Spatial Immersive Learning Environments in Primary Education: A Review of Impacts and Implementation Challenges

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ABSTRACT

Spatial immersive learning environments (SILEs) in primary schools show promise in enhancing student engagement and academic outcomes. This study reviews their benefits, including improved learning retention, motivation, social skills, and problem-solving abilities. However, challenges such as technical issues and lack of instructor training persist. Effective practices identified through this review include designing meaningful learning experiences and providing teacher support. Furthermore, SILEs can foster inclusivity and emotional engagement, leading to better learning outcomes.

CCS CONCEPTS

• **Immersive Learning** → Human-centered computing; Human computer interaction; Interaction paradigms; Mixed / augmented reality; Empirical studies in HCI.

KEYWORDS

spatial immersive learning, virtual reality, augmented reality, gamification, simulations, primary education, pedagogy, learning outcomes, personalized learning

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1 INTRODUCTION

The global market for educational VR and AR technologies is expected to reach USD 9.2 billion by 2026, driving interest in Spatial Immersive Learning Environments (SILE) as effective instructional tools [1, 2]. SILE combines VR and AR to create interactive platforms, enhancing engagement and knowledge retention [3, 4]. Despite challenges, integrating SILE into primary education can improve cooperation, critical thinking, and problem-solving [5]. The COVID-19 pandemic has accelerated the adoption of immersive education strategies like SILE, offering dynamic learning experiences beyond traditional classrooms [5].

Research shows SILE can enhance cognitive capacities, creativity, and learning outcomes [7]. It is crucial for educators, policymakers, and academics to explore the benefits and challenges of SILE in primary education [5]. SILE enables personalized learning, accommodates diverse preferences, and equips students for success in the digital age, contributing to the modernization of education [8, 9]. In addition, the utilization of efficient pedagogical approaches and integration strategies is required to make the most of the influence that spatial immersive learning environments have on students' learning outcomes [10]. This study examines SILE in primary schools, aiming to guide evidence-based decisions and transformative practices, especially within pandemic-related educational changes [11].

This research is dedicated to assessing the efficacy of Spatial Immersive Learning Environments (SILEs) in primary education and identifying the integration challenges that accompany their use. It aims to evaluate how effectively SILEs enhance learning outcomes for primary school students and to explore the multifaceted challenges and opportunities that arise from their integration into educational systems. By examining the effectiveness of SILEs and the practical issues related to their deployment, this study will provide insights into how these advanced technologies can be better tailored to meet educational needs while overcoming the barriers to their widespread adoption.

2 BACKGROUND

Technologies for spatial immersive learning: Virtual reality (VR) and augmented reality (AR), both spatial immersive learning technologies, have been proven to improve student learning outcomes in primary schools [4, 12]. VR and AR technologies enable students to explore ideas in three dimensions, providing dynamic learning environments [12]. The literature offers a multifaceted exploration of spatial immersive learning environments.

Pedagogical Methods: Effective pedagogical approaches are at the core of successful spatial immersive learning environments. The results of the literature survey show that pedagogical methods and technological interaction have a significant impact and grabbed participants' domain. Despite the insight of technological constraints in the utilization of these platforms, the participants' learning experience has been improved due to using SILEs along with conventional teaching practices. This has enabled the students to reinforce learning ideas and content, which is considered the

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most intellectual and technical barrier by Badilla, et al. [13]. Considering these significant results, educators have developed strategies to align these technologies with educational goals. Mainly constructivism, inquiry-based learning, and problem-based learning, are the two main approaches where were adopted and tailored to the specific needs of primary school students [14]. SILEs through game-based learning, incorporating learning goals into engaging settings by Dichev, et al. [15] is appeared as the most participant engaging approach. This is mainly due to improved coordination and social skills by blending information from various fields and fostering interaction among players as well as maximized engagement of the participants with the focus [14]. To fully benefit from immersive technologies, the authors have recommended that teachers modify their conventional educational strategies, and integrate SILEs into the conventional approaches [14]. The initial fusion of fusion of conventional strategies if followed with the systematic transition to the SILEs learning can help in achieving better results.

Advantages and Drawbacks: SILEs have improved learning outcomes, engagement and motivation, and critical thinking and problem-solving abilities in students in primary school [1]. However, the technological costs, a lack of access to technology, and the requirement for specialized training for teachers limit the SILEs adaptation and efficacy [16]. The advantages and challenges of spatial immersive learning environments are the focal points of this subsection. However, some studies have investigated the comprehensive impact of these technologies and environments amplifying student engagement, motivation, and retention of learning [13–15]. This addressed potential hurdles such as technical barriers and teacher training by utilizing data-driven insights, where we paint a comprehensive picture of the dynamic landscape of SILE in primary education [16].

Affective Reaction: Enthusiasm, curiosity, and presence are some emotions students experience in response to SILEs [17]. However, pupils' learning capacity could be negatively impacted by unfavorable emotions such as anxiousness and motion sickness [1].

Usability: The ease of use of SILEs plays a significant part in how effectively they function in elementary schools. According to the findings of some studies, SILEs should be designed for user-friendliness, as well as clear instructions and feedback. The technology must be reliable and quick to respond, and the user interface must be straightforward and easy to understand [18].

Lacunae and Restrictions: Even though there has been a rise in interest in SILEs in elementary schools, there are still some holes and limitations in the existing research. For example, not enough research has been done to investigate how SILEs will affect students' learning results over the long term [15]. More research is needed to determine whether using SILEs with various pedagogical approaches in elementary schools is effective [8].

SILE can raise student engagement and academic achievement in primary education. It was found that employing virtual reality to teach geometry improved students' spatial ability and academic achievement. Students are more engaged and interested in learning science when immersive virtual environments are used in the classroom [19].

To provide students with more personalized educational experiences, the combination of artificial intelligence (AI) and machine learning (ML) in three-dimensional (3D) immersive learning environments has shown some promising outcomes. In computer science education, a personalized learning approach that utilized a virtual reality environment was found useful in improving students' learning outcomes [20].

Spatial immersive learning environments in primary education face challenges like technology, financial constraints, teacher training requirements and adaptation associated issues highlighted in in the existing literature [2]. Also, possible problems that can be raised with integrating into primary school pedagogy due to the adopted technology or integration approach [15].

Integrating SILEs into primary education faces challenges but understanding their efficacy and integration possibilities can enhance learning outcomes and student engagement [2, 13]. Difficulties of adopting SILEs in primary education and offer suggestions for teachers and policymakers on how to apply them successfully. In this study, it is focused on reviewing traverse pedagogical methodologies, weighing advantages against drawbacks, gauging the effective reactions from learners, assessing usability aspects and identifying notable gaps and constraints in the existing body of knowledge.

3 REVIEW METHODOLOGY

The primary aim of our literature review was to investigate the application of spatial immersive learning in the context of primary education. Our review period spanned from 2010 to the present, a timeframe chosen due to the significant advancements and growing interest in immersive learning technologies and pedagogies during these years.

Our search strategy centred around the key phrase 'spatial immersive learning environments in primary education. This specific phrase was employed to directly target and identify articles pertinent to our review subject. In addition, to maintain a high standard of relevance and quality in our review, we established specific inclusion and exclusion criteria for screening papers found on Google Scholar and Scopus. These criteria were meticulously applied to ensure that only the most pertinent and rigorous studies were considered for our analysis. For inclusion, studies needed to be relevant to the review topic, published in English, and available as full texts where possible, though abstracts were included if they contained important information.

4 REVIEW FINDINGS

This section presents the outcomes from chosen publications to reflect a deep dive into the effectiveness, challenges, and strategic implementation of immersive technologies in educational settings. We explore how immersive virtual reality and augmented reality have impacted learning outcomes. This includes an assessment of academic performance, student motivation, and the cognitive resources involved in both collaborative and individual learning settings. We also discuss the technical barriers, teacher preparedness, and ergonomic issues that educators face, along with the opportunities for enhanced learning experiences through innovative pedagogical strategies. Furthermore, this section highlights how SILEs can significantly enhance the educational experience by fostering engagement, improving retention, and facilitating the development of critical problem-solving skills.

4.1 Effectiveness of SILEs in Primary Education

Most universities had to shift to online education when the Covid-19 pandemic spread in many countries. Distance learning was adopted due to the lockdowns. Many students lacked personal contact in the learning process. Classical web-based distance learning did not provide a means for natural interpersonal interaction. Therefore, the technology of immersive virtual reality (IVR) has been tried in many universities to mitigate this problem. The study by Sedlák, et al. [21] found IVR as a medium was an effective tool for learning geography. There was equal learning, speed gains, and performance motivation when comparing collaborative and individual learning. The collaborative learning group used significantly more cognitive resources than the individual learning group.

If an immersive technology's performance is better, it is due to its better effectiveness and efficiency. A review and meta-analysis of 105 primary experimental studies from 48 papers published from 2016 to 2020 by Coban, et al. [22] showed that the effect sizes of Immersive Virtuality Learning outcomes were small and were determined by educational level, the field of education, and computer-based or traditional sources.

A case-control study by Villena, et al. [23] aimed to analyze the eventual benefits of Virtual Reality in teaching history at the primary education level and compare it with traditional teaching resources in two dimensions: academic performance and the motivation of students. The VR method performed better with improved motivation and academic performance of students.

Different authors have tested many different techniques for using different types of SILE. Thus, we get a wide range of them. Some of the more important of them have been reviewed here.

For example, most of the student participants in a study by De Freitas, et al. [24] found virtual worlds like Second Life useful for learning. Spatial orientation skills developed with VR were more efficient and effective than those not using VR and less efficient and effective than GISc, geoportals and AR technology for second-year engineering students, as observed by Carbonell-Carrera, et al. [25]. To achieve the full potential of virtual immersive learning, students need to be familiar with IVR skills [26]. Thus, with sufficient IVR skills, high efficiency and effectiveness of immersive learning can be achieved. However, such high skill levels cannot be expected from primary school students, the target group of this review paper.

Another work by Muhammad, et al. [27] used handheld marker-based AR technology for effective learning of primary school students. The authors developed a set of four mobile applications based on students' academic courses at the primary school level for learning the English alphabet, decimal numbers, animals, and birds, and an AR Globe to learn about different countries. Without internet connectivity, these applications could be used on a mobile device, wherever and whenever a user wants. These applications contained performance evaluation quizzes (PEQs) for testing students' learning progress. AR-based learning was very effective in terms of increased motivation and performance of students compared to non-AR.

Chen and Chen et al. [28] found that software for glacier terrain was better for learning than the conventional method due to their special visualization and high geographic abilities. Also, most students showed positive attitudes towards using virtual reality-assisted software for geography course learning.

Šašinka, et al. [29] investigated collaboration's cognitive and social aspects in a shared, immersive virtual reality. The authors developed an application for implementing a collaborative immersive virtual environment (CIVE) with two scenarios for learning about hypsography. Gamification principles were also applied to both scenarios to augment user engagement during the completion of tasks. Twelve pairs of participants were observed during their CIVE experience, and a semi-structured interview or a focus group was conducted with them. The results showed the importance of the social dimension during education in a virtual environment and the effectiveness of dynamic and interactive 3D visualization.

Han [30] study examined the elementary students' perceptions of using immersive virtual field trips (VFTs) in the classroom. Reflection papers from 25 students were analyzed and triangulated with field notes from class observations and teacher interviews. Students perceived VFTs to be efficient regarding time and cost, to expand learning opportunities, to be engaging and real, and to provide an increased perception of virtual presence but lacking physical interaction. However, there were concerns about health, safety, psychological side effects, technical problems, and low social interactions.

Chang, et al. [31] experiment combined spherical video-based virtual reality (SVVR) and a hands-on activity to help fifth-grade students learn natural geomorphological knowledge. The results of the case-control study showed no difference in motivation and learning achievement between SVVR and the traditional method of teaching the subject. Thus, the IVR method was not effective in this study.

Lee, et al. [32] research aimed to verify the learning effectiveness of a desktop virtual reality (VR)-based learning environment and investigate the effects of a VR-based learning environment on learners with different spatial abilities. A quasi-pretest-post-test experimental design was employed with 431 high school students from four randomly selected schools, randomly assigned to either experimental or control groups based on intact classes. Students using virtual reality performed better, possibly due to their higher levels of engagement with the VR, reducing extraneous cognitive load. Learning mode was influenced by spatial ability regarding performance achievement. The performance of learners with low spatial ability was better in the experimental group than in the control group. However, in the case of high spatial ability, the performance of both groups was similar. Thus, the performance of low spatial ability learners compared with high spatial ability learners was more positively affected by the VR-based learning environment.

The aims of another study by Parong, et al. [33] were to compare the instructional effectiveness of immersive virtual reality (VR) versus a desktop slideshow as media for teaching scientific knowledge and to examine the efficacy of adding a generative learning strategy to a VR lesson. The students who viewed the slideshow performed significantly better on the post-test than the VR group but reported lower motivation, interest, and engagement ratings. Students who summarized the lesson after each segment performed significantly better on the post-test, and the groups did not differ in reported interest, engagement, and motivation.

A systematic review of 29 papers by Hamilton, et al. [10] showed that most papers reported significant positive effects of the IVR method over traditional methods. Others showed no difference, with two of them reporting negative outcomes due to the use of IVR technology. However, most studies used short interventions, did not examine information retention, and were focused mainly on the teaching of scientific topics such as biology or physics. Inadequate methods were noted in a few papers. Despite using the databases Core Collection), Science Direct, Sage, IEEE Xplore, EBSCO, Taylor & Francis, and Google Scholar, with many different search terms, only 29 papers could be selected for this review as the authors selected only peer-reviewed full texts.

A systematic and meta-analytic review of 43 papers (1993-2020) by Yu and Xu [34] showed that VR technologies could positively influence and improve learning outcomes in education globally, except in Europe, and facilitate learning outcomes at different educational levels except for the primary school level.

Checa and Bustillo [35] study aimed to identify the factual standards of the proposed solutions and the differences between training and learning applications. The review showed higher user satisfaction with the VR-SG experience than with other learning methodologies. Only 30% of the studies clearly demonstrated enhanced learning and training in their respective domains due to the use of VR-SGs. A clear advantage was not observed in 10% of the studies about the use of VR-SGs compared with conventional methodologies. Although most final users enjoyed the experience, they were not sufficiently familiar with the interfaces to benefit from the full potential for learning and training.

4.2 Challenges and Opportunities in SILE Integration

The integration of Spatial Immersive Learning Environments (SILEs) into primary education introduces a range of technical and ergonomic challenges, as well as significant educational opportunities [10]. This subsection categorizes the existing literature into two primary themes: Technical Challenges and Pedagogical Opportunities. Technical Challenges encompass issues related to the infrastructure and functionality of SILEs, including hardware limitations and software reliability. Pedagogical Opportunities highlight the transformative potential of SILEs to enhance educational experiences, fostering deeper engagement and interactive learning.

Serrano-Ausejo and Mårell-Olsson [36] explored 8th-grade students' and teachers' experiences regarding the opportunities and challenges of using virtual reality (VR) and augmented reality (AR) technologies to teach and learn stereochemistry and how these technologies might support students' spatial ability and 21st-century skills in K-12 education to participate in virtual lab environments. The need for teachers to possess AR and VR knowledge was a challenge. This becomes an opportunity for training teachers and, thus, solving the teaching and learning problems in these technologies.

Most of the challenges were related to usability and ergonomics, such as discomfort, inadequate tracking, vision, and audio, handling the equipment, and lack of tutorials. Other challenges included low performance, software compatibility issues, novelty effects, usability issues (difficulty of using, cognitive load), and teacher inadequacies [1]. According to Calvet, et al. [37], immersive technologies have failed to achieve widespread adoption due to the limitations of these technologies. The limitations are usability factors, display quality, lack of realism, recognition inaccuracies and high overheads incurred by content developers, instructors, and students.

Opportunities in game-based learning are in the games themselves, serving as a formative assessment tool, especially when embedded in the game, helping the user to assess performance, helping teachers to design and deliver courses effectively and using educational data mining and learning analytics for predictions. Tensions and challenges included the difficulty of aligning variables with learners' interests and prior knowledge of game-based learning, if any. The requirement of specific skills for design and implementation, lack of knowledge on how exactly games impart knowledge to users, and insufficient support and training to teachers were additional challenges. Addressing these challenges requires further research [38].

The need for new methodologies for evaluating the efficacy, benefits and challenges of learning in these new ways, slow learning systems, absence of some desirable features, presence of some undesirable features and connecting with the real world, all leading to reduced impact, were some challenges of IVR discussed [24].

From a review of 42 papers, Kuhail, et al. [1] identified some challenges. One challenge was the usability and ergonomics, such as discomfort, inadequate tracking, vision, and audio, handling the equipment, and lack of tutorials. Other challenges were the low performance, software compatibility issues, and novelty effect. The third challenge was that the currently available commercial products of immersive learning limited the range of possibilities and increased the cost of immersive learning. There is a lack of guidance to help educators identify educational contexts that could be enhanced by immersive technologies and in selecting and using appropriate immersive technology and interaction styles for the educational context. Some limitations of this review were the restricted period of review, using only four databases, errors in search terms, limited countries, misclassification, and bias in screening and selecting articles.

Serrano-Ausejo and Mårell-Olsson [36] aimed to explore empirically students' and teachers' experiences and the opportunities and challenges they encountered when they were using AR and VR technologies in activity research to teach and learn stereochemistry and how these technologies might support students' spatial ability and the new skills required for K-12 education by participating in virtual lab environments. The main challenge expressed by teachers and students in the post-test survey was the essentiality for a teacher to possess technological knowledge of VR and AR to achieve the intended goalsSome technical and orientation issues with the stereo glasses and positioning themselves for the virtual activity were expressed by some students in the NICE project research by Roussos, et al. [39]. Inadequacy of the science model, open-ended learning environment, and difficulties of collaborations with avatars were some additional problems.

According to Roopaei and Klaas [40] immersive technologies offer social and emotional skills apart from academic skills. Social and emotional skills are also essential for success in higher education and career. In STEM education, immersive technologies

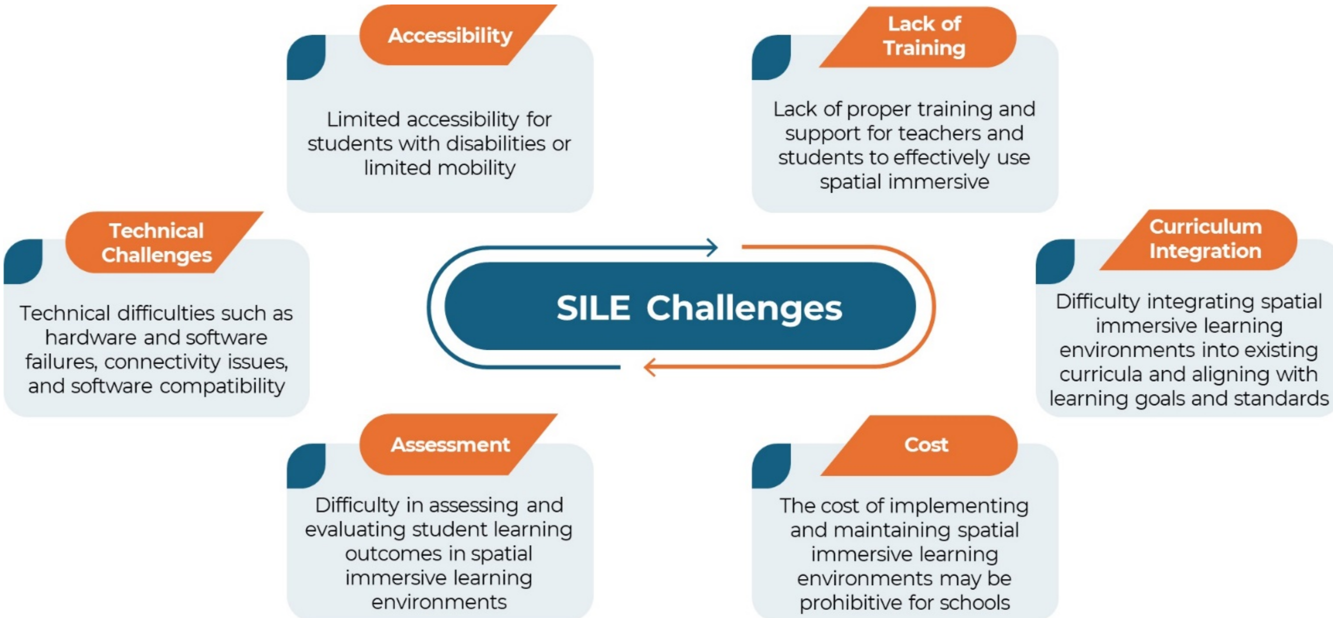

Figure 1: Challenges in Implementing Spatial Immersive Learning Environments

provide problem-solving skills to children, help them find answers to challenges, and equip them for future life.

Wu, et al. [41] identified three AR categories of instructional approaches stressing the "roles" (role-playing) ", tasks" (game-based, problem-based, and studio-based learning tasks) and "locations" (interaction-based learning environment). The purposes of the three categories are different. Mobile, multi-layer and game-based AR are used for students to play different roles and thus become active participants in learning. Through mobile devices, it is possible for learners to use geo positioning and collect relevant information on objects in different locations. Location-based learning provides authenticity to the topic they learn. Task-based learning, especially problem-based learning, stresses self-directed learning. AR offers both new learning opportunities and creates new challenges for educators. These are technological, pedagogical, and learning issues related to the implementation of AR in education. Some of these issues were cognitive overload caused by a large amount of information they encounter, the multiple technological devices to be used, and the complexity of tasks.

Some problems that arose when embedding immersive virtual reality (IVR) for learning into ICT and science classes in low-income high schools and their scholarly solutions by the research team were described by Southgate, et al. [42]. The authors used mixed methods, using teachers as co-researchers. Three areas explored were ethical and safety issues of using IVR in classrooms, negotiating the organizational context of a school system and problem-solving within the context of institutional restrictions on internet access, and educational reflections on collaborative learning and gendered aspects. The authors conclude from the study that classrooms are socially active and unpredictable and provide unique and credible insights into the use of highly immersive virtual reality for learning.

4.3 Current Research Insights and Future Directions

Immersive spatial learning environments offer a plethora of advantages that significantly contribute to the enhancement of primary education. These settings revolutionize traditional learning approaches by providing dynamic and engaging experiences, resulting in a host of benefits for young learners. Firstly, these environments serve as a catalyst for increased student motivation and engagement, captivating their interest through interactive and captivating learning opportunities [43]. Moreover, the utilization of spatial immersive techniques allows students to explore complex subjects in a dynamic and engaging manner, leading to improved learning retention [24, 44]. Additionally, these settings promote collaborative learning and communication among students, nurturing the development of essential social and communication skills [45]. Furthermore, the incorporation of challenging scenarios within spatial immersive learning environments nurtures the growth of students' problem-solving abilities by encouraging them to navigate and resolve intricate situations [46]. Through these remarkable advantages, immersive spatial learning environments emerge as a powerful tool for shaping a well-rounded primary education experience.

Despite their numerous benefits, immersive spatial learning environments in primary education also come with a set of limitations and challenges that need to be addressed for optimal implementation. Technical issues, such as hardware and software restrictions, can hinder the seamless execution of these environments, potentially limiting their effectiveness [47]. Moreover, a significant challenge arises from the insufficient preparation of teachers, who may lack the necessary training and resources to integrate spatial immersive learning techniques successfully into their classrooms [48].

Another potential hurdle is the presence of distractions inherent in immersive experiences, which could affect some students' engagement levels and overall learning outcomes [49]. These limitations and challenges underscore the importance of a comprehensive approach to incorporating immersive spatial learning environments, requiring attention to technical aspects, teacher training, and strategies to mitigate distractions, thus ensuring a balanced and effective primary education experience.

The implementation of immersive learning environments brings about certain challenges and limitations that are crucial to address for their successful integration into primary education. These challenges are highlighted in Figure 1. Among these obstacles, technical issues stand out, encompassing hardware and software limitations that can hinder the seamless execution of spatial immersive learning environments [47, 48]. Additionally, the lack of proper instructor training and necessary resources is a significant hurdle, often referred to as inadequate teacher preparation, as educators may struggle to effectively incorporate these novel techniques into their classrooms [49]. Another concern pertains to potential distractions stemming from the immersive nature of these learning environments, which might divert students' attention from their intended learning objectives [49]. Recognizing these challenges and limitations is essential for educators and policymakers to work collaboratively in devising strategies to overcome these hurdles and ensure the smooth and effective integration of immersive spatial learning environments into primary education settings [48–50].

5 CONCLUSIONS

This review aims to examine various immersive learning technologies for primary education. Papers on primary education were not enough to indicate the main problem. Hence, research on secondary schools and higher education and some non-spatial immersive learning were also included.

The review revealed definite advantages in terms of learning outcomes when Immersive Virtual Reality (IVR) technologies are used. These included better learning outcomes, increased student engagement and problem-solving aptitudes. However, problems such as hardware and software limitations, technical difficulties, a lack of instructor training, and pedagogical transformation must be addressed. Designing meaningful and pertinent learning experiences, giving teachers enough training and support, and ensuring smooth technology integration were noted as examples of best practices. This review highlights students' affinity for immersive learning and its role in fostering inclusivity. Focusing on outcomes, learner motivation, and time efficiency is indispensable for educators, researchers, and policymakers.

The lack of research on primary education is an important gap in research identified. Most research on this topic was done in developed countries. The influence of culture on the adoption of these technologies has not been investigated. Researchers need to pay attention to these relatively unresearched aspects.

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