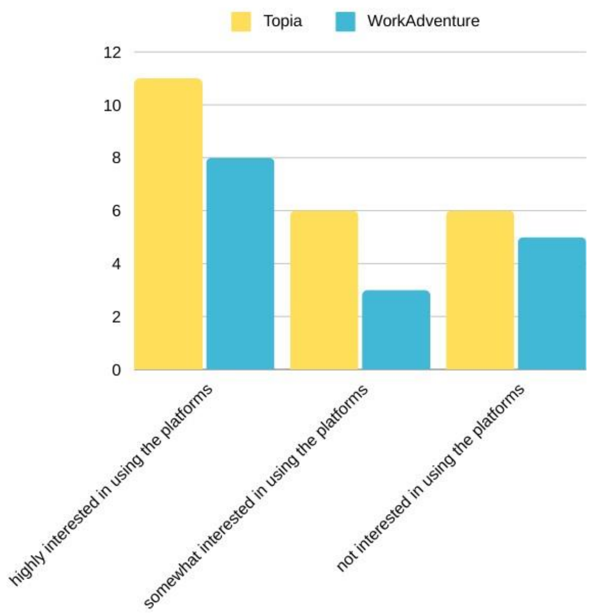

Figure 6: Survey results: "Would you like to use this platform or similar VGPs in future learning situations?

5.2 Support Strategies

The second subtopic showcases the results from the post-observation interviews with the university educators which collected personal feedback and experiences using the template. The interview focussed on the participants TSE and level of confidence and competence in using the template for their teaching situation. This included, ease of use, clarity of instruction, quality of resources and level of support. This data has been further supplemented with information collected during the observation of the learning scenario where the university educator used their edited template in a particular lesson activity. Through these results, we could gain a better understanding of the different support strategies and their effectiveness and thus, use this to examine TPACK, TSE and distributed scaffolding frameworks.

5.2.1 Learning scenario planning

During the study, one learning example from the *Topia* starter-kit template was created, and one from *WorkAdventure*. *Topia* was chosen to host an initial online icebreaker activity for an international student group based in Germany, Croatia, and Spain for their first meeting of the semester. They were split between four *Topia* worlds and interacted in pairs for three-minute sessions guided by simple "getting to know you" questions which replicated "speed dating," moving from one person to the next.

A second example adapted the *WorkAdventure* starter-kit template into a virtual space where international students based in Germany could access material and tools needed for their seminars at any time. This included an online cloud storage drive, related course websites, links to a video conference room and collaborative whiteboard as well as contact information of the teachers and opportunities to meet them directly in the template. Its use was observed through a scenario in which a group of students were offered an online guided tour of the template and its resources.

5.2.2 Adaption process

The time taken to adapt the starter-kit templates varied widely (Fig.7). *Topia* required a quick adaption with T1 taking between 1-3 hours and T2 taking less than 1 hour. However, for those who used *WorkAdventure* the adaption time was more moderate to lengthy because of the extra steps needed to download software and view modifications. It generally takes more time to set-up and use effectively. For example, T3 dedicated 5-10 hours and T4 took more than 10 hours to adapt their template. Generally, the more time teachers engaged with the software, the faster they could learn how to use it and adaption became more intuitive. However, it must also be noted that the number and various types of features that the teachers wanted to integrate into the template also had an effect. Some of these options meant editing the already included coding encryption which therefore took more time to complete.

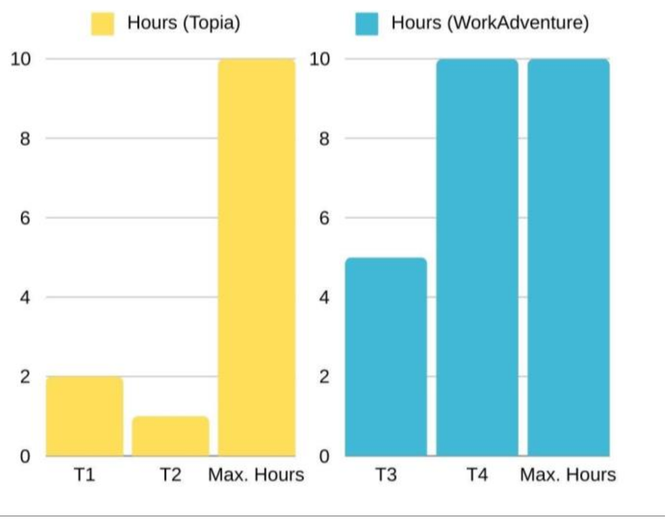

Figure 7: Survey results: "Approximately how many hours did it take you to adapt the starter-kit template for your learning scenario?"

5.2.3 *Perceptions of the starter-kit templates with integrated "how to" resources*

When using the starter-kit templates as an interface for on-boarding and learning how to use a new software, two participants rated this as "highly effective." One rated the on-boarding as "somewhat effective" and the final teacher did not use these resources, preferring to only use the one-to-one technical support (Fig.8). Generally, the templates provided a good starting point for the participants to create their own online rooms, as T3 noted "the template provides a good basis for an online room, with a few adjustments we could adapt it to our teaching scenario." In terms of the resources provided given to work with these platforms independently, most participants felt that the template provided the necessary resources. However, interestingly, the video tutorials embedded into these templates were only used by one participant. In terms of missing resources, T2 identified a need to provide guidance on how to help others (the students) use the tool and T1 suggested clearer information on the capabilities of the platform's features. For instance, knowing that when using the broadcasting feature, the other users are unable to give feedback.

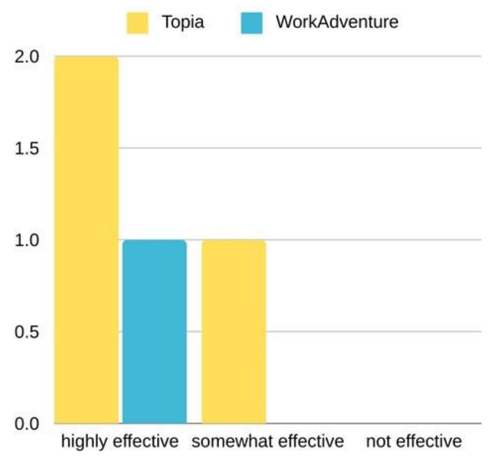

Figure 8: Survey results: "In your view, how effective was the template as an interface to access all of the onboarding resources and show what is possible"

5.2.4 *Effectiveness of the one-to-one on-boarding session*

The on-boarding sessions were rated most highly with all participants finding this type of support as "effective" or "very effective" (Fig.9). Furthermore, three of the participants noted that they would not have used these platforms if this type of support was not available to them. Regarding what could be improved in the on-boarding sessions, T3 suggested a better explanation on how to use *Github*, the online repository that allows users to self-host their *WorkAdventure* map.

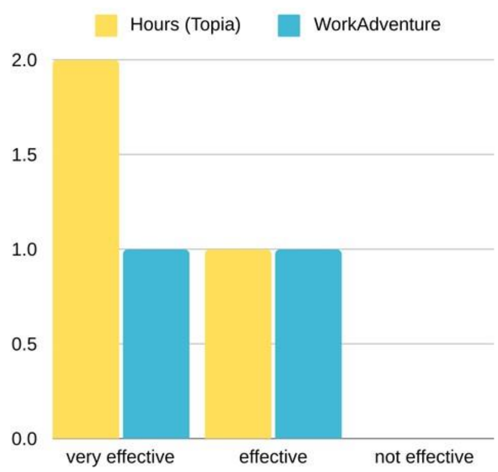

Figure 9: Survey results: "In your view, how effective was the one-to-one technical support and feedback during the 1:1 session?"

6. Discussion

The analysis of the survey results from the 35 participants reveals that they exhibit a diverse range of experiences and perceptions regarding VGPs *Topia* and *WorkAdventure*. Through this, various advantages and challenges associated with the use of these platforms in university teaching and learning environments were identified as well as the preferred support strategies that assisted their use. At first sight, these experiences could be assigned to the existing frameworks of TPACK, TSE and distributed scaffolding, as identified by previous literature. However, as a more detailed comparison below shows, there are some differences that only partially align, and these should be acknowledged when designing and implementing effective support strategies for the integration of 2D metaverse technology into educational practices.

6.1 User Perception

The study exposed a range of experiences among participants regarding VGPs, ranging from “novice” to “experienced” users. Understanding the participants’ proficiency levels against whether they viewed the platforms to be “effective” or not confirms the view of Gomez, et al. (2022) on the importance of understanding users' TSE when integrating virtual technologies into teaching and learning situations. For example, participants with higher TSE have more confidence using this technology and are more likely to better engage with and benefit from the interactive experiences offered by these platforms. Conversely, learners with lower TSE may face challenges in navigating and using the 2D metaverse environment, which could negatively impact their learning experience and performance. However, the study also highlights other variables that can affect TSE on technology performance-based outcomes. For example, while most participants found navigation and communication within the platforms “easy” or “somewhat easy”, a notable portion encountered difficulties because of connection issues despite their levels of experience. This led to their rating of platform effectiveness for collaboration and learning as “somewhat effective” or “ineffective.” It must be said that even when integrating tailored support strategies from TSE and TPACK framework models to accommodate diverse user needs, there is still a strong possibility that the communication channels of the user experience is challenged. This is especially the case for VGPs which aim to connect users from different locations. Therefore, the necessity of understanding external variables such as having access to the resources needed to effectively use these programs (in this case, a stable internet connection) has a stronger influence than previously thought.

Furthermore, the result of the study also shows a keenness to use these platforms in future despite the technical problems. This aligns with Zheng, Jun and Di (2022) who concluded that students are more susceptible to metaverse technologies and the features of *WorkAdventure* and *Topia* made an impact. The rate of technological development that students have become accustomed to provides hope that the stability and capacity of these platforms will improve in future, leading to a stronger confidence in using them in teaching and learning contexts. It can be argued that the recent pandemic’s impact on teaching and learning has influenced the current attitudes of the participants, particularly as they were the generation whose education experiences included a significant amount of telepresence in their real-time courses (Kang and Park, 2022).

6.2 Support Strategies

Insights into the adaptation process of starter-kit templates for specific learning scenarios highlighted varying time investments and perceptions on the integrated “How to” resources. Participants generally found the starter-kit templates effective for on-boarding, although improvements were suggested in certain areas. Interestingly, the low utilisation of the embedded user guides and video tutorials suggests a preference for more interactive and hands-on technical support methods. This challenges some of the principles of distributed scaffolding which suggests a system of support that involves multiple resources and demonstrations of a task with opportunities to practice independently afterwards. Participants instead expressed a need for a quick familiarity with the platform and this was enhanced during the one-to-one sessions where participants could meet directly within the templates and receive their on-boarding at a steady pace. Receiving immediate support through the tool itself allowed them to become more familiar with the platforms and better understand the collaborative user relationship that they demonstrate. In other words, they were essentially simulating the student collaborative experience that they would later facilitate. This resonates with Kshetri’s (2022) observation on metaverse technology and its ability to replicate practical exercises, an advanced form of active learning and problem solving.

Furthermore, the results show a preference for collaborative support structures when facilitating technology integration. For example, the effectiveness of one-to-one on-boarding sessions was highly valued by participants, emphasising their role in facilitating platform adoption and use. Personalised technical guidance initiated through scaffolding tools such as modelling and demonstrations on how to use VGPs proved effective for successful technology integration efforts. Moreover, encouraging a collaborative environment by defining clear goals with the participants with a shared aim in adapting the template to a particular learning setting promoted a mutual understanding and enhanced teamwork as well as implementing Pedagogical Content Knowledge. This necessity for tailored support aligns not only with the principles of distributed scaffolding, but reflects the interplay between technological knowledge, pedagogical knowledge, and content knowledge within TPACK.

6.3 Recommendations

Irrespective of the results obtained, there are limitations regarding the number of survey participants. Firstly, even though there were participants from various countries involved, only four university educators took part in the study. Therefore, subsequent future analysis should involve more participants for broader results that can be employed by quantitative methods and representative samples to validate and expand upon the current findings. Secondly, ongoing template development based on participants' feedback and suggestions would be the next logical step for enhancing the usability and effectiveness of VGPs in educational settings. However, it is also important to note the influence of the educator's utilisation of the template and how this can have an impact. For example, it would be interesting to research into potential design principles of VGPs and how this can increase their effectiveness in educational settings and mitigate troubleshooting issues. For instance, the exploration of the features of VGPs for resources to be used individually outside of the classroom within blended learning scenarios. This specific template direction not only avoids the technical problems previously encountered through an overloaded system from simultaneous usage but supports the potential of using these platforms as a storage space for accessing material at any time and meeting their peers or teachers aside from regular class activities.

7. Conclusion

This study shows the impact of VGPs *Topia* and *WorkAdventure* on both user perception and support strategies in higher education contexts. The findings generally support the potential of these platforms to enhance engagement, collaboration, and learning experiences, aligning with recent trends towards 2D metaverse technologies. However, the study also emphasises the complexity of integrating VGPs into educational practices highlighting challenges such as technical limitations and the need for tailored support strategies to effectively address diverse user needs. Current educational literature is constantly trying to address similar challenges by exploring various frameworks and methodologies to guide technology integration and develop the digital competencies of educators. This brings into question the best support needed for teachers to successfully engage with these technologies and streamline the adaptation of already existing learning materials.

Using the example of *Topia* and *WorkAdventure*, the study contributes to the existing literature by providing insights into the experiences of users, adaption methods and certain support strategies that can aid their use in higher education learning scenarios. It is already clear that their implementation can be adjusted to specific educational contexts as well as accomplish collaborative, hands-on technical support that simulates the interactive features of the platforms. This provides a valuable starting point for future study, particularly into suitable design principles of VGPs that increases their effectiveness in educational settings to mitigate troubleshooting issues. In addition, there is a necessity to understand external variables of the users such as location, access, and age as well as existing frameworks for educational technology integration. Only in doing so can the integration of VGPs into teaching and learning environments be successful. By addressing these areas and answering questions about the support needed for teachers, institutions can strike a balance between facilitating teacher-led initiatives and understanding the minimal technical support required to host them.

Ethics

Ethics approval was not required for this study. All participants provided informed consent before their involvement in any aspect of the research. As there were no experimental interventions, ethical review was neither sought nor deemed necessary.

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Implementation of a Visual Augmented Reality Method in a Carpentry Course: A Case Study

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https://doi.org/10.34190/ejel.22.3.3065

Abstract: In this study, an m-Learning environment that uses Augmented Reality (AR) as a central tool was successfully implemented to support the development of job skills in a basic carpentry course. The app, designed with visual reinforcements in the form of images, gifs and videos, allowed learners to interact with 3D models of the tool and materials inventory, using augmented reality glasses to enhance the learning experience. The results of the data analysis and discussion revealed several fundamental conclusions: firstly, the AR-assisted visual technique on mobile devices proved to be a highly effective complementary learning tool, highlighting its potential to significantly improve the educational process. Second, the AR tool showed greater effectiveness in low-performing learners, suggesting that this technology may be especially beneficial for those who face challenges in conventional learning. Furthermore, learners' positive attitudes toward the app supported the overall acceptance of the technology, and the positive activation between app evaluation and learning attitudes underscores the importance of the AR-enriched educational experience. This study not only presents conclusive results on the effectiveness of AR in skill training, but also highlights its potential to address specific challenges in indigenous communities, thus establishing a solid foundation for future applications and developments in the field of education and the training.

Keywords: Augmented reality, Job skills, Carpentry learning

1. Introduction

Considering the existence of indigenous communities that lack access to basic job training for the development of skills trade, the prevailing need arises to create a learning environment conducive to the development of skills and abilities in the basic carpentry trade. This approach is based on a detailed understanding of the tool inventory and its functions, as well as the materials inventory and its uses.

The challenge lies in the lack of modern teaching tools that can effectively address this gap in remote communities. It is in this context that augmented reality (AR) emerges as a viable solution. AR offers a unique interface for users by combining the real world with the virtual world. Unlike traditional virtual reality, AR allows fluid interaction with virtual objects that are integrated into the user's real environment, providing an authentic and natural experience in human-device interaction. The research question focuses on exploring how specific aspects of Wayuu culture, such as matrilineal family structure and social dynamics, could influence the way educational programs are designed and implemented, especially those that seek to improve skills and competencies in specialized trades. Then the research question is "How does the complex matrilineal family structure and the unique sociocultural dynamics of the Wayuu population impact the implementation and effectiveness of educational programs, especially in indigenous communities, with a focus on the development of skills and knowledge in trades specialized, like basic carpentry?

The implementation of AR in this context is simplified by requiring only a mobile device with a camera. By considering previous work carried out in indigenous communities, such as those of Maigua (2012) and Martínez (2017), where AR with markers was used to teach specific trades, a solid conceptual foundation is established. Maigua (2012) explored the process of observing images in a "Magic Book" to teach the craft of a graphic editor, while Martínez (2017) used a camera and an AR application to teach photography. In both cases, the effectiveness of the application of the visual technique in these communities was evident.

The structuring of the carpentry course is based on a systematic methodology that encompasses various sessions, each designed with specific objectives to cultivate specialized skills trades among apprentices. The conception of the course is closely aligned with the implementation of the Augmented Reality (AR) application, seeking to maximize the effectiveness of the learning process. Below are the crucial elements of course planning and how they integrate harmoniously with the AR application:

Initial Session - Tool Recognition and Handling, its objective is to familiarize participants with basic carpentry tools and promote a comprehensive understanding of their proper use. AR Integration is the AR application that

Cite this article: Beltrán Alvarado, G.A. 2024. “Implementation of a Visual Augmented Reality Method in a Carpentry Course: A Case Study”, *The Electronic Journal of e-Learning, 22(3)* pp 141-159, https://doi.org/10.34190/ejel.22.3.3065

becomes a pedagogical tool by presenting three-dimensional models of the tools, allowing learners to virtually explore each instrument and understand its functionality accurately. In the second session, the types of wood and materials are identified, the objective is to instruct students in the identification of various woods and materials essential for the exercise of carpentry, its integration with AR is the application and display of augmented images to illustrate types of wood and materials, providing a visual and contextual experience that facilitates the assimilation of information. A third session presents the techniques of cutting and assembling wooden pieces, its objective is to cultivate practical skills in cutting and joining wooden components, its integration with AR is the application of a virtual simulator, demonstrating cutting and assembly techniques through interactive 3D models, allowing learners to practice virtually before applying their skills trade in the physical environment. The fourth session has to do with the complex assembly of a wooden chair, its objective is to apply previous knowledge in the assembly of more complex structures, the Integration with AR is that the application guides participants through the assembly process using models 3D, offering real-time virtual feedback to optimize skill acquisition. And finally we find the fifth session, which is the comprehensive evaluation of competencies, its objective is to evaluate the assimilation of skills and knowledge throughout the course. The integration with AR is that the AR application is used for assessment, presenting virtual scenarios that challenge learners to apply their skills and respond to practical situations, providing a comprehensive assessment of their competencies.

The research is aimed at effectively implementing the visual AR technique as a learning tool in the carpentry course. The methodological strategy encompasses the definition of specific learning objectives, the efficient integration of AR to offer rich interactive experiences, the continuous collection of feedback to refine the educational experience, competency assessment using AR and practical projects, and data analysis to support conclusions and recommendations. This comprehensive methodology aims to provide students with robust and advanced training in carpentry, taking advantage of the capabilities of augmented reality to significantly enhance the acquisition of skills and knowledge in this specific field in a carpentry course intended for an indigenous community that needs improve your family income. The main objective is to evaluate the impact of this technique on the cognitive performance of learners, compare its effects between high- and low-achieving students, and analyze learners' attitudes towards the application. The transition towards the introduction of AR as an effective solution in this context highlights its potential to address the existing gap in carpentry training in underserved communities.

2. Literature Review

2.1 Evolution of Augmented Reality.

The concept of "Augmented Reality" was coined by researcher Caudell (1992), he used the concept to describe a system that would help workers assemble and install electrical wires in airplanes (Caudell & Mizell, 1992). Rosenberg & Feiner (1993) also developed an AR feature for aircraft maintenance, which improved operator performance by adding virtual information about the feature to be repaired. Furthermore, Loomis and colleagues (1993) made a GPS (Global Position System) AR-based system to aid the blind in assisted navigation by adding spatial audio information. Soon after, the first mobile AR system (MARS) capable of adding virtual information about tourist buildings was developed (Feiner et al., 1997).

In the following years, AR technologies have been developed mainly by research laboratories and higher education institutions around the world (Azuma 1997; Milgram & Kishino, 1994; Billinghurst, Kato, & Poupyrev, 2001). Washington University created the Magic Book, which superimposes 3D virtual images on actual books. Shelton & Hedley (2002) also used AR to teach higher education geography novices how to establish relationships between the Earth and the Sun. Kauffman (2003) from the University of Vienna, in addition, created a tool for geometry novices referred to as Construct 3D. In the same vein, Li (2010) from Universidad de Nuevo México used AR in an interactive narrative in a physical environment referred to as ARIS.

Over the past few years, technology has begun to slowly migrate from the research labs to the marketplace via applications ranging from marketing to entertainment, advanced visualization, maintenance, design, medicine, and publishing. Since then, several applications have been developed: Thomas et al. (2000) created ARQuake, a mobile AR video game; in 2008, Wikitude allowed compiling information about user surroundings through a mobile camera, the Internet, and GPS (Perry, 2008). In 2009, other AR applications, such as AR Toolkit and SiteLens, have been developed to add virtual information to the physical user's surroundings. In 2011, Total Immersion developed the D'Fusion and AR system for project design (Maurugeon, 2011).

In conclusion, AR offers the possibility to learn to visualize and act with phenomena that traditionally novices study theoretically, without the possibility to see and test in the real world (Chien, 2010). In recent years, applications have been developed that show the positive effects of this technology as a learning aid on greater content comprehension and memory retention, as well as on learning motivation and performance accuracy (Radu, 2014), academic success and motivation (Di Serio et al., 2013).

2.2 Augmented Reality – AR

During the last decades, Augmented Reality (AR) has broadly been defined and discussed. For example, Azuma (1997) mentions that AR is a variation of virtual environments (VE), or Virtual Reality, as it is more commonly referred to. VE technologies completely immerse the user in an artificial environment; while immersed, the user cannot see the real world around them. Kaufmann (2004) also argues that AR allows the user to see the real world, with virtual objects superimposed onto or composed of the real world. On the other hand, Goldiez (2001) describes AR as a field of technology in which the real world is superimposed with additional information from a computer-generated sensory display. For Perey (2011), the expression "Augmented Reality", refers to the emerging technology that allows the real-time blending of processed digital information with information coming from the real world by means of appropriate interfaces.

Other definitions, such as Kesima & Ozarslan (2012) assert that AR is a new medium that combines aspects of ubiquitous computing, tangible computing, and social computing. It offers unique possibilities, combining physical and virtual worlds, with continuous and implicit user control from the point of view of interactivity. Martins & Santos da Rosa (2016) also define AR as the enhancement of an individual's visual experience with the real world by integrating digital visual elements. It is characterized by a combination of the real and virtual worlds. Therefore, an augmented reality environment allows the user to view the real world with computer-generated virtual objects, in other words, real objects superimposed or merged.

Augmented Reality allows users to access information directly by superimposing digital information onto physical space by means of markers. Siltanen (2012) defines a marker as a sign or image that a computer system detects from a screen using image processing, pattern recognition, and computer vision techniques.

Feng & Kamat (2014) also refer to a marker as an image or corresponding descriptors with key features and points. Usually, an AR marker is easily recognized and tracked as it is a black and white image or a QR code. According to Thanaborvornwiwat & Patanukhom (2018), a marker is a special four-cornered pattern preferably with gray shades and symbols to estimate homographs. On the other hand, researchers such as Chen et al. (2016) state that a marker is based on geometric features considered for estimating a 3D object, which are often segments, well-marked straight lines, contours or points in cylindrical objects or a different combination of these features.

2.3 Overview of the Wayuu Community

The Wayuu population is made up of 278,212 indigenous individuals, as reported by DANE in 2015. Within this population, an overwhelming 97% speak the Wayuunaiki language. Wayuu society exhibits a distinctive and intricate matrilineal family structure, organized into 30 different clans, each of which has its own territory and totem animal.

Central to Wayuu society is the fundamental role of the "putchipu" or "palabrero", who serves as a bearer of the word and mediator in resolving conflicts between clans. The highest family authority rests with the maternal uncle, who actively participates in all family and domestic affairs.

In nuclear family dynamics, children are guided by the maternal uncle, diverging from the conventional role of the biological father. Women assume leadership and organizational responsibilities within the clan, participating actively and independently in political affairs. The Wayuu community is dedicated to various activities, including livestock, fishing, agriculture and salt extraction carried out by men. At the same time, women dedicate an important part of their time to making backpacks, nets, hammocks and managing domestic tasks, as noted by the Ministry of Culture of the Republic of Colombia in 2010.

2.4 Augmented Reality in Indigenous Populations

This section mentions research on the implementation of Augmented Reality in indigenous populations. Two studies that highlight the use of markers for content generation in AR are Maigua (2012) and Martinez (2017).

In the study of Maigua (2012), AR was implemented to develop a magazine on the indigenous history of Ecuador. It was done through a "Magic Book", which is an open book that contains markers to generate augmented reality content with the use of a smartphone in the school for indigenous girls in Saquisilí. The teacher taught the process of observing the images obtained from the "Magic Book" to teach graphic editing skills. Finally novices manipulated the markers to observe the images in AR, to then modify, retouch, optimize and place them definitively in the "Magic Book". Similarly, in an indigenous community of Cauca (Colombia), a group of indigenous people was trained in photography, Martinez (2017) used a camera, a Smartphone, and an AR application, several photographs of local birds were taken and stored in the Smartphone's memory, then the impressions of the markers were taken for each bird and with the application (app) they were observed in AR. Finally, novices observed the 3D images and chose those with the best quality to publish them to observers around the world. In the study by Zapata et al., (2023), the preservation of the Quechua language as the mother tongue in a Peruvian Amazon indigenous group was taken into account, where kindergarten children reinforce words with the help of augmented reality. According to Camacho et al., (2019), this article evaluated the level of influence that the use of a mobile application with augmented reality had on indigenous primary school students for learning the Quechua language, a quasi-experimental design was used and the sample it was made up of sixty students divided into two classrooms of thirty students respectively. On the other hand, in the document by Cabanillas M., Canchaya A. & Gómez R., 2020, it shows the development of an AR application following the mobile d methodology, for the creation of 3D models referring to pre-Inca cultures and determines the influence it would have on learning. of primary level students.

González, et al. (2015) highlight the importance of this holistic approach to preserve the ancestral knowledge of carpentry, strengthen the cultural identity of indigenous communities, and promote sustainable development.

In conclusion, AR can be implemented in indigenous communities for the training of skilled trades with the use of markers and mobile devices. The proposal is consistent with studies conducted in the state-of-the-art that show the effectiveness of this software when implemented in said communities.

3. Research Methods

3.1 Research Topic

This study involved 12 indigenous men from the Wayuu indigenous community. The software impact experiment was conducted in a rural division called Torcoromaná, La Guajira (Colombia), lasted three months and was developed in three stages: (1) Reconnaissance, whose objective was to identify the Wayuu indigenous community through an indigenous leader, who contacted the Torcoromaná *ranchería*, where activities were carried out in a small school without electricity or internet; (2) Training, five in-person meetings were held between the indigenous people and the researchers that focused on the knowledge of the course developed in A; and (3) Job competency assessment, the indigenous people in the sixth session had the task of assembling a chair, they were recorded in order to identify the job competencies in the carpentry trade.

3.2 Research Justification and Preparation of Experiments

In this section, the study focuses mainly on the supplementary learning effect of AR-based learning tools on a carpentry course. The group of novices in the test class were taught the content of "Inventory of tools and materials; assembly and fitting of parts". The master carpenter was interviewed prior to the design and development of this AR tool, and he noted that in his previous experiences, he had taught formal novices and not indigenous people from the region. However, he expressed his desire to review the content using an AR tool to guide a teaching process with good outcomes in learning the content involving "Inventory of tools and materials; assembly and fitting of parts". To carry out this experiment, a leader of the Wayyú ethnic group was contacted to invite a group of 10 indigenous individuals residing in the Mano de Dios ranch, who have no knowledge of the Spanish language or the carpentry trade. These participants, aged between 18 and 25, were previously instructed by a master carpenter using a specific guide. Their task was to assemble a chair made up of 10 pieces, without using the visual method of Augmented Reality. This group of individuals formed the control group in the study.

The most significant limitations to carry out this research and involve indigenous groups from various rancherías lie in their residence in a remote and hostile area, specifically in the northern part of Colombia, characterized by being completely desert and extremely difficult to access. The nomadic nature of these groups makes contact even more difficult, since they do not permanently settle in the same place. This results in a shortage of indigenous participants for the study. Additionally, the language barrier, called Wayuunaiki, presents an additional challenge in communicating with this ancient tribe. On some occasions, indigenous communities live in risk areas, which further complicates the possibility of visiting them for research.

In the first instance, the group of indigenous people from the Torcoromaná ranchería was subjected to the following corresponding sections as explained below:

The pre-test scores will represent the learning outcomes, the trainees will use a wooden chair assembly protocol and activity form, and the post-test scores will represent the learning outcomes after using an AR research-based learning tool. In this activity, using the inquiry method, responses of the novices in the test group had to be conclusions that they had to reach on their own when observing and exploring, In this case, the difference between pre-test and post-test scores will represent the learning effect. The questionnaire mainly assesses learning attitudes toward the AR learning tool.

To start the experiment, researchers pre-installed the AR software on each device. The experiment contains five sections, as shown in Table 1.

Table 1: Experiment design

Contents	**Operability**
Pre-test	Each student is required to complete an assignment and a questionnaire independently.
-Group training -Learning consultations using the activity form	- The class is randomly divided into four groups. - Each group is required to use the AR tool to learn as indicated on the activity form - Completing the form cooperatively without teacher guidance (AR toolkit contains AR-based software, bookmarks, and the activity form)
Post-test	Each student must independently complete the same test used in the pretest.
Survey	Each student is required to complete a questionnaire
Interview	Five learners are randomly chosen and interviewed about their feelings during the inquiry-based learning process.

3.3 Research Hypotheses

Performance Hypothesis:

> *Hypothesis 1: It is expected that the evaluation of the apprentices, when evaluated after using the Augmented Reality (AR) tool, will show a statistically significant improvement in their skills and knowledge in the carpentry trade.*

Performance Difference Hypothesis:

> *Hypothesis 2: It is anticipated that influential corrections to the AR tool among learners, as well as differences in impact between high- and low-performing groups, will be evident and can be compared for the purpose of identifying specific patterns of improvement.*

Motivation Hypothesis:

> *Hypothesis 3: The possibility is raised that the AR tool has a positive impact on the motivation of apprentices towards learning the carpentry trade. The aim is to explore whether the experience with the AR tool is meaningful and interesting for the apprentices, thus contributing to an increase in their motivation towards learning the trade.3.4. Measurement Instruments*

3.3.1 Pre- and post-testing

The questionnaire was designed by a carpentry instructor from the National Learning Service (SENA), who also collaborated in the design of the contents of the e AR application and further assessed by three carpentry experts. The questionnaire includes 30 questions, associated with the learning content "Inventory of tools and materials; assembly and fitting of parts". Prior to the experiment, a pre-test was conducted with the whole class: "Tools and Materials Inventory Test". Subsequently, the researchers randomly divided the class into 4 groups. Then, each group used the AR tool proposed in this paper to complete an inquiry-based learning task. After learning with AR, a post-test was conducted using the same questionnaire: the "Tools and Materials Inventory

Test". The questionnaire assesses novices' understanding and memorization of several key knowledge points in this content. The questionnaire uses a fill-in-the-blank format ; the questions are general knowledge questions and are briefly summarized as follows: Which are the cutting tools? On what material is it used? What is the maintenance process of a cutting tool? How many striking tools do you know about? Which is most commonly used? How are the tools distributed on the workbench? What does the maintenance process of a striking tool consist of? Questions about materials include what type of material do you use in making a chair? How many types of material do you know about? Which one has the highest hardness?

3.3.2 Manner of instruction and activity

Based on inquiry, three groups were created without teacher instructions under a group learning scenario where the novices had to perform explorations with the use of the AR tool and conclude on their own events inherent to knowledge. The form of this activity was designed by the researchers in accordance with the application and does not limit the novices' operations with the markers; moreover, it was designed to aid the learning process in the operational steps and encourage them to ask introductory questions, think, and draw conclusions. Considering that this is the first time novices gain knowledge about AR technology and are placed under a self-exploration scenario without teacher guidance, then, the activity form aims to show them how to use the markers to interact with the device and observe correctly. Novices are also encouraged to operate markers freely and intuitively to see what they may discover.

3.3.3 Post-questionnaire

According to previous studies where questionnaires were conducted using the constructs of learning attitude, software satisfaction, cognitive validity, and cognitive accessibility, a questionnaire was developed using a 6-point Likert scale: where 1 represents "strongly disagree" and 6 represents "strongly agree". In the paper by Hwang & Chang (2011), a review of items of the construct "learning attitude" was conducted where ten items were considered. Based on the research by Chu, Hwang & Tsai (2010), 11 items were adopted for the construct "satisfaction with the software", similarly for the construct "cognitive validity", six items were chosen and for the construct "cognitive accessibility", three items were taken from the work of Chu et al. (2010). In this activity, 12 copies of the questionnaire were distributed and 12 were received, all considered valid. For the reliability of the complete questionnaire and each construct a reliability analysis was performed, according to Cronbach's Alpha coefficient the questionnaire is (0.815), see Table 2. Each construct is considered to have a high internal consistency and reliability, according to Cronbach's Alpha coefficient, which for each construct should be higher than 0.70.

3.3.4 Interview protocol

The purpose of the interview is to further explore novices' learning experiences through the AR tool. The following questions were asked during the interview

- Do you think this AR tool facilitates your carpentry learning?
- Why do you think this tool is useful? In what areas does the tool help you?
- Do you want to use AR software to learn carpentry in the future? Why?
- For which content do you think AR tools are better?
- Do you think the AR software has any disadvantages? Which ones?
- Can you offer any tips to improve this AR learning tool?

Table 2: Cronbach's Alpha Coefficient

Variable	Number of items	Cronbach's alpha
Learning attitude	10	0,722
Satisfaction	11	0,863
Cognitive validity	6	0,865
Cognitive accessibility	3	0,811
In general	30	0.815

3.4 Introduction to the AR Toolkit

The AR toolkit developed during this study contains AR software, 20 markers, an assembly protocol, and an activity form. The software contains an application specific to tool and material inventory reconnaissance, (5) tool maintenance animation gifs, and (2) short videos on the assembly of wooden parts. The interaction tool used with this software is the marker. One set contains twelve printed markers from the tool inventory and another set of markers contains eight printed markers from the material inventory, each marker has printed on one of its sides the tool to be viewed that can be selectively applied. Once the software is installed on the devices, the novices can use different markers to view the 3D image on the device screen and perform inquiry-based learning as indicated in the activity form and generalize further concepts and conclusions.

3.4.1 Instructional design of the experiment

In contrast to previous AR studies, a learner-centered scenario was adopted, in which learners are divided into groups and learn in an AR environment on their own. They use markers to represent the inventory of tools and materials and intuitively appropriate knowledge from a simulation of natural movements. Novices are expected to explore and reach conclusions through group effort without benefiting from direct teacher instructions. In this case, the activity form shows the operational steps and poses questions corresponding to the required knowledge points, which encourage them to think and research. The following is a description of how activity 1, the "Tool Recognition" case, is developed. In this case, the first group of markers represents twelve different tools related to the carpentry trade. Activity 1 takes 10 to 15 minutes to complete, as does the second set of markers representing the eight materials to be used in the procedure. The activity form instructs the operating procedure for this activity and poses questions about what the novices observed in each 3D image. With the 3D models shown from different markers, novices are expected to master the reconnaissance of tools and their functions and the types of materials and their uses. With this hands-on activity, novices are expected to memorize, learn, and know the tools and type of wood to be used. We also positively predict that novices can better memorize the process with the 3D object viewing operation.

3.4.2 Design and development of the AR environment

In this research, an M-learning environment was designed on a mobile platform with an AR visual technique and with devices such as Smartphone and tablets, the application was made in a free software called Scope (version 0.5). The essence of the human-device interaction with this application is to detect and record the position of each marker in the camera view, since the application will activate different animations when the marker is in different positions. In other words, the interaction between users and devices is based on position.

Activity one was developed in two sessions. In the first session, novices were trained in the use of the AR-based application (Figure 1).

The developed environment contains two learning activities described below:

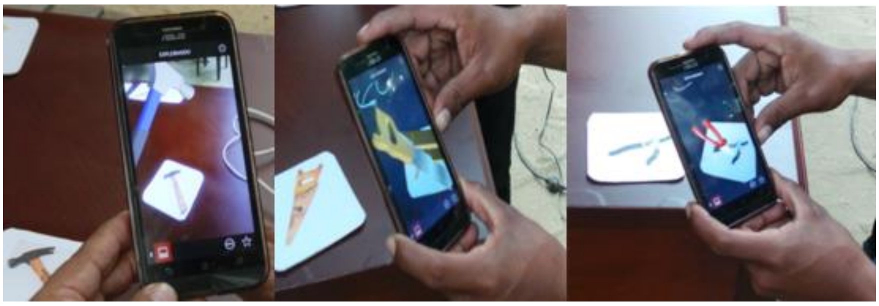

Figure 1: Novices using markers

The purpose of the second session was to introduce novices to basic carpentry tools, according to the activity form, such as: hammer, saw, screwdriver, wrench, tape measure, ruler, clamp, pencil, chisel, planer, file, and brace. During this session. Novices manipulated the markers to be able to see the AR effect on the mobile device, they thus got to know the tools virtually (Marcincina et al., 2013). (Figure 2).

Figure 2: Viewing tools in AR

During this session, and according to the activity form, novices recognized the types of wood in the region suitable for carpentry work according to their physical properties such as density, hardness, and flexibility. Similarly, subsequently the AR application developed in Scope was opened, on the “Types of Woods" menu, and the types of trees were recognized using markers and it was possible to observe pine, snail, cedar, and oak in AR. In this session each novice had the possibility of manipulating the mobile device and observe the effect of AR on learning about the shape of the tree and the view of the wood after cutting (Figure 3).

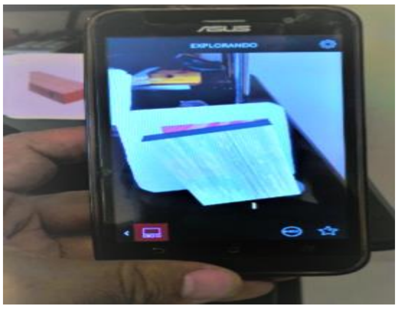

Figure 3: Wood cutting

With the help of the form in activity two, novices were shown video content on tool reconnaissance (Figure 4A), regarding uses and maintenance (Figure 4B), and also topics of measurement and wood cutting were also shown with an explanation of the techniques of cross-cutting and longitudinal cutting, and finally, the total assembly was shown including the verification of the joining of parts, polishing, and finishing.

In the development of the course, theoretical lessons on the application of augmented reality (AR) were cohesively integrated with physical carpentry practices. Each theoretical session on the recognition and handling of tools, identification of types of wood and materials, cutting and assembly techniques, complex assembly of a wooden chair, and the comprehensive evaluation of competencies, was complemented with practical applications in the physical environment. The participants, after acquiring theoretical knowledge through AR, had the opportunity to apply these teachings practically in the actual construction and assembly of carpentry structures. This integrated approach not only strengthened the theoretical foundations, but also allowed apprentices to consolidate their skills through practical experience, thus creating a meaningful connection between the application of technology and the physical execution of carpentry tasks.

A B

Figure 4: Reconnaissance of tools (A) and use of tools (B)

3.5 Methods of Data Analysis

In this experiment, both the quantitative method was used to explore the change in novieces scores and the qualitative method was used to delve into novices' feelings and experiences throughout the process.

3.5.1 Quantitative research methods

To analyze the data obtained from the test and the questionnaire, a paired t-test was performed on the pre- and post-test scores and an independent t-test on the scores of high- and low-performing novices to determine the differences between them. Descriptive statistics were calculated for each questionnaire item and each construct as a whole, including mean score, standard deviation, and maximum and minimum values. In addition, a Pearson correlation coefficient was calculated between learning attitude and the other three constructs.

3.5.2 Qualitative research methods

A 40-minute video was made and photographs were taken during the class. In addition, researchers obtained exceptional performance records from novices. After the class, five novices were interviewed, and the interviews were recorded. The video, images, and notes acquired from the case study were analyzed. Several scenes from the experiment are shown in Figure 5.

Figure 5: Scenes from the experiment

4. Data Analysis and Conclusions

The research used various tools to evaluate the impact of the Augmented Reality (AR) tool on indigenous participants. Initially, a test for paired samples was administered, aimed at evaluating the prior knowledge of the indigenous people before the intervention with the AR tool. The significant improvement in post-intervention scores suggests that the AR tool positively contributed to the cognitive performance of the participants. In addition, an independent test was carried out, classifying the participants into high and low performance groups. The significant differences between these groups indicate that the AR tool had a particularly positive impact on those with lower initial performance.

To understand the variability in indigenous responses, descriptive statistics are applied to the questionnaire responses, evaluating each item and construct. This methodology allowed us to identify specific patterns and areas of interest. Furthermore, Pearson's rating coefficient was calculated to measure the relationship between learning attitude and other constructs, providing insights into how indigenous people's disposition towards learning relates to their perception of the AR tool. In addition, observations and interviews were carried out to obtain qualitative information on indigenous people's attitudes and evaluations towards educational technology, offering a deeper understanding of their individual experiences. Together, these tools will provide a comprehensive assessment of the impact of the AR tool on Indigenous participants.

4.1 Overall Cognitive Performance

The experiment produced 12 * 2 test copies (12 for the pretest and 12 for the posttest), all of which were considered effective. A paired samples t-test was performed for the pre-test and post-test score variables. The variable tested is a posttest score minus the pretest score, which represents the difference obtained after using the AR tool for each student. The results are shown in Table 3.

Table 3: Paired samples t-test for pre- and post-test scores

	aver.	Dev. deviation	Dev. Deviation error	95% confidence interval of the difference: Lower	95% confidence interval of the difference: Superior	t	gl	Sig. (bilateral)
Par1 Begin. P. Afer	-,80000	,31909	,09211	-1,00274	-,59726	-8,685	11	,000

Table 3 shows that the p-value (two-tailed) of the mean is close to zero (t = -8.685), p-value = 0.000). When the significance level is 0.05, we should reject the null hypothesis, which suggests that novices' scores after using the AR research-based learning tool are significantly higher than those obtained before the learning activity.

4.2 Comparison of Learning Gains of High- and low-performing Novices

Ordering the pre-test scores of novices from highest to lowest, the first 33% are categorized as high-performing novices and the last 33% as low-performing novices. The average learning gains of both groups are calculated, as shown in Table 4. Then, an independent t-test is performed with the difference between learning gains of high-performing novices and learning gains of low-performing novices, as shown in Table 5.

Table 4: Mean scores for low- and high-performing groups.

Group	Pre-test average	Post-test average	Gain average
High-achieving	26	27.5	1.5
Low-achieving	11.3	17.5	6.2

For Levene's test for equality of variances shown above in Table 3, F = 3.516 p = 0.090> 0.05, which suggests that we cannot reject the null hypothesis and must accept that the variance difference is not significant at the 0.05 significance level; we should refer to the "Equal variances assumed" row. In the top row, t = 3.541 and p = 0.005 <0.05, suggesting that the difference in mean and learning gains between the low-performing group and the high-performing group are significant at the 0.05 level.

Table 5: Independent sample test

	Levene's test of equality of variances		T-test for equality of measures					95% confidence interval of the difference	
	F	Sig.	t	gl	Sig. (bilateral)	Measurement differences	Standard deviation differen	Lower	Superior
P. after: Equal variances are assumed	3,512	,090	3,541	10	,005	4,88889	1,38064	1,81263	7,96515
Equal variances are not assumed			5,854	9,897	,000	4,88889	,83518	3,02537	6,75241

4.3 Attitudes Toward the AR Tool with a Questionnaire Analysis

In the questionnaire analysis, we calculated the score for each construct by averaging all the corresponding items within each construct. The descriptive statistics obtained are shown in Table 6.

Table 6: Descriptive statistics for the four constructs of the questionnaire

	N	Min.	Max.	Average	Std. Desviation
Attitude	12	3,25	5,59	4,2150	,62769
Satisfaction	12	3,90	5,27	4,4733	,34254
Validity	12	3,21	5,78	4,3692	,93181
Accesibility	12	3,06	5,78	4,1925	,87922
	12				

In the above table, it is possible to observe that the construct "Cognitive Validity" has the highest mean value, suggesting that the assessed novices generally have positive learning attitudes. In contrast, the construct "Satisfaction" has the lowest mean value, suggesting that the usability of this AR-based learning tool is not as satisfactory as that of the other three constructs and needs to be further improved. Descriptive statistics of each item in the four constructs shown, respectively, in the tables below. The descriptive statistics for the items related to the construct "Learning Attitude" are shown in Table 7.

Table 7: Descriptive statistics for the construct "Learning attitude"

	N	Min.	Max.	Average	Std. Desviation
I find learning about "tool and function recognition" rewarding	12	3,23	5,56	3,6933	,68250
I find learning basic woodworking rewarding.	12	3,23	4,78	3,9725	,53350
I believe that learning and observation related to the contents of basic carpentry, in addition to books, are significant.	12	3,05	5,56	3,9225	
I think that learning and observing things related to carpentry is interesting	12	3,23	4,78	3,8042	,58232
I will actively look for information related to basic woodworking in books or guides.	12	3,23	4,56	3,7142	,53670
When I run into problems learning basic carpentry, I consult teachers, classmates, books, or guides for solutions.	12	3,23	5,56	3,8158	,86888
I believe that learning carpentry is important to the community.	12	3,23	4,56	3,6600	,56350
I think that doing the activities using AR is novel	12	3,23	4,56	3,8750	,51410
It is good to use new technology tools	12	3,23	4,56	3,7425	,51864
I find that learning carpentry with devices is interesting	12	3,05	5,56	4,0775	,76692
Valid N (per list)	12				

The statement "I find learning carpentry with devices interesting" has the highest value (Mean = 4.07), which has a close to full score of 6, suggesting that most novices consider learning carpentry with the help of devices important. Whereas the item "I think learning woodworking is important to the community" has the lowest score (Mean = 3.66), which means that although they find learning woodworking important, most novices only learn woodworking in class or in the workshop and do not actively seek to share the information. Table 8 shows the descriptive statistics for the items related to the construct "Satisfaction".

Table 8: Descriptive statistics for the construct "Satisfaction"

	N	Min.	Max.	Average	Std. Desviation
AR-based learning app is more interesting than previously used learning methods	12	3,23	5,56	3,6933	,68250
This learning tool can help me discover new questions.	12	3,23	4,78	3,9725	,53350
Using the AR-based app allows me to see woodworking concepts like knowing tools in their basics in a different way.	12	3,00	5,56	3,9142	,93540
I like to learn basic carpentry using AR	12	3,23	4,26	3,5542	,38907
The design of this app is nice and genuine.	12	3,23	4,25	3,6308	,46647
I hope other skilled trades apply AR tools to learning as well.	12	3,23	5,89	3,8708	,91704
I hope to use similar AR tools to learn another skilled trade in the future if possible.	12	3,23	4,56	3,6600	,56350
I will recommend the AR learning tool to other classmates	12	3,23	5,96	3,7917	,80803
I'm interested in using AR-based learning tools.	12	3,23	4,56	3,8258	,50905
The content of this application is closely related to "the assembly of parts", which is an interesting topic for me.	12	3,05	5,87	3,9750	,91459
The AR-based learning tool allows me to learn not only on my own, but also with my friends and classmates.	12	3,23	5,56	3,4883	,66386
Valid N (per list)	12				

In this table, the item, "The content of this application is closely related to the assembly of parts, which is an interesting topic for me," has the highest score, 3.97, which suggests that novices enjoy the AR learning tool and that it poses new questions to solve. Although the statement "I enjoy learning basic carpentry using AR" has the lowest value, 3.55, suggesting that novices may find the AR tool interesting, there are still issues that discourage them from recommending the software to other classmates.

Descriptive statistics for the items related to the construct "Cognitive Validity" are shown in Table 9.

Table 9: Descriptive statistics for the construct "Cognitive validity"

	N	Min.	Max.	Average	Std. Desviation
Operating the AR application is not difficult	12	3,23	5,56	3,6933	,68250
Learning to use this AR tool doesn't cost me a lot of time and energy	12	3,23	4,78	3,9725	,53350
The content and procedures of this learning activity are clear and understandable to me.	12	3,00	5,56	3,9142	,93540
Valid N (per list)	12				

In this table, the item "Learning to use this AR tool does not imply much time or effort" has the highest score, 3.97, whereas the item "Operating the AR application is not difficult", has the lowest score, 3.69. These results suggest that, although novices think they can master how to operate the application very quickly, they still lack practice in the procedures. Therefore, to improve the efficiency of the AR tool, we need to improve the cognitive load that the application imposes on novices. Table 10 shows the descriptive statistics for the items related to the construct "Cognitive Accessibility".

Table 10: Descriptive statistics for the construct "Cognitive Accessibility"

	N	Min.	Max.	Average	Std. Desviation
I think the AR demo makes the learning tools and materials more detailed and understandable	12	3,23	5,56	3,6933	,68250
I think using this AR learning tool is very helpful in learning basic woodworking	12	3,23	4,78	3,9725	,53350
This AR learning tool is more effective than any other.	12	3,00	5,56	3,9142	,93540
Using this AR application allows me to master important knowledge	12	3,23	4,25	3,6308	,46647
The AR learning tool provides me with ample space to learn basic woodworking.	12	3,23	5,89	3,8708	,91704
I think that learning carpentry is beneficial for everyone	12	3,23	4,79	3,9759	,533371
Valid N (per list)	12				

In this table, the mean scores of the six items are very close to each other, suggesting that most students judge the AR tool to be useful for their learning.

The foregoing tables show that novices generally have a positive learning attitude and provide positive feedback about the software.

To be consistent with expectations, an analysis of the correlation of novices attitudes and their assessment with the AR tool was performed. Table 11 shows that the Pearson correlation coefficient between "Learning attitude" and "Satisfaction" is 0.498, p = 0.001 <0.05. Pearson's correlation coefficient between "Learning attitude" and "Cognitive validity" is 0.427, p = 0.004 <0.05. Pearson's correlation coefficient between "Learning attitude" and "Cognitive accessibility" is 0.668, p = 0.003 <0.05. These coefficients suggest that learning attitude has a significant positive correlation with novices' satisfaction with the AR tool and equally with the assessment of cognitive validity and accessibility of the AR tool. In other words, the more important a novice thinks it is to learn carpentry, the more useful and satisfying he will believe that the AR tool is, consistent with our expectations.

Table 11: Pearson's correlation coefficient

		Learning attitude	Satisfaction	Cognitive validity	Conectivy Accessibility
Learning attitude	Pearson´s correlation N	-- 12			
Satisfaction	Pearson´s correlation Sig (bilateral) N	.498 .0001 12	--		
Cognitive validity	Pearson´s correlation Sig (bilateral) N	.427 .0004 12	.076 .027 12	--	
Conectivy Accessibility	Pearson´s correlation Sig (bilateral) N	.668 .0003 12	.477 .044 12	.376 .032 12	--

4.4 Observations and Interviews

During the experiment, researchers were constantly observing, taking notes, and recording novice performance, who were excited, impressed, and motivated about the learning activities considering inquiry. We found that most novices failed to use the protocol and activity form, they preferred interacting with the AR application. According to this observation, the ease of use of the application was reflected upon and we decided to remove the detailed instructions in the future and instead attempt to incorporate video or audio instructions using a Tablet, mobile telephone or a PC, to improve the capability of the AR tool.

At the end of the experiment, five novices, (A1-A5) were randomly chosen to be assessed through a personal interview. Six questions were asked during the interview where the answers had to refer to their own feelings about the learning process using the AR tool. The questions and some of the answers are discussed below:

Questions 1, 2, 3: Do you think this AR tool facilitates your learning of the carpentry trade? Why do you think this tool is useful? What knowledge are does the tool help you with?

The AR tool can help me memorize the inventory of tools and materials, learning the technical process in carpentry is not difficult, and sometimes we are not able to imagine how to assemble the parts of a chair or table with only the teacher's instructions. The application is more interesting, which allows us to record and remember more in-depth in our mind. (A1) I found that learning in real space can be really exciting than doing it on our own plans, the images look real as if we are seeing them in reality.

(A2) The AR application makes the contents of the inventory of tools and learning materials look better and more understandable, I could observe the tool features better by moving the marker (A5). When asking the 5 novices if they would like to use the AR tool for future studies, all of them said "yes". A3 said that the AR tool is much more interesting than traditional learning materials and would like to use it in the future.

Question 4: How does this AR software compare with other learning tools you have used? In what areas do you think AR is better than those tools?

The AR tool could help us develop skills in tool inventory management, in the maintenance part. To especially remember the knowledge of technical procedures specific to the trade. (A1)

Question 5 and 6: Do you think the AR software has any disadvantages? What are they? Can you offer any advice on how to improve this AR learning tool?

The model can be unstable and when the marker is being operated sometimes the image takes too long to display on screen or is displayed too fast. (A4)

I suggest that in the application the animations should be more fascinating. (A2)

All the interviewed novices expressed their willingness to use the AR tool again in future learnings; furthermore, they exhibited a positive attitude toward the AR tool.

Additionally, novices mentioned some advantages of the AR tool such as interesting, clear, and understandable material, spatial rather than flat experience, helps to visualize 3D objects well. Some novices commented that it is easier to remember knowledge and procedures using the AR tool, which makes it easier for them to do their procedural experiments that are otherwise difficult to perform. Other novices referred to some disadvantages, most novices mentioning that the model can be unstable at times. One novice stated that the simulation should be more realistic, another suggested introducing more inviting animated elements. These suggestions provided by the novices are valuable and invaluable data so that the product can be reviewed and completed.

5. Discussions and Conclusions

The present study on the implementation of Augmented Reality (AR) in carpentry training for indigenous communities, specifically the Wayúu ethnic group, contributes significantly to the field of learning and educational technology. Compared to previous research that has explored the application of AR in educational settings, this study stands out for its specific focus on indigenous communities, addressing particular access and cultural challenges.

Unlike broader research that has examined the use of educational technologies in diverse contexts, this study dives into a specific and culturally unique environment, offering valuable insights into how AR can adapt and benefit communities with particular characteristics. The research contributes to knowledge by highlighting the effectiveness of AR not only as a learning tool, but as a means to address inequalities in job training, especially in remote and marginalized communities.

This study also stands out by proposing and examining specific strategies for integrating AR into a practical course such as carpentry. This contribution may be of interest to researchers and professionals in the field of educational technology, especially those interested in the design of specific educational interventions for communities with particular needs. Taken together, this study stands as a step forward in understanding how technology, in this case AR, can be applied effectively and culturally sensitive in job training settings for Indigenous communities.

5.1 Preliminary Conclusions and Discussions

After a comprehensive data analysis, which included evaluation of the learning effect and attitudes of the trainees, as well as observations and interviews, several significant conclusions were reached. The study conclusively confirms that the Augmented Reality (AR) tool has a notable supplementary learning impact compared to the use of traditional protocols or guide texts. The pretest scores reflect the limitation inherent in using conventional methods, where, despite learning in class, memory decline was inevitably experienced within a week, resulting in low scores on the pretest. This finding highlights the effectiveness of the AR tool in improving long-term learning retention compared to more traditional teaching methods.

The use of the AR tool in low-performing novices produces more significant learning gains than for high-performing novices because (1) The original scores of high-performing novices are very high, some even approaching the maximum score. (2) The test was relatively basic and was already mastered by high-performing novices at the starting point. (3) The AR tool aims to assist novices in exploring and generalizing concepts, by means of more in-depth analysis of the test, we found that novices' attitudes toward the test are inconsistent.

The AR tool provides a new cognitive method and is expected to have a long-term memory effect on novices through their research-based observation and operation.

Several groups made noticeable errors in following the activity form due to carelessness, novices had to explore on their own, without teacher guidance, so incorrect procedures and lack of feedback could explain these errors. On the other hand, it was possible to note that during the experiment, most novices did not like to refer to the operation in the procedures provided in the paper activity form; when the images are shown, novices focus on the device screen and ignore the activity form. From the perspective of the usability of the AR tool, it may not be appropriate to provide long and detailed instructions for novices.

In summary, this study has conclusively demonstrated that the implementation of Augmented Reality (AR) as a learning tool in a carpentry course in indigenous communities, specifically in the Wayuu population, is highly effective. Through an m-Learning approach and the application of the visual AR technique, learners experienced significant complementary learning, especially those with lower initial performance. Positive attitudes toward the app further supported its usefulness, and the positive acceleration between app evaluation and learning attitudes reinforces the overall acceptance of this methodology.

The contribution of this study to the field of AR-based education and learning is significant, highlighting the effectiveness of AR in improving long-term learning retention and adaptability to address specific challenges in remote and indigenous communities. These findings suggest that integrating AR into similar educational contexts can offer innovative and effective solutions to improve training and skill development in diverse settings.

5.2 Conclusions

This research addresses the implementation of augmented reality (AR) as a pedagogical tool in a carpentry course aimed at indigenous communities, specifically the Wayúu ethnic group. Through careful planning, a structured program was designed that integrates AR into different sessions, addressing key aspects of the craft.

The Wayúu population presents distinctive sociocultural characteristics, such as its complex matrilineal family structure and the importance of roles such as the "putchipu" in conflict resolution. These peculiarities were considered when adapting the course to the specific needs and contexts of this community.

The experiment carried out with a group of Wayúu indigenous people demonstrated their willingness to participate, even overcoming the language barrier. A control group that did not use AR was developed, allowing an effective comparison. However, the geographical and linguistic limitations present in indigenous communities made it difficult to recruit participants, affecting the representativeness of the sample.

The proposed hypotheses suggest significant statistical improvements in the evaluation of trainees after using the AR tool, as well as the need to observe and compare the influence of this tool between high- and low-performing trainees. The research also sought to explore the impact of AR on apprentices' motivation towards carpentry.

Despite the logistical and cultural challenges inherent in research with indigenous communities, the results are expected to provide valuable information on the effectiveness and adaptability of AR in specific educational contexts. Furthermore, the importance of addressing these challenges in an ethical and respectful manner is highlighted, recognizing the cultural and geographical particularities of the indigenous communities involved.

The application of augmented reality (AR) in Wayúu indigenous communities incorporates key technological elements to enrich the educational experience. Some of these elements are described below: Mobile Application with AR Functionality: The main tool is a mobile application that uses the device's camera to overlay virtual elements on the real world. This application is designed in an accessible and easy-to-use manner, considering the participants' possible lack of familiarity with the technology. In addition, Interactive Three-Dimensional Models were used: AR allows the presentation of three-dimensional models of tools, types of wood, materials and carpentry processes. These interactive models allow learners to virtually explore each element, improving understanding of its functionality and application.

Likewise, virtual simulators in specific sessions are used to show cutting, assembly and other practical aspects of carpentry techniques. These simulators offer trainees the opportunity to practice virtually before applying their skills in the physical environment. Regarding the Integration of Augmented Images, for the identification of types of wood and materials, the integration of augmented images is used. This involves displaying virtual images that illustrate different materials, providing a visual and contextual experience that facilitates the assimilation of information.

On the other hand, Real-Time Virtual Feedback during practical sessions, such as assembling a wooden chair, the application guides participants through 3D models, offering real-time virtual feedback. This optimizes skill acquisition and allows for immediate adjustments.

Regarding Assessment through Virtual Scenarios, the AR application is employed for assessment, presenting virtual scenarios that challenged learners to apply their skills and respond to practical situations. This provided a comprehensive assessment of their competencies.

These technological elements are carefully integrated into the carpentry course design, leveraging the capabilities of AR to improve teaching and learning in indigenous Wayúu communities. Cultural and linguistic adaptation of technology is essential to ensure its effectiveness and acceptance within these particular contexts.

This study on the implementation of Augmented Reality (AR) in carpentry training for the Wayúu indigenous community has yielded significant conclusions that highlight the transformative potential of the technology in specific and culturally diverse educational contexts. The quantitative results reveal a positive and significant impact of the AR tool on the cognitive performance of the participants, pointing out its effectiveness as an educational resource in learning carpentry. Importantly, this improvement will not only be observed in general, but was particularly significant among low-performing learners, evidencing the ability of AR to close learning gaps.

Furthermore, the positive attitudes of the participants towards the AR tool, especially in terms of cognitive validity, highlight the acceptance and favorable perception of this technology in the context of carpentry training. However, the relatively low score on the satisfaction construct suggests areas for improvement in usability and user experience, pointing out the importance of considering cultural and contextual factors in the design of technology-based educational tools. These conclusions offer significant contributions to the field of education and technology, highlighting the need for personalized and culturally adapted approaches to maximize the effectiveness of educational interventions in specific communities, such as the Wayúu.

Its findings highlight not only the effectiveness of Augmented Reality (AR) as an educational tool in learning carpentry for the Wayúu indigenous community, but also the importance of considering elements of acceptance, satisfaction and motivation. The positive attitude of the participants towards the AR tool, especially in the area of cognitive validity, indicates that the technology was perceived as authentic and relevant to their learning, which contributed to their intrinsic motivation to participate in the educational process.

It is crucial to note that these results were obtained after comparison with a control group of 10 indigenous people who participated in the same carpentry learning process, but without the intervention of Augmented Reality technology. It was observed that the group using the AR tool experienced significant improvements in cognitive performance compared to the control group. This evidence supports the claim that the implementation of AR in training environments can have a positive and differential impact on skill acquisition, especially in contexts where conventional training might have limitations.

In terms of satisfaction, although areas for improvement are identified, the comparison between both groups highlights the positive contribution of AR to the educational process. The intrinsic motivation of the participants, evidenced by the positive attitude towards the AR tool, suggests that technology can play a crucial role not only in the acquisition of technical skills, but also in active participation and commitment to learning. These results, supported by the comparison with the control group, emphasize the relevance and transformative potential of Augmented Reality in specific and culturally diverse educational environments.

5.3 Possible Improvements and Future Research

Within the perspectives of this research the following aspects could be included:

Firstly, the Impact on the Formation of the Indigenous Community, the research seeks to implement augmented reality (AR) as an effective tool in the carpentry course aimed at an indigenous community. Perspectives would include evaluating how this visual technique can significantly improve woodworking training, especially in underserved communities that lack access to modern teaching tools. Another aspect would be the Evaluation of Cognitive Performance, the objective of which is to evaluate the impact of the AR technique on the cognitive performance of the learners. The implementation of this tool is expected to provide an improvement in the assimilation of skills and knowledge, and prospects could be aimed at observing an increase in trainees' evaluations on the questionnaire after using the AR tool.

On the other hand is the Comparison between High and Low Performing Students, this perspective is important because it compares the effects of the AR tool between high and low performing students. This could reveal how the technology may be more beneficial for certain groups of students and provide valuable information about the adaptability of the tool to different skill levels. Motivation and Attitudes towards Application is another perspective of the research and is also aimed at exploring whether the AR tool has an effect on students' learning motivation towards the carpentry trade. Perspectives here could include analyzing whether participants find the experience meaningful and interesting, which could have implications for the design of future educational programs.

Similarly, there is Overcoming Logistical and Cultural Challenges, which, taking into account that the indigenous community lives in inhospitable areas and presents logistical and cultural challenges, perspectives could focus on how to overcome these limitations to carry out the research in an efficient manner effective and respectful of culture and mobility of the community.

Finally, the research perspectives range from the concrete impact on training to more subjective aspects related to the motivation and attitudes of learners, thus providing a comprehensive view of the potential of augmented reality in specific educational environments.

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Augmented and Virtual Reality in Computational Thinking: A Systematic Review of Their Individual Impacts, Advantages, Challenges, and Future Directions

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https://doi.org/10.34190/ejel.22.3.3992

Abstract: Computational thinking (CT) skills are increasingly important in education to prepare students for the challenges of the digital age. Augmented Reality (AR) and Virtual Reality (VR) have been introduced as immersive technologies that have the potential to enhance CT skills through more interactive learning experiences. However, there is still a gap in understanding the effectiveness of these technologies in supporting the development of CT, particularly in different levels of education and disciplines. Although several studies have highlighted the benefits of AR and VR in education, no systematic review integrates these findings to identify advantages, challenges, and opportunities for further implementation. Therefore, this study conducted a systematic review based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines by analyzing 25 empirical studies (AR=17, VR=8) obtained from the Scopus database (2008-2024). The analysis addresses four key research questions: (1) the current state of AR/VR in CT development, (2) their advantages, (3) implementation challenges, and (4) future research directions. The results show that AR is more widespread than VR at various levels of education, with dominance in higher education followed by secondary and primary schools. Computer science is the main field of application of AR and VR, while AR is also widely applied in mathematics to increase interest and problem-solving. A total of 11 studies reported significant impacts of these technologies on CT, with AR being superior in increasing student motivation and engagement, as well as aiding in problem-solving and debugging. In contrast, VR provides a more immersive learning experience by strengthening concept understanding, especially in programming and recursion. However, several obstacles in the application of AR and VR, such as hardware limitations, costs, and user skills, affect the effectiveness of these technologies in the learning environment. This study also identified potential future research, including the exploration of VR in primary and kindergarten education, the application of VR in non-computer science fields, and the efficient use of these technologies in supporting the CT process. This study provides more precise insights into the optimal ways of utilizing AR and VR in developing CT skills. It is a reference for educators, policymakers, and researchers in supporting CT learning.

Keywords: Augmented reality, Virtual reality, Computational thinking, Education, Systematic review, PRISMA

1. Introduction

In the rapidly evolving digital era, AR and VR have become two significant technological innovations with great potential to revolutionize various sectors, including education. AR, defined as physical reality enhanced with virtual elements, integrates digital information with the physical world, allowing direct interaction between users and virtual objects in real space without requiring them to focus solely on device screens (Sakr and Abdullah, 2024). By adding digital data in real-time, AR creates engaging, interactive experiences in areas such as education, healthcare, and entertainment while remaining accessible through devices like smartphones or tablets (Dargan *et al.*, 2023; Samala *et al.*, 2023). Conversely, VR is an advanced technology that creates a fully immersive and interactive artificial three-dimensional environment where users can navigate and interact in real-time through sensory channels (Jongbloed, Chaker and Lavoué, 2024). Using specialized headsets or glasses, VR enables students to experience and explore various concepts in realistic simulations separated from the real world (Burdea and Coiffet, 2024). While AR is more accessible due to mobile device compatibility (Fan and Liu, 2011; Begum *et al.*, 2023), VR requires dedicated headsets, limiting its adoption in resource-constrained settings. For instance, the AR market is projected to grow at 30.9% CAGR (Sheena *et al.*, 2023), reflecting broader

Cite this article: Fadillah, M.A et al. 2025. "Augmented and Virtual Reality in Computational Thinking: A Systematic Review of Their Individual Impacts, Advantages, Challenges, and Future Directions", *The Electronic Journal of e-Learning, 22(3)* pp 160-174, https://doi.org/10.34190/ejel.22.3.3992

applicability, whereas VR's immersive nature suits specialized training (e.g., programming recursion) but faces higher costs (AlGerafi *et al.*, 2023; Chiliquinga, Arguello and Mayorga, 2025). Despite their different approaches, these two technologies can provide learning experiences that conventional teaching methods cannot deliver (Sakr and Abdullah, 2024). Empirical studies show that integrating AR and VR in education increases student engagement and facilitates a deep understanding of subject matter, especially in science and technology learning (Alzahrani, 2020; Cromley, Chen and Lawrence, 2023).

Along with these technological developments, CT has been identified as one of the essential skills of the 21st century. CT, defined as a cognitive process based on computer science principles, encompasses problem-solving, system design, and abstract thinking (Wing, 2008; Tsai *et al.*, 2022). It includes key components like abstraction, decomposition, generalization, and algorithm design, as well as qualities like confidence and perseverance in addressing challenges (Selby, 2015; Chen *et al.*, 2023). CT serves as an essential foundation across various disciplines, encouraging critical and creative thinking to solve complex problems (Kong, 2022). In the context of education, AR and VR have been shown to support CT development by providing interactive learning environments that allow students to apply computational thinking skills in both real and simulated scenarios (Abdul Hanid *et al.*, 2022a; Huang, Tarng and Ou, 2023). For instance, AR supports abstraction and generalization through interaction with digital objects that represent real-world concepts (Lin *et al.*, 2021; Koumpouros, 2024). Meanwhile, VR offers immersive learning settings that enable students to explore, visualize, and manipulate abstract concepts like algorithms and data structures in scenarios close to reality (Agbo, Oyelere, *et al.*, 2023; Oyelere, Agbo and Oyelere, 2023). Together, AR, VR, and CT provide transformative opportunities to enhance learning experiences and equip students with essential skills for the digital age.

Various studies have explored the application of AR and VR technologies in education, particularly in the context of developing CT skills. For instance, Angraini et al. (2024) investigated the effectiveness of AR in enhancing middle school students' CT skills through a quasi-experimental approach. The study revealed that using AR in mathematics learning significantly improved CT skills compared to conventional methods. Similarly, Theodoropoulos and Lepouras (2021) conducted a systematic review of the use of AR in programming education, finding that while AR positively impacts CT learning, further analysis is needed to understand its characteristics, advantages, and limitations. Acevedo-Borrega et al. (2022) provided a broad review of CT and educational technology, highlighting the need for a more comprehensive understanding of the roles of curriculum and teachers in CT development. However, their review offered limited insights into how AR and VR could be integrated into CT learning strategies. Additionally, Sukirman et al. (2022) discussed game-based CT learning strategies using VR. Although they proposed a conceptual framework linking game elements, VR features, and CT skills, their study was limited in scope, reviewing only 15 studies. While several studies have attempted to address the integration of AR and VR in education, most have focused only on general benefits, such as increased student engagement and improved learning outcomes for specific subjects. In-depth analyses of the impacts, challenges, and future directions for using AR and VR in CT development across various educational contexts remain rare. This indicates a critical gap in the literature.

As illustrated in Figure 2, from 2008 to the present, only 100 publications on Scopus have discussed AR in the context of CT, and 113 publications have examined VR and CT. These figures suggest that research in this domain is still in its early stages. In contrast, other educational technologies have been extensively studied in relation to CT. For example, X. Wang et al. (2023) reviewed game-based learning (GBL) for CT development, highlighting its potential while identifying shortcomings in addressing CT elements such as abstraction and triggers. Varghese and Renumol (2024) explored video games as CT assessment tools but noted a lack of empirical evidence supporting their effectiveness. Belmar (2022) presented a global review of CT and programming education, emphasizing significant gaps between developed and developing regions but without a focus on AR or VR. Even in studies specifically addressing AR and VR, such as Theodoropoulos and Lepouras (2021), analyses remain limited to general insights without a detailed evaluation of these technologies' roles in CT. It underscores the novelty of the present study, which represents the first systematic review comprehensively evaluating AR and VR contributions to CT development across educational levels and subjects.

Therefore, this study aims to bridge these gaps by addressing the following research questions:

- RQ1: What is the current state of research on AR and VR in CT development, considering educational levels, target subjects, and practical outcomes?
- RQ2: What are the advantages of using AR and VR for CT development?
- RQ3: What challenges exist in implementing AR and VR to enhance CT?
- RQ4: What are the future research directions to optimize AR and VR for CT development?

By answering these questions, this review provides a comprehensive foundation for educators and policymakers.

2. Methods

A systematic review is a rigorous and comprehensive approach to summarizing and evaluating the existing research literature on a particular topic or research question that involves systematically searching, selecting, appraising, and synthesizing multiple studies to provide an unbiased and reliable overview of the available evidence (Aromataris and Pearson, 2014). This study adopted a commonly used three-step methodology in systematic reviews (Yadegaridehkordi *et al.*, 2019; Wang and Chan, 2024). The first step is the implementation of an appropriate keyword search strategy. The second step involves the selection and quality assessment of the literature found. The final step is coding to answer the research questions. Each step is described in detail below to provide a clear picture of the process used in this study.

2.1 Search Strategy

The first step in this research was to design and implement an effective search strategy to find relevant studies. Researchers used the Scopus database, which is recognized as one of the most comprehensive sources of scientific literature (Festiyed, Tanjung and Fadillah, 2024; Maral, 2024). Scopus was chosen because it covers a wide range of disciplines and source types, including peer-reviewed journals, conferences, and other academic publications. It ensures that the scope of data retrieved is broad and of high quality. Scopus also has a rigorous selection process for the sources included, so the data obtained is generally considered highly reliable. In addition, Scopus includes most journals that are also indexed in Web of Science, Medline, Google Scholar, and Embase, making it a very comprehensive source for this study (AlRyalat, Malkawi and Momani, 2019; Zyoud *et al.*, 2023). While Scopus covers most journals indexed in Web of Science and PubMed (AlRyalat, Malkawi and Momani, 2019), future reviews could include multiple databases to mitigate selection bias.

Searches were conducted using specific keywords to identify studies that address AR and VR in the context of computational thinking. The keywords used for the AR search were (“augmented reality” OR “AR”), and for VR, were (“virtual reality” OR “VR”). These keywords were combined with the term “computational thinking” to ensure that all studies relevant to the research topic were identified. In addition, to limit the search to the educational context, additional phrases from the systematic literature review by Z. Wang & Chan (2024) were used, namely educat* OR student* OR learn* OR teach* OR class*. These phrases helped ensure that the studies found were relevant to the use of AR and VR in education for the development of computational thinking.

It is important to note that the search was conducted separately for AR and VR. It means that each topic was analyzed independently to identify relevant literature. The search was conducted on article titles, abstracts, and keywords all at once (TITLE-ABS-KEY), without any specific time limit, to ensure that all relevant studies, both new and old, were captured in the search. All data for this study were downloaded on July 21, 2024, to avoid potential bias due to the continuous updating of the Scopus database.

2.2 Selection and Quality Assessment

After implementing the search strategy, the next step was to select and assess the quality of the literature found. The data exported from Scopus was saved in "csv" format and analyzed using Microsoft Excel. This export file contains important information such as title, abstract, link, DOI, and others. From our database search, we identified 213 relevant records, consisting of 100 records for AR and 113 records for VR (see Figure 1). All records were from one database (Scopus), and no duplicate records needed to be removed. We manually screened all records carefully using meta-data (title and abstract) to assess whether they met the inclusion and exclusion criteria. Exclusion criteria included articles for which full text was not available, non-empirical studies, topics not related to the use of AR and VR in the development of computational thinking, non-educational purposes, and articles not written in English. In contrast, the inclusion criteria included articles for which full text was available, empirical studies, topics related to the use of AR and VR in the development of computational thinking, educational purposes, and written in English. It is important to note that these criteria were not applied simultaneously to AR and VR but rather applied separately to each topic. In other words, studies relating to AR and VR were analyzed individually, with the same exclusion and inclusion criteria, but applied separately to ensure a more in-depth understanding of each technology's impact on computational thinking.

After the initial screening, 179 records were removed from further analysis, consisting of 79 for AR and 100 for VR. These deletions were mainly due to the irrelevance of the topic, not an empirical study, and not for educational purposes. Of the remaining records, we excluded 2 records for VR due to lack of relevance to the research topic. We then analyzed the full text of the remaining 32 publications, consisting of 21 for AR and 11 for VR. Of these publications, 25 studies (AR = 17; VR = 8) were judged eligible for this review. Studies were mostly excluded because the full text was unavailable and not written in English (see Figure 1). The studies included in this research are listed in the Table 1.

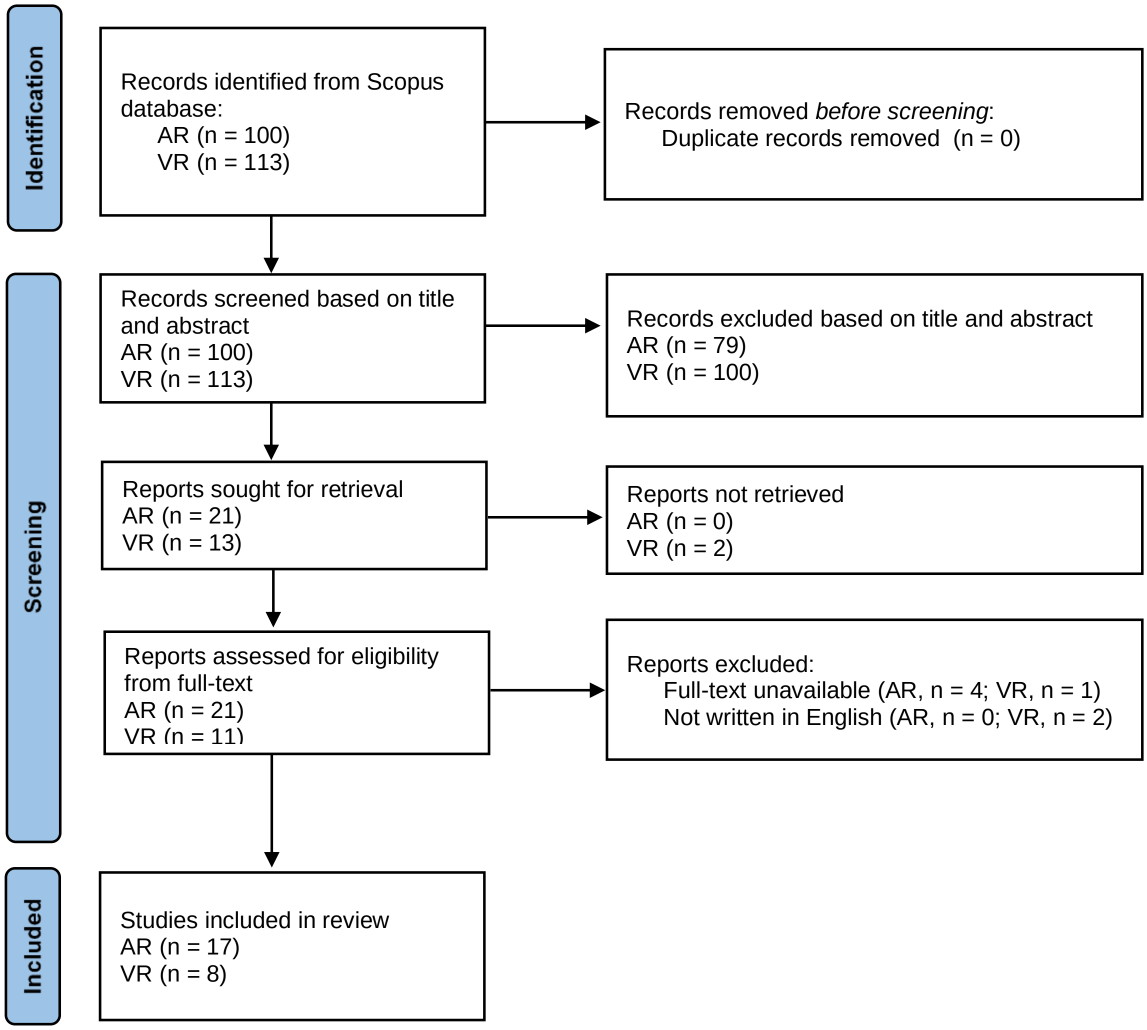

Figure 1: Article selection process based on PRISMA

Table 1: Studies included in review

Author(s)	Article topic	Participants' educational levels	Objective subjects	Practical impacts
Angraini et al. (2023)	AR	Secondary school	Mathematics	Major effect
Angraini et al. (2024)	AR	Secondary school	Mathematics	Major effect
Işik Arslanoğlu et al. (2024)	AR	Kindergarten	Computer science	Major effect
Chung & Hsiao (2020)	AR	Higher education	Computer science	Major effect
Esteves et al. (2019)	AR	Elementary school	General objective	Effective
Gardeli & Vosinakis (2019)	AR	Elementary school	General objective	Effective
Gardeli & Vosinakis (2020)	AR	Elementary school	Computer science	Effective
Abdul Hanid et al. (2022a)	AR	Secondary school	Mathematics	Major effect

Author(s)	Article topic	Participants' educational levels	Objective subjects	Practical impacts
Abdul Hanid et al. (2022b)	AR	General education	Mathematics	Effective
Hidayat et al. (2024)	AR	Higher education	Electronics engineering education	Major effect
Huang et al. (2023)	AR	Elementary school	Computer science	Major effect
Lee & Hsu (2023)	AR	General education	General objective	Effective
P.-H. Lin & Chen (2020)	AR	Higher education	General objective	Major effect
Y.-S. Lin et al. (2021)	AR	General education	Computer science	No effect
Lunding et al. (2022)	AR	Elementary school	General objective	Effective
Saraiva et al. (2021)	AR	General education	General objective	Effective
Ou Yang et al. (2023)	AR	Higher education	Computer science	Minor effect
Agbo et al. (2021)	VR	General education	General objective	Effective
Agbo, Oyelere, et al. (2023)	VR	Higher education	Computer science	Major effect
Agbo, Olaleye, et al. (2023)	VR	Higher education	Computer science	Major effect
Chen et al. (2020)	VR	General education	Computer science	Effective
Coenraad & Weintrop (2018)	VR	Secondary school	General objective	Effective
Gerini et al. (2023)	VR	Secondary school	Computer science	Effective
Sims et al. (2021)	VR	Higher education	Computer science	Minor effect
Lai et al. (2021)	VR	Higher education	Information engineering	Major effect

Note: We used "general education" and "general objective" because the study did not clearly specify the participants' educational levels or the target subjects. Therefore, we decided to use the term "general" for clarity.

2.3 Coding Scheme

Once selection and quality assessment were applied, the next step was data extraction and coding. Coding was conducted based on procedures developed from a previous systematic review with the aim of answering the research questions posed (Wang and Chan, 2024). Coding involved identifying and recording important data from each selected article, including education level, target subjects, practical effects, advantages, and challenges of using AR and VR in the development of computational thinking. Each selected article was reviewed in detail by the authors, and the necessary data was recorded using Microsoft Excel. Each selected article was coded independently by two authors to ensure consistency and accuracy in coding. After the initial coding was completed, the coding results were compared to identify similarities and differences. In case of disagreement between the two authors in coding, the differences were discussed in a group discussion involving all authors. This approach allows for more comprehensive discussions and more collective decision-making (Richards, Hemphill and Flory, 2022). Suppose after discussion there are still significant differences. In that case, a final decision will be made based on a majority vote, or, if required, a senior researcher will be asked to provide a final opinion. This systematic coding process ensures that all important aspects of relevant studies are carefully identified and analyzed so that the results of this research can make a significant contribution to understanding the role of AR and VR in the context of computational thinking.

3. Results

3.1 Analysis of Publication Descriptions Taken From Publication Trends

The publication trend on AR and VR in the context of computational thinking shows a significant increase in recent years (see purple line in Figure 2). Publications on AR have increased since 2016, with a peak in 2023 of 25 publications. Although the 2024 data only covers up to July 21, there are already 10 publications identified, indicating continued interest. VR has also seen an annual increase, with a peak of 33 publications in 2023 and 7 publications in 2024 through July 21. Some publications were selected for systematic review according to specific criteria (see orange lines in Figure 2). AR studies that met the criteria ranged from 2019 to 2024, mostly from 2023, reflecting the peak of the literature. For VR, relevant studies were from 2018 to 2023, with a predominance of recent literature from 2023, which makes an important contribution to the understanding of the use of VR in the development of computational thinking.

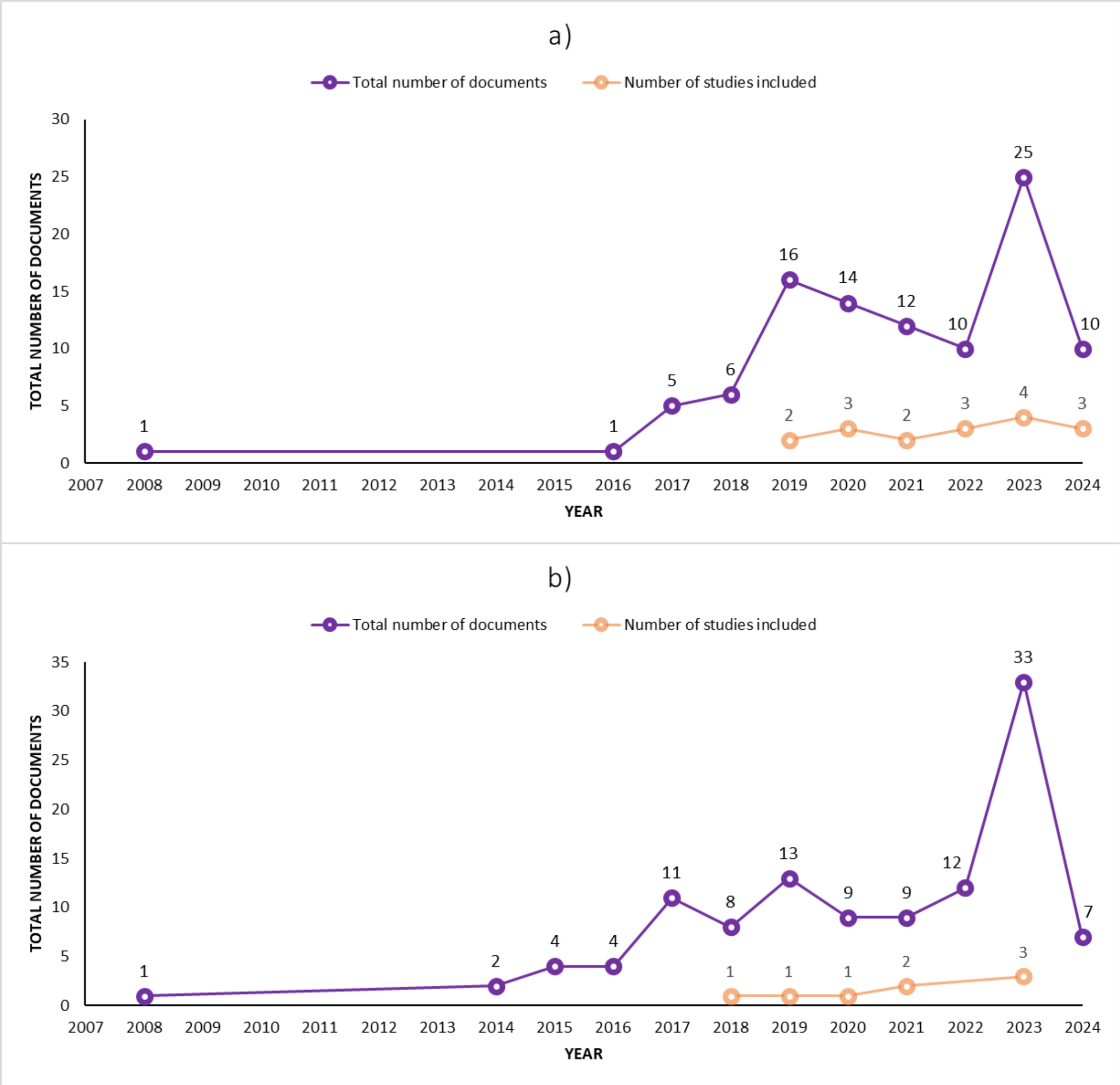

Figure 2: Total number of documents and number of studies included: a). Documents for AR in the context of computational thinking; b). Documents for VR in the context of computational thinking

3.2 Participants' Educational Levels

Table 2 shows that most studies (32%) focused on AR and VR at the college level, with VR (50%) more prevalent than AR (23.53%). Higher education dominates their application, leveraging students' advanced computational thinking (CT) development skills. In secondary schools (20%), AR appeared in 3 studies (17.65%) and VR in 2 (25%), enhancing engagement and meaningful learning. AR was more common in primary schools (5 studies, 29.41%), while VR was absent, indicating AR's potential for early technology exposure. One study (5.88%) explored AR in kindergarten for basic CT skills, but VR was not used, likely due to student limitations. Additionally, 24% of studies did not specify an educational level but examined AR (4 studies) and VR (2 studies) in general CT development. AR (68%) was more widely used than VR (32%), likely due to its easier integration across different education levels.

Table 2: Educational levels of AR and VR study participants

Educational levels	Number of ARs	% AR	Number of VRs	% VR	Total	Total (%)
Kindergarten	1	5.88	0	0.00	1	4.00
Elementary school	5	29.41	0	0.00	5	20.00
Secondary school	3	17.65	2	25.00	5	20.00
Higher education	4	23.53	4	50.00	8	32.00
General education	4	23.53	2	25.00	6	24.00
Total	17	100.00	8	100.00	25	100.00

3.3 Objective Subjects

Figure 3 shows that AR and VR are primarily used in computer science, with 11 AR and 5 VR studies enhancing programming and CT skills through practical approaches like coding (Chen, Lai and Lin, 2020) and robotics (Ou Yang, Lai and Wang, 2023). VR is also integrated into game-based learning, fostering problem-solving through algorithms, decomposition, and pattern recognition (Agbo, Olaleye, *et al.*, 2023; Lee and Hsu, 2023), while interactive VR games boost engagement and cognitive abilities (Agbo *et al.*, 2021; Agbo, Oyelere, *et al.*, 2023). AR has also been applied in mathematics (4 studies), using animated visualizations to enhance problem-solving interest, while VR was not explored in this field. In electronic and information engineering, one AR and one VR study demonstrated benefits for intellectual development. Additionally, eight studies investigated AR and VR in general education contexts, highlighting their versatility, though VR use in computer science still needs further exploration.

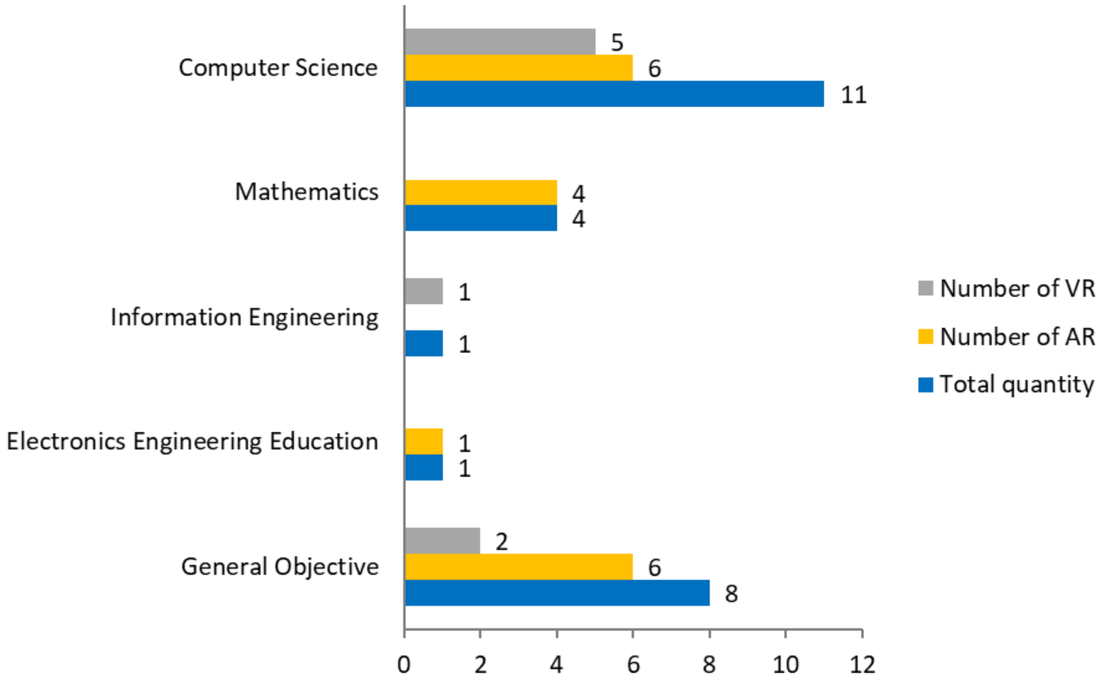

Figure 3: Target study subjects

3.4 Practical Impact

Table 3 summarizes the practical impact of using AR and VR on CT. Of the 25 studies analyzed, 11 studies reported a significant impact or major effect on students' CT, where AR recorded a major effect ratio of 0.47 and VR of 0.38. This significant effect is mainly related to AR and VR's ability to provide an interactive learning environment that supports problem-solving and higher student engagement (Gardeli and Vosinakis, 2020). On the other hand, 11 studies reported these technologies as effective, i.e., having a positive impact on improving students' CT, although without testing the level of significance. The use of AR in the effective category showed a ratio of 0.41, while VR reached a ratio of 0.50. Studies in the effective category show that AR and VR are capable of enriching students' learning experience but focus more on the process of using the technology rather than on its measurable outcomes or impact. In addition, some studies noted limitations to the impact of these technologies. Two studies showed minor impacts, one for AR (Ou Yang, Lai and Wang, 2023) and one for VR (Sims *et al.*, 2021), and there was one study that found that AR did not affect students' CT (Lin *et al.*, 2021). Barriers such as time constraints, technical difficulties, and the need for additional support in technology-based learning also affect the effectiveness of AR and VR (Gardeli and Vosinakis, 2020; Işik Arslanoğlu, Kert and Tonbuloğlu, 2024).

Table 3: The practical impact of AR and VR

Practical impacts	Quantity of AR	Quantity of VR	Total	Impact to Number of Technology Ratio	
				AR Ratio	VR Ratio
Major effect	8	3	11	0.47	0.38
Moderate effect	0	0	0	0.00	0.00
Effective	7	4	11	0.41	0.50
Minor effect	1	1	2	0.06	0.13
No effect	1	0	1	0.06	0.00
Sum	17	8	25	1.00	1.00

3.5 Advantages of Using AR and VR in CT Development

AR and VR technologies have a significant role in the development of CT skills in students (refer to Table 4). AR can increase learning motivation, engagement (Abdul Hanid *et al.*, 2022a; Angraini, Yolanda and Muhammad, 2023; Angraini *et al.*, 2024; Işik Arslanoğlu, Kert and Tonbuloğlu, 2024), and facilitate problem-solving (Lin and Chen, 2020; Saraiva *et al.*, 2021; Abdul Hanid *et al.*, 2022a) and debugging in learning (Chung and Hsiao, 2020; Abdul Hanid *et al.*, 2022b; Huang, Tarng and Ou, 2023). Moreover, AR is particularly useful for children, including those with special conditions such as ASD (Autism Spectrum Disorder) (Lee and Hsu, 2023), in developing computational thinking through an intuitive approach (Esteves, Santana and Lyra, 2019; Gardeli and Vosinakis, 2020). On the other hand, VR helps students engage more intensely through immersive virtual environments deepen recursion understanding (Coenraad and Weintrop, 2018; Lai *et al.*, 2019; Agbo *et al.*, 2021; Agbo, Olaleye, *et al.*, 2023; Agbo, Oyelere, *et al.*, 2023; Gerini *et al.*, 2023), as well as facilitate reflective thought processes that support conceptual understanding in CT (Agbo, Oyelere, *et al.*, 2023).

Table 4: The main advantages encountered in the use of AR and VR technologies for CT development in students

Technology	Main advantages	Explanation	Reference
AR	Facilitates feedback and engagement	AR supports immediate feedback, engaging interactions, and in-depth learning content that reinforces understanding of the material	Abdul Hanid et al. (2022a); Angraini et al. (2023), (2024); Işik Arslanoğlu et al. (2024)
	Supports problem-solving	AR helps students think critically in problem-solving and motivates them to improve academic performance	Abdul Hanid et al. (2022a); P.-H. Lin & Chen (2020); Saraiva et al. (2021)
	Strengthens algorithmic and debugging skills	AR effectively improves algorithmic thinking skills and helps in debugging tasks by reducing errors in code design	Abdul Hanid et al. (2022b); Chung & Hsiao (2020); Huang et al. (2023)
	Improving special children's CT skills	With games and social strategies, AR can help ASD children learn CT more intuitively and engagingly	Lee & Hsu (2023)
	Developing basic CT skills at the elementary level	AR encourages students to create a game design map, training them to plan and calculate steps	Esteves et al. (2019); Gardeli & Vosinakis (2020)
VR	Increases engagement and immersion	VR provides access to realistic virtual environments and supports students' full engagement in learning	Agbo et al. (2021); Coenraad & Weintrop (2018); Gerini et al. (2023)
	Facilitating CT development through complex learning	VR supports complex learning processes such as algorithmic thinking, problem decomposition,	Agbo, Oyelere, et al. (2023); Lai et al. (2019)

Technology	Main advantages	Explanation	Reference
		and pattern recognition, which are important in CT development	
	Improving understanding of recursion	The high interaction and engagement of students with VR can improve their understanding of the concept of recursion	Agbo, Olaleye, et al. (2023)
	Supports reflection and understanding of CT concepts	VR helps the reflective thinking process that promotes students' deep understanding of CT concepts	Agbo, Oyelere, et al. (2023)

3.6 Challenges of Using AR and VR in CT Development

The use of AR and VR technologies in the development of CT faces various challenges, especially in the aspects of limited device technology and high development costs (refer to Table 5). The use of AR is still limited by hardware quality (Esteves, Santana and Lyra, 2019; Lunding *et al.*, 2022; Angraini *et al.*, 2024), interaction features (Chung and Hsiao, 2020), time and cost (Esteves, Santana and Lyra, 2019; Gardeli and Vosinakis, 2020), and student dependence on teacher guidance (Gardeli and Vosinakis, 2020; Angraini *et al.*, 2024). In addition, different levels of interest based on gender also affect the effectiveness of AR use in the classroom (Angraini, Yolanda and Muhammad, 2023). Meanwhile, VR requires high-quality devices (Sims *et al.*, 2021; Gerini *et al.*, 2023), adequate user experience (Agbo, Oyelere, *et al.*, 2023), adequate cognition (Huang, Tarng and Ou, 2023), and adaptation time due to potential physical discomfort (Coenraad and Weintrop, 2018). Cost and educator skill factors also limit the utilization of VR in education (Coenraad and Weintrop, 2018; Chen, Lai and Lin, 2020), although its potential for CT development is significant.

Table 5: The main challenges faced in the use of AR and VR technologies for CT development in students

Technology	Main challenges	Explanation	Reference
AR	Device technology limitations	Sub-optimal hardware quality prevents AR from functioning optimally; some devices do not support the expected performance	Angraini et al. (2024); Esteves et al. (2019; Lunding et al. (2022)
	Dependence on graphic quality and interaction	AR does not yet support tracking eye gaze and hand movements, limiting interaction with virtual content	Chung & Hsiao (2020)
	Requires guidance in its use	Students have difficulty understanding difficult material and need teacher support for discussion	Angraini et al. (2024); Gardeli & Vosinakis (2020)
	Development is costly and time-consuming	AR application development is time-consuming and costly and requires the development of scenarios according to students' learning needs	Esteves et al. (2019); Gardeli & Vosinakis (2020)
	Unevenness of interest by gender	Male students' interest in using AR is higher than females, which may be influenced by the perception of AR as a "game."	Angraini et al. (2023)
VR	Dependence on user experience	Many students are still new to using VR so it takes time for adaptation.	Agbo, Oyelere, et al. (2023)
	Cognitive difficulties in understanding the material	Complex learning materials can cause a high cognitive load for students	Huang et al. (2023)
	Technological limitations of VR devices	The quality of graphics, navigation, and instruction in VR still needs improvement to meet learning needs	Gerini et al. (2023); Sims et al. (2021)
	High cost and limited educator skills	The utilization of VR in CT education is still limited due to the cost and inadequate skills of educators.	S.-Y. Chen et al. (2020); Coenraad & Weintrop (2018)
	Physical comfort factor	Head-mounted VR devices can cause discomfort, so it takes time for user adaptation.	Coenraad & Weintrop (2018)

3.7 Future Research of Using AR and VR for CT Development

There is some potential for future research into using AR and VR to support CT development in education. This study can help increase various parties' understanding of the impact of advanced technology in education.

- **Use of VR at elementary school and kindergarten levels**: Table 1 shows that AR technology has been applied at all levels of education. Six studies show that AR has been successfully used to support CT development in students in primary schools and kindergartens, proving that children at this level are quite capable of using high technology. As VR shares similar characteristics with AR, future research could test the potential of VR to develop CT in students at these two levels of education, as well as understand the capabilities and challenges they face.
- **Use of VR in non-computer science disciplines**: Currently, the use of VR for CT development is mostly in computer science-related fields (see Figure 3). Since AR has been applied in various non-computer science disciplines, such as mathematics, future research could examine the use of VR in other fields, such as mathematics, biology, and physics, to broaden the horizon of the application of VR in various disciplines.
- **Efficiency of VR use to support the ct process**: The quality of technology is proven to affect students' CT development. The use of advanced technology can increase comfort and ease of use (Esteves, Santana and Lyra, 2019). Previous study recommendations suggest that future researchers explore the efficiency of VR devices and track constraints on them (Gerini *et al.*, 2023). The results will provide important insights into how much VR efficiency can affect user adoption and reliance on this technology in studying CT in education.
- **Use of AR in various disciplines**: Several studies have examined the application of AR in computer science, mathematics, electronics engineering education, and information engineering. Future studies could examine the benefits of AR in other disciplines, such as physics, biology, and chemistry, to create more engaging and visually real learning experiences (Angraini, Yolanda and Muhammad, 2023; Angraini *et al.*, 2024).
- **Number and environment of participants in AR research**: The number of participants and the research environment or location have the potential to provide new insights into AR's effectiveness. Future studies could increase the number of participants (Gardeli and Vosinakis, 2020; Angraini, Yolanda and Muhammad, 2023; Ou Yang, Lai and Wang, 2023) and test AR implementation in different environments to see the impact of using this technology in various locations (Chung and Hsiao, 2020; Gardeli and Vosinakis, 2020).
- **The effect of CT elements on academic achievement in AR use**: The study of Abdul Hanid et al. (2022a) shows that AR-based learning with CT has a positive impact on student academic achievement but has yet to examine all CT elements. Ou Yang et al. (2023) found that the algorithm design element had a positive impact. However, this may be due to limited time, making students focus on solving questions without using efficient algorithms. Future studies could examine all elements of CT, such as pattern recognition, abstraction, generalization, decomposition, and debugging, and their impact on academic achievement with a longer research duration.

4. Discussions

The findings of this study demonstrate a notable rise in the application of AR and VR technologies for developing CT skills, with a surge in research output in 2023 (RQ1). This trend suggests an increasing recognition of the potential of immersive technologies in education. One major factor driving this rise is the COVID-19 pandemic, which accelerated the adoption of digital and immersive learning tools to address challenges posed by remote learning. Bermejo et al. (2023) highlight how the pandemic catalyzed the integration of AR and VR as educators sought innovative ways to maintain student engagement and facilitate interactive learning in virtual environments. This surge aligns with broader shifts toward digital transformation in education, further emphasizing the relevance of these technologies in a post-pandemic world (Matsieli and Mutula, 2024).

AR and VR have been adopted at various educational levels, with AR more prevalent in primary education due to its accessibility and child-friendly nature. Our findings align with Pellas et al. (2019) and Radu (2012), who noted AR's suitability for younger learners due to its intuitive interface. Conversely, VR is favored in higher education settings, where complex cognitive skills, such as recursion and algorithmic thinking, are required. Bermejo et al. (2023) and Radianti et al. (2020) similarly emphasize VR's role in enhancing engagement and comprehension of abstract concepts in advanced learning environments. The constructivist framework explains how AR/VR's interactive environments align with active learning principles (AlGerafi *et al.*, 2023; Vashisht, 2024; Kononov *et al.*, 2025), reinforcing CT skills like abstraction (see Table 4). AR's dominance in primary education (29.41% of studies, Table 2) correlates with its lower cost and device compatibility (Fan and Liu, 2011; Begum *et al.*, 2023), whereas VR's scarcity (0% in primary schools) reflects infrastructural barriers.

The advantages of AR and VR in CT development (RQ2) extend beyond engagement, significantly enhancing problem-solving, debugging, and algorithmic thinking. Theodoropoulos and Lepouras (2021) highlight AR's impact on programming education, providing immersive visualizations that aid understanding. Similarly, VR supports reflective and deep thinking, as noted by Elmqaddem (2019), enabling students to interact with complex problem spaces in ways traditional methods cannot replicate. This immersive learning experience fosters greater retention and application of CT concepts, as supported by K.-T. Huang et al. (2019) and Reeves et al. (2021), who found VR and AR effective in promoting experiential learning in science disciplines.

However, this study also identifies significant challenges (RQ3), echoed in the broader literature. The high cost of VR devices and the technical expertise required for effective implementation remain barriers to widespread adoption, particularly in underfunded educational systems. Belmar (2022) and Radianti et al. (2020) note similar issues, suggesting that financial constraints and limited access to training for educators hinder the integration of these technologies. Furthermore, gender disparities in AR engagement, where male students exhibit higher interest, mirror findings by Khan and Khan (2019), pointing to the need for more inclusive approaches to technology adoption. Physical discomfort and adaptation challenges with VR technology also pose obstacles, as highlighted by Barteit et al. (2021) and Pellas et al. (2019), necessitating improved device ergonomics and user acclimatization processes.

Future research should address these gaps (RQ4), exploring VR's potential in early education to nurture CT skills from a young age. DeJarnette (2018) and Radu (2012) emphasize the need to adapt immersive technologies for younger learners, leveraging AR's accessibility to introduce foundational CT concepts. Additionally, expanding the application of AR and VR beyond computer science to subjects like biology and math could broaden their educational impact. K.-T. Huang et al. (2019) found AR particularly effective in improving knowledge retention in science education. Exploring interdisciplinary applications could reveal new opportunities for these technologies to enhance learning in diverse contexts.

Nonetheless, there are limitations in this study that need to be recognized. First, this analysis used the Scopus database as the primary source for relevant articles. Although Scopus is one of the most comprehensive academic databases for reviews (Festiyed, Tanjung and Fadillah, 2024; Maral, 2024), relying solely on this data source may exclude important publications found in other databases such as PubMed or Web of Science. This limitation may affect the generalizability of the findings, as insights from these omitted sources could provide a more nuanced understanding of AR and VR applications. In addition, the list of keywords used in this study was based on previous literature, primarily focusing on the educational field (Wang and Chan, 2024). While this method aimed to cover a broad spectrum of relevant terms, some crucial keywords may have been excluded. This limitation could lead to false negative results, potentially overlooking studies significant to the research objectives. Therefore, future reviews should consider diverse keyword strategies and include multiple databases to ensure a more comprehensive analysis.

5. Conclusion

The results of this study indicated significant developments in the use of AR and VR to support CT development. Both technologies have demonstrated substantial benefits in improving computational thinking skills, problem-solving, and student engagement. However, challenges such as device accessibility, educator skill limitations, and differences in student interest underline the need for effective mitigation strategies. In addition to providing insights into the effectiveness of AR and VR, this study underscores the importance of addressing these challenges. Educators should prioritize AR for early CT development due to its accessibility, while VR is better suited for advanced concepts in higher education. Policymakers must address cost barriers through funding initiatives. Future research should focus on adapting these technologies across different educational contexts, evaluating their impact on broader disciplines, and developing more inclusive and cost-effective implementation guidelines. For example, explore VR in kindergarten settings (as AR has shown promise, Işik Arslanoğlu et al., 2024) and interdisciplinary applications (e.g., biology) to broaden CT integration. By doing so, the benefits of AR and VR in CT development can be fully realized across various educational levels and learning environments.

Acknowledgements

The authors would like to thank the Institute of Research and Community Service of Universitas Negeri Padang, which has provided support for this research

AI Statement: Authors declare that artificial intelligence was not used to prepare this study.

Ethics Statement: This study was a systematic review of existing literature and did not involve direct participation of humans or animals. Therefore, formal ethics approval was not required. All data were extracted from publicly available sources.

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Editorial on the Special Issue on Extended Realities 2025: The Long Road to Unlocking Alluring Treasures

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https://doi.org/10.34190/ejel.22.3.4613

Abstract: Virtual Reality (VR) and Augmented Reality (AR) technologies are increasingly integrated into education across diverse contexts, from primary schools to higher education and vocational training. The collection associated with this editorial provides insights from eleven recent studies on VR/AR-enhanced learning, including systematic reviews, experimental designs, and case studies in resource-constrained environments. The articles in the collection have been organized into three key clusters of research: (1) reviews and taxonomies that attempt to structure the rapidly evolving field, (2) empirical studies in higher education testing immersive and collaborative platforms, and (3) practice-oriented case studies that apply AR in trades and indigenous communities. While the findings of the articles highlight significant potential for motivation, collaboration, and inclusivity, issues such as methodological fragmentation, small sample sizes, and cost barriers remain persistent challenges in conducting VR/AR experiments. We argue that future work must move beyond isolated case studies toward integrated curricula, inclusive frameworks, and cost-effective solutions to ensure that VR and AR become sustainable, reliable tools in education.

Keywords: Virtual reality, Augmented reality, Education, Computational thinking, Indigenous communities, Higher education, Systematic review, Inclusive learning

1. Introduction

Johnson-Glenberg (2018) emphasizes that extended realities (XR), such as augmented reality (AR) or virtual reality (VR), add didactic value when the two core affordances are used: presence (feeling "there") and embodied interaction (gestures/manipulation in 3D). A similar observation has been made in the Cognitive Affective Model of Immersive Learning (CAMIL, Makransky & Petersen, 2021) by stating that the perceived feeling of presence and agency are the key affordances of immersive learning. Affordances (Gibson, 2014) of learning technologies are educationally meaningful options for action and perception that digital media open up for learners and teachers. They result from the interaction of technology, learning context, and user skills (Kirschner, 2002). Subsequently, the design of XR learning scenarios along the unique affordances of VR is being called for (Froehlich, Plass and Homer, 2025). Examples of affordances in the medical field—one of the frontrunners for the educational use of XR—include authentic 3D simulations of critical situations, automated feedback, high interactivity, emotional involvement, automated feedback, objective performance evaluation, immersive presence, risk-free training without danger to anyone involved, and multiple repetitions of complex situations (Jiang *et al.*, 2022; Wu *et al.*, 2022; Neher *et al.*, 2025). One example of how affordances can be exploited is that XR is particularly strong when it comes to spatial-procedural learning objectives. Reviews consistently find that XR is particularly suitable for training (Xie *et al.*, 2021), spatial understanding (Gittinger and Wiesche, 2024; Yang *et al.*, 2025), abstract or invisible phenomena (e.g., molecules, fields) (Alnagrat *et al.*, 2022; Emma, 2026), and contexts that are difficult to access, dangerous or expensive in real life (Alnagrat *et al.*, 2022; Gil Parga *et al.*, 2024; Malungana and Chimbo, 2024)

For guiding the meaningful design of XR learning tools, models of learning with XR have been established, which then also result in design guidelines that are organized in so-called frameworks. Not to be forgotten is the extension of the Cognitive Theory of Multimedia Learning (CTML), which has been supplemented by the Immersion Principle (Mayer, 2024). Other models and frameworks include Meaningful Immersive VR Learning (M-iVR-L) (Mulders, Buchner and Kerres, 2020), the XR-Ed Framework (Yang, Zhou and Radu, 2020), and the Immersive Virtual Reality Pedagogical Model (iVRPM) (Bicalho, Piedade and Matos, 2025). With particular reference to the pivotal role of affordances, one of the most influential models of immersive VR learning, the

Cite this article: Söbke, H. and Spangenberger, P. 2025. "Editorial on the Special Issue on Extended Realities 2025: The Long Road to Unlocking Alluring Treasures", *The Electronic Journal of e-Learning 22(3)*, pp P175-179, https://doi.org/10.34190/ejel.22.3.4613

CAMIL (Makransky and Petersen, 2021), focuses on presence and agency as core affordances and interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation as factors influencing learning processes in immersive VR.

The considerations outlined above indicate XR is a particularly instruction-design-intensive medium. A prominent trend is the transfer of proven multimedia instructional principles to XR (Çeken and Taşkın, 2022), including segmentation (Wyssenbach, Kaufmann and Schwaninger, 2025), signaling (Albus, Vogt and Seufert, 2021), cues (Weerasinghe *et al.*, 2022), pre-training (Huang, 2018; Buchner, Buntins and Kerres, 2022; Nurjanah and Retnowati, 2024), or guided tasks (Herbert *et al.*, 2022; Liao *et al.*, 2024). An example is a framework that combines CTML (Cognitive Theory of Multimedia Learning) principles with immersive VR specifics and derives concrete guidelines from them (Mulders, Buchner and Kerres, 2020). More recent syntheses explicitly collect evidence-based design and didactic principles for educational VR, including signaling, guidance, interaction design, and assessment (Radianti *et al.*, 2020; Won *et al.*, 2023; Steindorff *et al.*, 2024; Zackoff, Klein and Real, 2024; Oje, Hunsu and Fiorella, 2025).

Having seen impressive technical achievements in recent years, this Special Issue now enumerates insights that have been gained in XR-related teaching/learning research since 2018. The articles have been organized into three key clusters of research: (1) reviews and taxonomies that attempt to structure the rapidly evolving field, (2) empirical studies in higher education testing immersive and collaborative platforms, and (3) practice-oriented case studies that apply AR in trades and indigenous communities.

2. Cluster 1: Reviews and Taxonomies

Reviews and taxonomies help to structure the (still) fragmented field of VR and AR research. Recent reviews have looked more closely at specific target groups (e.g., special education) and derived requirements for adaptability, accessibility, overload avoidance, and supportive forms of interaction. In the review by (Wehrmann and Zender, 2024), a framework for inclusive VR learning applications has been developed based on the Universal Design for Learning framework. It emphasizes the need to design VR environments that accommodate diverse student populations in K–12 education. (Bisswang *et al.*, 2023) provide a taxonomy of VR use cases in higher education. Their classification offers both researchers and practitioners a systematic foundation for further design and evaluation. Reviewing 25 empirical studies, (Fadillah *et al.*, 2025) compare AR and VR in fostering computational thinking skills. It highlights AR's greater prevalence and VR's strong immersive qualities, while also pointing to high costs and device limitations as obstacles. (Walstra, Cronje and Vandeyar, 2023), again, analyzed 100 articles across twelve countries, to capture teachers' perceptions of VR in primary schools. Teachers acknowledge the motivational potential of VR but also note practical barriers such as infrastructure and training gaps.

3. Cluster 2: Empirical Studies in Higher Education

Given this continuous development of theoretical and technical foundations and the rapidly growing number of studies in recent years (Jiang *et al.*, 2022; Tudor Car *et al.*, 2022; Wu *et al.*, 2022), this Special Issue focuses on empirical studies related to virtual platforms that enable collaborative learning, which is an effective strategy zur Förderung von u.a. tiefem Verständnis, Motivation, sozialer Kompetenz und Lernleistung (Makransky and Petersen, 2023; Khan, 2024; Montag *et al.*, 2025). The mixed-method study in this Special Issue by (Wong *et al.*, 2024) explores the Classlet metaverse platform with students in Hong Kong and Thailand. Results suggest positive effects on learners' intention to use immersive environments, though technological hurdles persist. Comparing Gather.town-based discussions with face-to-face learning, the quasi-experimental study by (Rayyan *et al.*, 2024) finds comparable or even improved outcomes in language learning. It demonstrates the potential of virtual discussion platforms in foreign language teaching. Through a case study, the work of (Foster, Barth and Chaudhry, 2024) evaluates platforms such as Topia and WorkAdventure. The study reveals that educators' technological self-efficacy is a decisive factor in adoption and effective use. The study by (Averbeck *et al.*, 2024) compares VR headsets for collaborative activities with 360° video integration for reflection in social work education. Both approaches proved pedagogically valuable, albeit with different strengths. Finally, surveying 321 respondents in Indonesia, (Binowo *et al.*, 2023) apply structural equation modeling to understand continued use of virtual education exhibitions. Findings underline the importance of perceived usefulness and flow experiences for sustained adoption.

4. Cluster 3: Practice-Oriented AR Case Studies

Case studies can pave the way for deriving larger research questions based on particularly unique fields of learning, or bringing insight into areas which have rarely been investigated (yet). In the case study by (Beltrán and Huertas, 2023) mobile AR-based learning environment for carpentry skills among the Wayuu community in Colombia has been designed. Despite the small sample, results show that AR can provide effective vocational training in marginalized settings. Extending their earlier work, the authors implement in another article the AR application in a structured carpentry course with twelve participants, showing that AR can enhance skill acquisition and foster learner engagement (Beltrán Alvarado, 2024).

In summary, this special issue's body of work demonstrates that VR and AR are no longer confined to experimental pilots but are on the brink to mainstream education. From primary schools to indigenous vocational programs, these technologies are diversifying learning environments and expanding pedagogical possibilities. Further, the findings highlight significant potential specifically for motivation, collaboration, and inclusivity. Yet, significant challenges remain. The field is marked by small-scale studies, heterogeneous platforms, cost barriers and inconsistent, fragmented evaluation methods (e.g., (Martella *et al.*, 2026)). Systematic reviews and taxonomies offer structure but cannot substitute for coherent theoretical models. Future research must therefore prioritize – amongst others – inclusivity, scalability, and cost-effectiveness. Developing integrated curricula, fostering digital self-efficacy among educators, and lowering technological barriers will be crucial. Such measures would be crucial for moving VR and AR beyond fragmented niches to become transformative, equitable tools in global education.

5. Concluding Remarks

Finally, the scientifically based design of XR learning tools and their use have made great strides in recent years, as the contributions in this Special Issue notably demonstrate. XR learning tools are capable of being extremely powerful when utilized in accordance with their affordances. However, it must also be noted that there is still much work to be done before XR learning is fully understood. For instance, there is still a need to investigate the extent to which XR learning tools (and other complex learning tools) are subject to the same principles as those established in the Cognitive Theory of Multimedia Learning. Some of these principles have been proven, while others have been contradicted by findings (e.g., the reversal of the modality principle (Albus and Seufert, 2023)). XR also seems to prevail where the high cost of establishing XR learning tools can be offset by a comparative advantage, i.e., where the use of XR learning tools generates the greatest benefit through specific affordances. A comparative advantage is evident, for example, when excursions are made possible virtually through VR environments, resulting in massive cost savings (Spangenberger and Söbke, 2025). But even if the costs of creating and using XR learning tools can be reduced, there is still a comparative advantage, for example in 360°-based desktop VR excursions (Wolf *et al.*, 2023). A comparative advantage is also met where one would be exposed to danger or where it would not be possible to have certain experiences without VR. Given this continuous development of theoretical and technical foundations and the rapidly growing number of studies in recent years (Jiang *et al.*, 2022; Tudor Car *et al.*, 2022; Wu *et al.*, 2022), the potential impact of future technological advances, such as AI, warrants further investigation.

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