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Utilisation of Augmented Reality (AR) and Virtual Reality (VR) in Education: A Systematic Review

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ABSTRACT

This review systematically examined the effectiveness and challenges of utilising Augmented Reality (AR) and Virtual Reality (VR) technologies in the field of education over the past decade. As immersive technologies developed, AR and VR offered new approaches that were interactive, contextual, and constructivist in the teaching and learning process. This study employed a systematic review method based on the PRISMA protocol to analyse 60 scholarly articles published between 2015 and 2025, covering various educational levels, fields of study, and learning outcome indicators. The findings revealed that the application of AR and VR generally enhanced conceptual understanding, motivation, student engagement, and psychomotor skills, particularly within the contexts of science, engineering, medical education, and vocational training. Nevertheless, the implementation of these technologies still faced several obstacles, including infrastructure limitations, teacher preparedness, and potential psychological effects such as disorientation and cybersickness. The review also highlighted a growing trend of collaboration between educational institutions and technology industries in the development of AR/VR content, as well as the importance of policy support in expanding access to and the quality of immersive technology-based learning. Thus, AR and VR held significant potential as integral components in the transformation of future educational ecosystems, provided they were accompanied by appropriate pedagogical strategies and adequate readiness of supporting ecosystems.

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1. INTRODUCTION

The development of information and communication technology has created significant opportunities for transformation within educational systems, including the delivery of content, pedagogical approaches, and teacher-student interactions. In this context, immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) have come into the spotlight due to their ability to create interactive, immersive, and contextual learning experiences. AR technology allows for the integration of virtual elements into the real world in real-time, whereas VR creates a fully immersive digital environment that enables users to engage in simulations or explore artificial learning spaces [1]. These technologies have demonstrated potential in revolutionising traditional educational practices by enriching students' learning experiences, enhancing motivation, and strengthening conceptual understanding. In recent years, the implementation of AR and VR in education has garnered considerable interest among educational and technology researchers. One of AR's main appeals is its capacity to present complex visual information in 3D form, directly integrated into real environments. This is particularly beneficial in the teaching of science, engineering, and mathematics, where spatial understanding and concept visualisation are crucial. For instance, in a study by Cheng and Tsai, it was found that AR helped students better understand abstract scientific concepts by presenting information in a more concrete and visually accessible manner [2].

VR excels in creating learning environments free from real-world distractions. Virtual settings can be tailored to various educational purposes, ranging from medical training and laboratory simulations to history or geography lessons with an exploratory approach. In a study by Radianti et al., VR was shown to significantly enhance engagement and retention of training material, especially in educational contexts requiring procedural or technical skills [3]. Pedagogically, AR and VR support constructivist learning approaches, whereby students build knowledge through direct and exploratory experiences. These technologies also facilitate project-based learning, problem-based learning, and collaborative learning approaches. Fonseca et al. demonstrated that integrating AR in geometry projects improved students' spatial understanding and engagement in mathematics learning [4]. Similarly, the use of VR in engineering education allows students to practise practical skills in simulated environments that closely resemble real-world conditions, such as in a study by Gavish et al., which explored industrial maintenance training using VR [5].

AR and VR technologies also contribute to the affective aspects of learning. Visual interactions and immersive experiences increase students' motivation and interest in learning. In research conducted by Bressler and Bodzin, students demonstrated a significant increase in science learning motivation after using a location-based AR application for environmental exploration [6]. In the context of VR, immersive learning experiences can foster empathy and emotional engagement, as shown by Barreda-Angeles and Hartmann in a study on the use of VR for ethics and social values education [7]. The implementation of AR and VR also has substantial implications for vocational education and professional training. For instance, in the medical field, VR is used for surgical and diagnostic training, allowing medical students to practise complex procedures without posing any risk to patients [8]. In aviation training, VR-based cockpit simulations have been shown to improve technical skills and responses to emergency situations [9]. AR is also used in fieldwork training, such as machine maintenance or geospatial mapping, where digital information needs to be integrated with real-world conditions [10].

However, the use of AR and VR in education also faces several challenges. One such challenge concerns infrastructure and hardware readiness. High-quality VR devices remain relatively expensive, and the use of AR often requires mobile devices with specific technical specifications. Moreover, pedagogical challenges also arise, such as digital skill gaps among teachers. Many educators still lack the capacity to design or integrate these technologies into the curriculum. Research by Akçayır and Akçayır revealed that the lack of teacher training and technical support are major barriers to AR implementation [11]. Another significant challenge involves ethical and psychological issues. For instance, prolonged use of VR may cause symptoms such as cybersickness or spatial disorientation. Some parties also express concern over the potential impact of intense emotional engagement in virtual environments on students' social development, particularly among children and adolescents [12]. A study by Wiederhold suggests that the use of VR in education should be monitored and combined with other teaching approaches to avoid adverse psychological effects [13].

In terms of effectiveness, several meta-analyses have been conducted to evaluate the impact of AR and VR on learning outcomes. A meta-analysis by Garzón and Acevedo concluded that the use of AR consistently yields positive results in conceptual understanding and learning motivation across different educational levels [14]. Meanwhile, a systematic review by Hamilton et al. found that VR is effective in supporting the learning of motor and technical skills, although its effectiveness depends on instructional design and context of use [15]. The aspect of assessment in AR and VR utilisation has also evolved. These technologies allow for performance-based assessments, whereby students' skills can be observed and measured directly through their interactions within virtual environments. A study by Huang et al. showed that VR-based assessment systems can more authentically evaluate collaborative and critical thinking skills compared to traditional tests [16]. These assessments are also real-time and adaptive, enabling teachers to obtain immediate feedback to refine their teaching strategies.

One of the greatest advantages of using AR and VR in learning is flexibility and personalisation. These technologies allow for customisation of content and delivery methods based on individual preferences and needs. In the context of inclusive education, this represents a significant added value. Research by Lindgren indicates that students with special needs can learn more comfortably and effectively through VR environments specifically designed for them [17]. Furthermore, AR and VR support interdisciplinary learning. For example, in history education, students can explore historical sites through VR simulations or view reconstructions of past buildings using AR. In language learning, students can engage in conversation with avatars in contextual simulations [18]. These technologies have also been applied in cybersecurity training, space exploration, and environmental education, demonstrating their flexibility in supporting multidisciplinary learning [19].

Collaboration plays an essential role in the development and implementation of AR and VR technologies. Cooperation among educators, software developers, and researchers is necessary to ensure that the learning content developed is not only visually engaging but also pedagogically relevant. According to Radu, the quality of instructional design greatly influences the success of AR and VR implementation in education [20]. Meanwhile, user-centred design methodologies are increasingly adopted in the development of AR/VR-based educational content [21]. At the policy level, various countries have begun integrating immersive technologies into their national education strategies. Governments and educational institutions are encouraged to provide infrastructure, training, and funding to support the adoption of these technologies. A report by UNESCO recommends increasing access to immersive technologies to support the Sustainable Development Goals (SDG 4), particularly in improving education quality and reducing access inequality [22].

The involvement of the technology industry is also a crucial factor in the AR/VR education ecosystem. Many tech companies are now collaborating with educational institutions to develop AR- and VR-based learning platforms for widespread use. For instance, the Google Expeditions project has enabled thousands of students to take "virtual field trips" to different parts of the world through VR [23]. Meanwhile, platforms such as CoSpaces Edu allow teachers and students to create their own interactive VR content aligned with their learning topics [24]. In the future, the trend of using AR and VR in education is predicted to continue growing, driven by technological advances, increased access to devices, and shifting learning paradigms in the post-pandemic era. The COVID-19 pandemic has accelerated the adoption of educational technology, and VR has emerged as one of the most promising alternatives for remote learning [25]. With the right combination of learning strategies and strong policy support, these immersive technologies have the potential to become integral components of the future educational ecosystem.

2. METHOD

A systematic review is a scientific approach aimed at identifying, evaluating, and synthesising all relevant research findings on a specific research question, using explicit, transparent, and replicable methods. Unlike narrative literature reviews, which are descriptive and subjective, systematic reviews are based on rigorous procedures, including systematic literature searches, selection based on inclusion and exclusion criteria, and critical analysis of existing findings [26]. The goal of a systematic review is to provide a comprehensive, evidence-based overview of prior research outcomes to inform both scientific and practical decision-making. In the context of this study, the systematic review is used to explore trends, benefits, challenges, and learning outcomes related to the use of Augmented Reality (AR) and Virtual Reality (VR) in education over the past decade.

The systematic review process in this study follows principles based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, which prioritises transparency and traceability in each stage of the review [27]. PRISMA is widely used in social sciences and education to ensure the quality and accuracy of findings derived from systematic studies. Using this approach, the study is designed to produce valid, objective, and trustworthy scientific contributions.

The study began by clearly formulating the research focus and objectives, namely to investigate how AR and VR technologies have been utilised in learning contexts and to evaluate their impact on effectiveness, motivation, and student engagement. Based on these objectives, the main research question posed is: "What are the trends in the use of Augmented Reality and Virtual Reality in education over the past decade, and what are their impacts on learning processes and outcomes?" This formulation served as a guide in developing the literature search and selection criteria.

The search process yielded a large number of articles, which were then filtered according to inclusion and exclusion criteria. The inclusion criteria were: (1) empirical studies utilising AR or VR technologies in formal or non-formal educational contexts, (2) articles published in reputable international peer-reviewed journals, and (3) studies available in English. The exclusion criteria included: (1) conceptual or opinion papers without empirical data, (2) articles with a primary focus outside the field of education, and (3) duplicate publications or those not available in full text.

Following the selection process, 60 articles were deemed to meet all criteria and were eligible for further analysis. These articles were categorised based on several main aspects: the type of technology used (AR, VR, or both), the educational level (primary, secondary, tertiary, or non-formal education), the field of study (science, engineering, arts, languages, etc.), and the measured learning outcomes (cognitive, affective, or psychomotor). This classification helped map the trends in AR and VR usage and organise thematic synthesis of the available findings. A study by Siddaway et al. emphasised the importance of inter-rater validity in systematic reviews to ensure that the results accurately reflect comprehensive and unbiased findings [28].

To analyse the data from the selected articles, a thematic analysis approach was used by identifying patterns and main themes emerging from the study results. The analysis was conducted qualitatively, considering the context, methodology, and findings of each study. This technique allows researchers to explore the nuances of AR/VR usage in education and reveal differences in effects based on usage context [29]. The methodological quality of each article was also assessed using tools such as the Critical Appraisal Skills Programme (CASP) to evaluate the reliability and validity of the research. Studies with low quality or weak research designs (e.g., lacking control groups, having small sample sizes, or not reporting complete outcome data) were noted but not used as a primary basis for conclusions [30]. This critical appraisal is essential to maintain the integrity of the literature synthesis produced by the systematic review.

To avoid publication bias, efforts were made to include several pieces of grey literature, such as research reports, conference proceedings, and relevant open-access dissertations. This literature was still carefully assessed to ensure it did not compromise the overall quality of the review. As explained by Paez, the inclusion of grey literature can enrich understanding of the topic under review, particularly as formal scientific publications tend to report only positive results [31].

In the writing and reporting process, transparency was maintained by documenting each stage in detail. This includes the number of articles identified, screened, and analysed, as well as the reasons for excluding certain studies. A PRISMA flow diagram was used to visually depict the study selection process and help readers understand the chronological flow of the research. This step aligns with the recommendations by Page et al., who emphasised the importance of visual reporting in enhancing the transparency and credibility of systematic reviews [32].

Through this systematic review approach, it is hoped that this study will not only provide in-depth insight into how AR and VR have been applied in education but also identify research gaps, implementation challenges, and future directions for the development of immersive technologies in learning. By analysing empirical evidence from various educational contexts, this study aims to make a significant contribution to the educational technology literature and support evidence-based innovative teaching practices.

3. RESULTS AND DISCUSSION

This review identifies and analyses 60 scholarly articles discussing the use of Augmented Reality (AR) and Virtual Reality (VR) technologies in educational contexts over the past decade. Thematic synthesis of these studies reveals that the adoption of immersive technologies has experienced rapid growth, with a notable increase both in the number of studies and the diversity of application contexts. Findings show that AR and VR technologies have been widely implemented across various educational levels, from primary to higher education, and in diverse disciplines, such as science, engineering, the arts, languages, and professional training.

One of the key trends identified is the significant rise in the use of AR in science and mathematics education. AR is used to visualise abstract and complex concepts in a 3D format that is easier for learners to comprehend. This enables students to observe molecular structures, human body systems, and chemical reactions in a more intuitive way. Studies within this category report marked improvements in conceptual understanding and knowledge retention. These findings support the notion that visual engagement in learning promotes deeper meaning-making.

In technical and vocational education, the use of VR is more dominant. Immersive virtual environments provide a safe space for students to practise procedural and technical skills without risking safety or damaging equipment. Common use cases include mechanical training, surgical practice, and flight simulation. These environments allow for repeated practice at low cost and with high flexibility. Findings suggest that VR is highly effective in developing motor skills, enhancing hand-eye coordination, and reinforcing operational readiness in the field. This demonstrates that VR is not merely a visual aid but a medium for active learning through authentic simulation.

The adoption of AR and VR has also been shown to enhance the affective aspects of learning, particularly motivation and interest. In many studies, students expressed positive attitudes towards immersive technology, feeling more engaged and perceiving learning to be more enjoyable. These findings are particularly relevant in 21st-century education, where student engagement is a key indicator of learning success. AR enables user-guided exploration, while VR offers deep experiences that stimulate curiosity and emotional involvement. These results also reinforce the argument that experiential learning has a profound psychological impact.

Both AR and VR demonstrate positive impacts on the cognitive, affective, and psychomotor domains, although the effects vary depending on instructional design and the type of interaction involved. For example, studies employing project-based learning with AR found improvements in critical thinking and problem-solving skills. Similarly, the use of VR in interactive simulations for medical and nursing training showed enhancements in clinical skills and student confidence. However, the effectiveness of these technologies heavily depends on content quality, contextual relevance, and alignment with learning objectives.

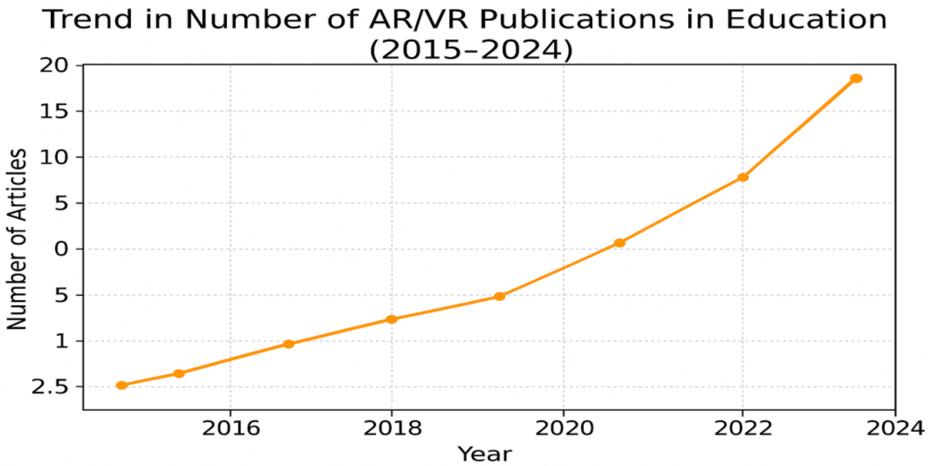
In terms of educational level, the majority of articles (approximately 60%) were derived from higher education. This indicates that universities and vocational institutions are leading in the adoption of immersive technology. Primary and secondary education accounted for about 35%, while the remainder came from non-formal education. This data highlights a gap in access to and adoption of immersive technology at the primary education level. Contributing factors include limited resources, lack of teacher training, and institutional policies that have yet to prioritise the integration of such technologies. The table below presents the distribution of technology types and subject areas based on the 60 articles analysed:

Table 1. Distribution of Technology Types and Subject Areas

Technology Type	Subject Area	Number of Studies
AR	Science & Mathematics	18
AR	Language & Literature	4
AR	Geography & History	6
VR	Engineering & Vocational	12
VR	Medicine & Health	9

VR	Social Sciences & Humanities	3
AR/VR Combination	Multidisciplinary	8

In the following graph, annual trends in publication show a significant increase in the number of studies from 2015 to 2024, with the most notable spike occurring after 2020, coinciding with the COVID-19 pandemic. The pandemic spurred the exploration of remote learning technologies and accelerated the integration of AR and VR-based solutions as alternatives to face-to-face instruction.



Graph 1. Trend in AR/VR Publication in Education

This rise has also been supported by the growing affordability of hardware and the increased accessibility of educational AR/VR content development platforms, such as CoSpaces Edu, Unity, and Google ARCore. Meanwhile, user-centred design approaches and collaboration between educators and technology developers have become crucial in ensuring the pedagogical relevance of the applications used. Studies adopting these approaches report a higher success rate in integration compared to technology-centric approaches that exclude end-user involvement.

However, challenges remain a key part of the discussion. Several studies reveal that although students are attracted to immersive technology, learning effectiveness is not always optimal when content does not align with learning objectives or when users encounter technical difficulties. Issues such as cybersickness, hardware limitations, and lack of teacher training are frequent barriers. In some cases, technology integration was rushed without thorough pedagogical planning, thereby diminishing the quality of the learning intervention.

In terms of learning outcome assessment, AR and VR technologies open new possibilities for performance-based evaluation. For instance, assessment in VR environments allows direct observation of procedural skills, response to scenarios, and team collaboration. In studies evaluating the effectiveness of VR-based training for firefighting techniques, participants were assessed based on response time, decision-making, and team coordination in complex simulated scenarios. This far exceeds the capacity of conventional tests in capturing the authentic dimensions of work-related competencies. The table below presents learning outcome indicators and the technologies most frequently used to measure them:

Table 2. Learning Outcome Indicators and Technology Used

Learning Outcome Dimension	Dominant Technology	Example Measurement
Cognitive	AR	Concept understanding test
Affective	AR & VR	Motivation & interest questionnaire
Psychomotor	VR	Observation of simulation skills

In terms of accessibility and inclusivity, AR and VR demonstrate strong potential in supporting education for students with special needs. Studies evaluating the use of VR for students with autism, motor impairments, or communication challenges found that controllable and personalised virtual environments helped reduce anxiety and increase participation. In other cases, AR has been used to provide contextual visual cues for students with dyslexia, enabling them to comprehend instructions visually and spatially.

The discussion also points to the importance of appropriate learning strategies. Studies combining immersive technologies with pedagogical approaches such as problem-based learning, experiential learning, and inquiry-based learning have yielded far more effective results than those relying on technology alone. This indicates that AR and VR are not automatic solutions to educational challenges, but tools that must support well-designed learning strategies.

In the context of educational policy, government and institutional support plays a significant role in the successful integration of AR and VR. Studies conducted in countries with pro-technology policies show higher and more systematic adoption rates. For example, South Korea and Singapore have national programmes for integrating immersive technologies in education, including teacher training, hardware provision, and technology-based curriculum development. This highlights that successful integration depends not only on technological readiness but also on supporting infrastructure, including policy, resources, and organisational culture.

AR and VR technologies have strong transformative potential in education. They not only enrich delivery media but also create a new paradigm in learning experiences. However, this potential can only be maximised through implementation strategies that are well-planned, collaborative, and grounded in sound pedagogical principles. Further research is needed to explore the long-term aspects of these technologies, including their impact on learners' cognitive, social, and emotional development. As technology continues to evolve and empirical evidence grows, AR and VR are predicted to become integral components of future educational ecosystems.

4. CONCLUSION

The discussion of this review indicates that the integration of Augmented Reality (AR) and Virtual Reality (VR) technologies in education has significantly enhanced the quality of learning across various educational levels and disciplines. Based on findings from the 60 articles analysed, it can be concluded that immersive technologies consistently increase student engagement, strengthen the understanding of abstract concepts, and support the development of cognitive, affective, and psychomotor skills. AR has proven effective in visualising complex information in a contextual and real-time manner, while VR can create deep, distraction-free learning simulations, making the learning process more focused and meaningful.

The analysis also highlights the diversity in the implementation of these technologies, in terms of pedagogical approaches, subject areas, and educational levels. AR and VR are widely used in constructivist, project-based, and collaborative learning approaches, which promote active and exploratory learning. Nonetheless, their effectiveness heavily relies on the quality of instructional design and the alignment between the technology used and the learning context and objectives. Challenges such as infrastructure limitations, digital competence gaps among educators, and ethical and psychological concerns still hinder widespread implementation. Therefore, cross-disciplinary collaboration and supportive policies are vital for ensuring the sustainability of AR/VR integration in education.

Augmented Reality (AR) and Virtual Reality (VR) hold great potential to revolutionise traditional learning systems towards more personalised, flexible, and inclusive approaches. This review provides empirical evidence that immersive technologies serve not merely as visual aids but as profound mediums of pedagogical transformation. Moving forward, the development of AR/VR-based content must involve active participation from educators, technology developers, and researchers to ensure the resulting solutions are relevant, impactful, and adaptable to the needs of future education.

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