Exploring the Educational Potential of Virtual Reality and Mixed Reality: Immersive Learning, Student Engagement, and Knowledge Retention

Mila Dodevska
Faculty of Computer Science and Engineering
Ss. Cyril and Methodius University
Skopje, North Macedonia
mila.dodevska@finki.ukim.mk

Zivko Atanaskoski
Faculty of Computer Science and Engineering
Ss. Cyril and Methodius University
Skopje, North Macedonia
zivko.atanaskoski@finki.ukim.mk

Mile Jovanov
Faculty of Computer Science and Engineering
Ss. Cyril and Methodius University
Skopje, North Macedonia
mile.jovanov@finki.ukim.mk

Emil Stankov
Faculty of Computer Science and Engineering
Ss. Cyril and Methodius University
Skopje, North Macedonia
emil.stankov@finki.ukim.mk

Petre Lameski
Faculty of Computer Science and Engineering
Ss. Cyril and Methodius University
Skopje, North Macedonia
petre.lameski@finki.ukim.mk

***Abstract*—The integration of Virtual Reality (VR) and Mixed Reality (MR) technologies in education presents new opportunities for immersive and interactive learning. This paper reviews recent applications of VR/MR in educational contexts, emphasizing their impact on student engagement, cognitive development, and knowledge retention. The analysis highlights key benefits such as enhanced motivation, improved practical skills, and effective visualization of abstract content, while also acknowledging limitations including cognitive load and motion sickness. In addition to the literature review, the grounds of an experimental study are presented.**

***Index Terms*—Virtual Reality (VR), Mixed Reality (MR), Immersive Learning, Student Engagement, Knowledge Retention, E-learning, Educational Technology.**

I. Introduction

Quality education is essential for fostering economic growth, reducing inequalities, and empowering individuals with the knowledge and skills needed for sustainable development [1]. The level of education within a community directly influences its social progress, workforce competence, and overall quality of life, reinforcing the idea that investing in education leads to long-term societal and economic benefits [2].

Technology and education have become inseparable. One of the roles of technology in education is to serve as a tool during teaching and learning [1]. The face-to-face (f2f) learning process was replaced by online or mixed learning. Learning media also evolved from paper-based media to digital-based media and cloud-based media. Digital-based media refers to any electronic format used for learning, replacing traditional paper-based materials. Cloud-based media involves storing and accessing educational content online via cloud computing services instead of local storage. Cloud-based media allows students and teachers to collaborate in real time, access resources from anywhere, and save progress automatically without relying on physical storage. AR/VR has become the most crucial technological resource for stimulating unlimited creativity and facilitating knowledge through experience.

Virtual reality (VR) technology has been used to create situated and realistic learning contexts that learners cannot easily access. One of the examples of VR usage is providing access to scenes and environments that are difficult to observe in the real world, such as surgical procedures — which are typically inaccessible to individuals outside the medical profession. VR can also simulate micro or macro phenomena, such as blood cells or the solar system, making abstract or otherwise unobservable concepts more tangible, as mentioned by [3]. As VR is expected to be widely used in classrooms and adopted by students, particularly over the next couple of years [4] [5], it is argued that, if these predictions hold true, VR technology has the potential to transform teaching pedagogy in ways that are currently unimaginable [6].

The use of computer technology can be perceived through an external component or device, best known as a VR helmet or head-mounted display (HMD). A head-mounted display allows users to experience the virtual surroundings thoroughly as long as they wear the helmet [7]. HMDs extend the advantages of traditional VR in terms of visualization and interaction by tracking head movements to display the corresponding 3D scenes in front of one's gaze and allowing natural manipulation in virtual spaces. In particular, [5] states that VR allows users to experience and feel environments where they are not physically present and manipulate objects in the environment.

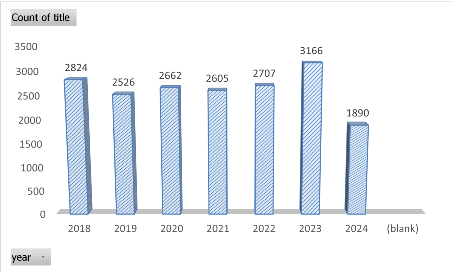

Fig. 1. Number of papers on the topic by each year

For instance, we can grab an object in a VR environment with the help of virtual hands that look like our hands in the real world, move it, lift it, and drop it by moving it to a different point in the virtual environment [7].
In this paper we make a literature review on the topic, and propose further experiment. The paper continues as follows. In the second section we briefly explain our aproach for the literature review. In the following two sections the literature review is presented, and in the fifth section we expose the future steps of our research.

II. Our approach for the literature review

This section describes the systematic process used to identify the most relevant recent contributions published in the literature. The compilation of applicable literature was facilitated through the online academic service Google Scholar, which served as the sole academic database for this research. Publications were searched containing all keywords related to virtual reality applications specifically for educational purposes: "virtual reality in education". Results from Google Scholar were sorted according to relevance, and only freely accessible papers without a paywall that explicitly included all keywords in their titles were selected. Publications considered for review were limited to the period between 2018 and 2025, as earlier contributions were excluded due to the rapid recent advancements in this area.

A spreadsheet was created to systematically organize and evaluate all relevant identified papers, visually shown in Fig. 1, with the focus strictly narrowed down to systematic review papers and experimental studies. A spreadsheet including the key experimental studies that influenced our study are shown in Table I. A visual representation of all of the key literature review studies is omitted due to restrictions in the paper size.

III. Literature Review

Virtual Reality (VR) has gained significant attention in the field of education due to its potential to enhance learning experiences. Several studies have explored the application of VR in various educational settings.

The benefits and potential impact of VR in education have been highlighted in previous research [8]. VR is one of the technologies that could overcome the limitations of space and time by providing numerical simulation and an immersive, interactive environment [9]. It can bring users into an environment that was not generally available because of price, security, or other obstacles [7].

Kong [10] conducted an empirical study on the effects of VR on experiential education, suggesting that more research is needed to determine the effectiveness of such approaches. There is still need to find out whether VR implementation could develop one's skills and how effective VR is compared to other methods of learning and training [7] [11].
There are, in our opinion, relatively few studies that compare the drawbacks of conventional teaching strategies with game-based or immersive learning that makes use of Extended Reality (XR) technologies. Prior research [12] [13] has highlighted how VR technology can complement various learning theories, such as multimedia learning, situated learning, and embodied learning, by simulating the real world and improving learner performance [3].

Wu, Yu, and Gu in [3] focused on the development and student perception of VR specifically for implant surgery, showcasing how VR can be used for specialized training purposes.

Han in [14] reviewed the application of VR in engineering education, highlighting the benefits of VR as an assistive technology in this field. Wei and Yuan [15] summarized the current research status and future trends of immersive VR in education, suggesting potential scenarios for the application of Metaverse and gamification in educational settings.

Sports training has been a general VR application, considering that VR technologies help users to analyze and improve their performance in respective sports branches [7] [16] [17].

Feng, Yuhuan, et al. in [18] focused on the integration of computer VR technology in college physical education, emphasizing the use of Web-based VR technology for teaching and practice. [19] explored the development of health-preserving competence in physical education teachers using VR technologies based on N. Bernstein's theory of movement construction. The study found that VR models were effective tools for enhancing teacher competence.
Putranto, et al. in the study [7] highlight motion capture devices as one of the most commonly used tools to enhance the implementation of VR technology. Motion capture enables the digital recording of human movements, which is particularly useful in sports for tracking and analyzing athletes' actions. For instance, in baseball VR training, motion capture can track a player's swing to estimate the ball's speed and landing position. This technology allows athletes to train flexibly, regardless of location, as long as the necessary equipment is available. Additionally, motion capture is suggested as a valuable tool for improving athletes' skills by providing precise movement analysis during training.

TABLE I
SPREADSHEET SUMMARIZING KEY PAPERS.

Author(s)	Year	Title	Sample Size	Key Outcome	Limitations
Anggara, Risan Putra, et al.	2021	Application of VR and AR in elementary science education	50 students (varied by method)	Hybrid (teacher + VR/AR) had highest improvement (24%) in comprehension	Small sample, early-stage platform
Cieri, Robert L., et al.	2021	VR and AR in morphology and medical education	Multiple case studies	Improved visualization and understanding in anatomy and paleontology	Exploratory case studies, no control group
Remolar, Inmaculada, Cristina Rebollo, and Jon A. Fernandez-Moyano.	2021	Learning history using virtual and augmented reality	50 students	VR/AR improved retention; 40% of students scored perfectly vs. 0% in control group	Navigation issues in VR, limited generalizability
de Moraes Rossetto, Anubis G., et al.	2023	An analysis of the use of augmented reality and virtual reality as educational resources	Not tested in classroom	AR/VR platform for visualizing planets could enhance astronomy education	Tool not yet classroom-tested
Zwolinski, Grzegorz, et al.	2022	Extended reality in education and training: Case studies in management education	Multiple case studies	XR increased engagement, interest, and mood by at least 10%	Limited to short-term feedback, no long-term outcome data
Parong, Jocelyn, and Richard E. Mayer.	2018	Learning science in immersive virtual reality	Lab experiment	Immersive VR improved engagement but not always retention	Context-specific outcomes
Palmisano, Stephen, Robert S. Allison, and Juno Kim.	2020	Cybersickness in head-mounted displays is caused by differences in the user's virtual and physical head pose.	Experimental study	Mismatch in pose tracking causes motion sickness	Limited to sensory conflicts, not learning outcome
Truchly, P., et al.	2018	Virtual reality applications in STEM education	Survey & pilot studies	VR enhances practical skills and concept understanding in STEM	Variation across disciplines
Han, Insook.	2020	Immersive virtual field trips in education: A mixed-methods study on elementary students' presence and perceived learning.	Elementary students (N not given)	Presence and perceived learning improved in immersive field trips	Subjective measures only
Cooper, Grant, et al.	2019	Using virtual reality in the classroom: preservice teachers' perceptions of its use as a teaching and learning tool.	Survey study	Preservice teachers view VR positively as a pedagogical tool	Attitudinal focus, not classroom-tested

In sports, virtual reality is being promoted as a way for athletes to reduce the risk of injury during training. Most sports education and training are originally located in an open room where many obstacles can be encountered [7].
Researchers in the study [7] discuss how various business sectors leverage VR technology to enhance their services. For example, in the healthcare industry, RelieVRx, an immersive multisensory virtual reality therapy, is used at home for managing chronic lower back pain. This prescription-based treatment, approved by the FDA, offers an alternative pain relief method for adults. In the tourism sector, the global travel agency Thomas Cook introduced a VR experience called 'Try Before You Fly,' allowing potential travelers to virtually explore their desired destinations before booking a trip.

Since students should learn from their experience when they are actively involved in solving problems, virtual reality applications and games have a potential to support students' motivation to learn significantly and even to improve their social, collaborative, and cognitive skills [20] [21]. While immersion is defined as the sensitivity level of the sensory features offered by VR systems to users, presence is evaluated as the users' psychological reactions to the virtual environment [7].

A contemporary perspective suggests that immersive learning involves engaging learners in virtual environments that simulate real-world experiences, thereby enhancing cognitive processes essential for learning. This approach leverages technologies such as virtual reality (VR) and augmented reality (AR) to create interactive and realistic scenarios, facilitating deeper understanding and retention of information. Furthermore, recent studies have explored the impact of immersive learning environments on cognitive states. For instance, research has indicated that VR training can enhance the sense of presence, particularly in terms of sensory and realism factors, leading to improved learning efficacy in mechanical assembly tasks [22].

Furthermore, it's essential to highlight the Cognitive-Affective-Social Theory of Learning in Digital Environments (CASTLE), which illustrates how immersive learning experiences are influenced by cognitive, affective, and social factors. Cognitively, learners engage in problem-solving and knowledge retention, while affective factors such as motivation and emotional connection influence engagement. Social interaction is also essential for improving learning outcomes in virtual environments. This includes peer collaboration and instructor guidance [23]. Although the authors consider technologies like AR and VR to be more interactive among participants of the learning process, there are several studies that imply the downsides of these modern technologies usage. Multiple research studies indicate that participants using head-mounted display (HMD)-based immersive learning systems may experience increased cognitive load and motion sickness.
For instance, a study found that complex motor tasks performed in immersive virtual reality (VR) using HMDs led to higher cognitive load and decreased motor performance compared to conventional computer screens [24].

It is worth noting that some studies reported that participants in HMD-based immersive learning also had higher levels of motion sickness and cognitive load than those in non-immersive learning [25]. The immersive nature of HMDs can induce motion sickness, often referred to as cybersickness, due to sensory conflicts between visual inputs and physical motion [25]. These factors are important to consider when implementing HMD-based immersive learning environments.
The integration of game-based learning with Head-Mounted Display (HMD) technology enhances immersion and role-playing opportunities, allowing learners to engage in vivid, realistic scenarios that evoke emotions such as empathy and professional identity [27].
Studies indicate that immersion plays a crucial role in psychological engagement, contributing to a greater sense of

presence, increased motivation, and a more positive attitude towards learning [28]. Additionally, immersive experiences in VR have been linked to improved learning perceptions and subject retention, making them valuable tools for educational and training environments. [29] addressed the ethical and social dimensions of using VR in education, emphasizing the importance of considering socio-ethical challenges associated with the integration of new technologies in educational practices.

Overall, these studies collectively demonstrate the growing interest and potential of VR in enhancing educational experiences and outcomes.

IV. Review of the in class studies

VR applications have been explored in subjects such as science, history, social studies, geography, language learning, and medical training, demonstrating their potential to enhance engagement, retention, and practical skill development. Several studies have investigated VR/AR-based educational tools, highlighting their effectiveness in visualization, simulation, and experiential learning. This section reviews relevant research on VR and AR applications in education, focusing on studies conducted in classes with students - consumers of the introduced technologies.

An important domain where VR applications gradually appear is represented by VR applications suitable for educational deployment [20]. It can be seen that the application of XR in education is mainly related to medical, biology, science, history, social, geography, and language topics. Besides the famous real-life simulators whose usage is widespread (For VR; Nearpod, VR Museum, MelScience, Math VR, Labster; for AR: Google Lens, PokemonGO, Snapchat and Instagram filters, IKEA place), there are several studies on these topics, with an idea similar to our own that are worth mentioning.

Siqueira's study on augmented and virtual reality in astronomy education presents a web-based AR/VR environment designed to help students visualize and interact with graphical representations of planets in the solar system. The authors highlight the potential of this tool for enhancing classroom learning by providing an interactive and immersive experience. However, they note that the system has not yet been tested in an actual classroom setting, leaving its practical educational impact unverified [30]. A 2020 study on virtual planetariums explored the implementation and use of VR technology for teaching astronomy in schools. The developed software aimed to provide an immersive, interactive, and intuitive learning experience, allowing students to navigate through the solar system using VR headsets and auxiliary controls. Users could explore planets and access detailed information about celestial bodies in a simulated environment. Physical questionnaires were given to student users in order to evaluate its efficacy; the results showed that the tool was highly usable and well-received, indicating that it has the potential to improve astronomy instruction [30].

Anggara et al. [31] explored the use of e-learning in science education for third-grade students, focusing on a virtual approach to illustrate real-life events and natural phenomena. Their study involved testing the e-learning platform with a small group of five students and a teacher in an elementary school in Jakarta. The study conducted testing to evaluate the effectiveness of three distinct learning methods for teaching natural sciences to third-grade elementary students: (1) e-learning without teacher explanation, (2) conventional classroom teaching without e-learning tools, and (3) a hybrid approach combining teacher explanation with e-learning methods utilizing Virtual Reality (VR) and Augmented Reality (AR) technologies.

According to the findings, e-learning by itself, without the assistance of an instructor, improved student comprehension by an average of just 8%. Conventional learning methods, relying solely on teacher explanations without digital tools, resulted in an average improvement of 12%. The hybrid learning strategy, which integrates teacher-led instruction with interactive e-learning applications developed using Unity software for Android, had the highest efficacy, resulting in an average enhancement in student comprehension of 24%. The findings suggest that integrating teacher instruction with e-learning methods enhanced by VR and AR technologies significantly increases students' motivation, interest, and overall comprehension of science concepts.

The paper [32] explores four case studies involving different XR technologies applied in education. Each case focuses on a specific learning scenario and uses different AR/VR approaches. The given scenarios were: A projector-based AR system projected guidance on a workspace desk; Fire Safety Training and emergency decision-making; A branching VR scenario where the student played the role of a manager handling an employee's tardiness issue; A mobile-based AR application where students designed product packaging and optimized logistics. Feedback questions for users followed each case study, and student empirical testing revealed that using XR technologies in experiments had a positive impact, increasing mood, engagement, stimulation, and interest by at least 10%.

Another study important to mention is [33], where the authors conducted two experiments to evaluate the effectiveness of a VR and AR-based history learning experience. Although some had minor issues with VR navigation, 25 secondary school students who tested the game's playability, engagement, and usability found it to be very interactive and effective for learning. The second experiment compared AR/VR-based learning with traditional teaching across two student groups (N=50). Results showed that students using VR and AR significantly outperformed those in traditional learning, with 40% achieving perfect scores compared to none in the traditional group. The findings indicate that VR/AR improves enthusiasm, knowledge retention, and inspiration, rendering it a feasible substitute for traditional approaches. Students had favorable responses to gamification, suggesting that history education can significantly benefit from engaging educational tools.

Cieri et al. in [34] demonstrate the application of VR and AR in morphology, medical training, and education through multiple case studies. VR was used for 3D anatomical visualization, improving pulmonary airflow analysis, cardiac function modeling, and dinosaur track formation studies. Students used interactive virtual reality (VR) modules to learn about dentistry and paleontology, which helped them retain concepts and develop practical skills. The results show that VR/AR offers affordable, immersive, and interactive research and pedagogy options while also greatly improving visualization, analysis, and knowledge acquisition. The study [34] demonstrates how VR and AR, with their user-friendly and collaborative experiences, are revolutionizing morphology research and education. These technologies bridge the gap between the digital and physical worlds, enabling better scientific visualization, collaboration, and learning.

V. Description of the Future Research Steps

VR technologies have great potential to improve conventional teaching strategies by providing dynamic and captivating learning environments, but despite promising results, a direct comparison between traditional learning methods and VR-based learning approaches remains underexplored. Our future work aims to address this question. In the next phase of our research, we plan to conduct an experimental study to systematically compare the effectiveness of conventional teaching methods with immersive VR-based learning. The experiment will involve two groups of students: one using traditional techniques and the other utilizing VR-based environments. Key metrics such as knowledge retention, comprehension, student engagement, and practical skill development will be measured and analyzed.

Additionally, we intend to assess the subjective experience of students participating in VR learning. This evaluation will cover factors such as ease of use, perceived effectiveness, emotional response, motivation, and potential discomfort (e.g., motion sickness). By combining both quantitative performance data and qualitative feedback, we aim to gain a comprehensive understanding of VR's advantages and limitations in educational contexts.

The findings should provide empirical evidence on the effectiveness of immersive technologies, helping educators and policy makers evaluate their advantages over traditional methods and make informed decisions about integrating VR into educational systems.

VI. Conclusion and Future Approaches

The expanding role of virtual reality in education was examined in this research, with an emphasis on information retention, student engagement, and immersive learning. Our analysis of the literature showed how VR technologies have a great potential to improve conventional teaching strategies by providing dynamic and captivating learning environments. While admitting possible drawbacks including higher cognitive load and motion sickness, numerous studies have shown that virtual reality can enhance students' understanding, motivation, and practical abilities across disciplines.

Despite the promising results, a direct comparison between traditional learning methods and VR-based learning approaches remains underexplored. The future steps of our research, explained in the paper, will address these issues. Our aim is to provide empirical evidence on the effectiveness of immersive technologies, helping educators and policymakers evaluate their advantages over traditional methods and make informed decisions on integrating VR into educational systems.

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