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Review

Unlocking the Potential: A Comprehensive Evaluation of Augmented Reality and Virtual Reality in Education

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Abstract: Augmented Reality (AR) and Virtual Reality (VR) are poised to revolutionize education by offering immersive and interactive learning experiences. This research comprehensively evaluates the educational applications of AR and VR, specifically emphasizing their impact on student motivation, learning outcomes, engagement, and overall learning experiences. The analysis explores how AR and VR can improve student learning, knowledge retention, and skill acquisition by systematically reviewing existing the literature from diverse educational domains, including K-12 education, higher education, STEM education, professional training, and lifelong learning. Additionally, the research investigates the pivotal role of AR and VR in fostering immersive and interactive learning environments, unveiling how these technologies promote active learning, collaboration, and critical thinking through simulations and interactive experiences. The evaluation considers the potential of AR and VR beyond traditional classroom settings in distance education and assesses the feasibility of virtual classrooms, web-based learning environments, and Massive Open Online Courses (MOOCs). A significant aspect of the study involves understanding student attitudes toward AR and VR technologies and their influence on intrinsic motivation, interest, and enthusiasm for the learning material. Based on a thorough analysis of relevant literature, the research aims to provide practical recommendations for educators to effectively incorporate AR and VR into education practices. The recommendations prioritize a pedagogically sound design, educator training, and accessibility consideration to ensure equitable access for all learners. In summary, this extensive research reveals the significant impact of AR and VR on education by understanding the strengths, limitations, and challenges of making informed decisions on utilizing these technologies to create engaging, impactful learning experiences, fostering a generation of technologically proficient and knowledge-driven learners.

Keywords: augmented reality; virtual reality; STEM; metaverse; virtual environment

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1. Introduction

Technological advancements have significantly influenced the education landscape, propelling traditional teaching methodologies into immersive and interactive learning experiences [1]. Transformative technologies like Augmented Reality (AR) and Virtual Reality (VR) are at the forefront, indicating a new epoch in the realm of education [2].

AR is the fusion of digital information with the physical environment, allowing users to interact with virtual elements effortlessly without concentrating on a device's screen [3]. Consequently, AR distinguishes itself from alternative interaction paradigms by facilitating users to sustain an uninterrupted connection with their environment, thus keeping their attention fixed on the real world. The absence of contextual isolation leads to the creation of an augmented real world. AR capitalizes on a user's visual and spatial abilities. AR increases the real world by layering extra information rather than engrossing the user into an isolated virtual world confined to the computer [4,5]. In an educational context, Virtual Reality (VR) refers to the use of immersive digital environments and simulations to enhance teaching and learning experiences. It allows students to engage with educational content in a more interactive and experiential way, often going beyond traditional methods of instruction. Unlike AR, VR exists in an entirely artificial environment, where participants are either immersive or non-immersive members of the simulated world. In VR, users can interact with and manipulate computer-generated objects through haptic interfaces while fully engaged in the virtual environment [6].

In the education context, Virtual Reality (VR) and Augmented Reality (AR) diverge in their approaches to enhancing learning experiences. VR engulfs students in a fully immersive digital world, facilitated by headsets that transport them entirely into computer-generated environments. With VR, students can explore simulated realms, interact with objects, and navigate through intricate scenarios. This technology is often harnessed for immersive simulations, historical recreations, and intricate scientific explorations, providing an unmatched level of engagement and enabling students to vividly comprehend complex concepts.

Conversely, Augmented Reality (AR) seamlessly overlays digital elements onto the real world, allowing students to simultaneously perceive both their physical surroundings and digitally added components through devices like screens or mobile devices. AR amplifies real-world experiences by supplementing them with contextual information. Students can interact with physical objects enriched with digital annotations or access 3D models that pop up within their actual environment. AR serves as an informative layer that enhances tangible experiences, making it particularly useful for guided tours, interactive visualizations, and real-time data integration. Unlike VR, AR maintains a bridge to the real world, fostering a blend of physical and digital interactions that offer a unique way to augment education.

The application of AR and VR in educational settings has the potential to revolutionize how knowledge is acquired and applied, providing students with unparalleled opportunities to engage with content, explore complex concepts, and interact with virtual environments. Consequently, this has culminated in the emergence of the metaverse in the education landscape. The gradual transformation of the metaverse concept from mere science fiction to a tangible reality has revolutionized the perception and interaction with the digital world. The idea of the Metaverse, a shared virtual space that blends augmented reality, virtual reality, and the internet, was introduced by Neal Stephenson in his 1992 novel *Snow Crash* [7]. In recent years, technological advancements have propelled the metaverse concept from speculative fiction to a concrete possibility with substantial implications for various industries, including education. Researchers have extensively discussed the metaverse concept and have presented diverse viewpoints on its definition [8]. Lee et al. [9] depict the metaverse as a blend of virtually enhanced physical reality and physically persisted virtual space. Ning et al. [10] consider it a modern category of internet applications and social structure that merges several advanced technologies. In education, the metaverse is perceived as a new space where people can socially interact, requiring proactive measures from higher educational institutions to assimilate it into the teaching and instructional experiences [11]. Likewise, Schlemmer and Backles [12] highlight that the metaverse provides immersive possibilities of 3D digital virtual worlds, which rely on avatars for communication and interaction to generate a sense of presence.

Nevertheless, because of technological progress and its increasing impact, researchers contend that the metaverse has developed beyond its prior definition, necessitating a new outlook. Among new definitions, a recent study emphasizes the classification of the metaverse into four distinct scenarios, comprising augmented reality, lifelogging, presence of virtual worlds, and mirror worlds as integral components of the metaverse setup [13]. Park and Kim [14] argue that integrating mobile technology and deep learning has enabled ubiquitous access to the metaverse, resulting in a more immersive environment than its predecessors. In light of these dynamic shifts, researchers claim that one of the most consequential applications of the metaverse is in the field of education. This conviction originates from the concept that the metaverse can function as a pioneering education setting, blending metaverse-related technologies with elements from both the virtual and real education spheres [15,16]. The advent of new technologies, such as wearable devices, allows learners to effortlessly access this educational environment anytime, anywhere, and participate in live interactions, using digital personas with various entities such as avatars, chatbots, and virtual learning tools. This learning environment provides learners with a profound sense of presence while being physically present in the real-world educational context. From this perspective, integrating the metaverse in education promises to unlock many extraordinary learning experiences for students [17].

Creating a learning environment that centers around the learners is a crucial benefit of these educational innovations. This approach fosters the uptake of novel pedagogical techniques and the assimilation of innovative and instructional methodologies into the educational process [18]. Given the surging interest among researchers in AR and VR technologies, various reviews and systematic mappings have explored these technologies in the educational context. However, it has been noted that many studies emphasize specific aspects of education or solely focus on AR or VR technologies. Prior research is often specific to particular target audiences. It fails to encompass the diverse educational context ranging from K-12 education, higher education, job training, distance education, medical education, and vocational training. Moreover, several aspects remain unexplored, hindering a comprehensive understanding of the effectiveness of implementing AR and VR applications in education.

To bridge this research gap, this study concentrated on the following fundamental questions:

- What are the research trends and feasibility of AR/VR in education?
- How does integrating AR and VR in classroom instructions influence students' academic performance and learning outcomes?
- What are the effects of utilizing AR and VR technologies on student engagement, motivation, and interest in the learning process compared to traditional instructional methods?
- How do AR and VR simulations enhance students' understanding and retention of complex concepts?
- What are the perceptions and attitudes of educators and students toward implementing AR and VR in educational settings, and how do these perceptions impact the successful integration of these technologies?
- How do various factors such as technical accessibility, training for educators, and content design influence AR and VR's effective adoption and sustainability in different educational contexts?
- What is the overall impact of incorporating AR and VR technologies in educational settings and the learning experience?

By addressing these questions, this research aims to provide a comprehensive understanding of the potential benefits and challenges associated with implementing AR and VR technologies in education, ultimately paving the way for more informed and effective integration of these transformative technologies in diverse educational settings.

2. Materials and Methods

2.1. Strategy

To facilitate a comprehensive review with a broad scope, we adopted a flexible framework for this narrative review, as recommended in the literature [19,20]. A narrative review is helpful in presenting extensive coverage of existing literature and allowing for flexibility in incorporating evidence to evolving concepts, knowledge, outcomes, historical perspectives, and critical areas that require greater attention for further development in the area of interest [21]. The purpose of including a narrative literature review is because of its reliability in exploring specific areas of the subject domain, allowing for the critical assessment and summarization of existing theories and concepts. Adopting such an approach is beneficial in identifying recurring patterns and emerging trends within the literature, while also pinpointing gaps within the existing body of literature. This study adopted a narrative systematic review that employed certain strengths of systematic reviews, such as a structured search strategy, inclusion and exclusion criteria, study selection, and data extraction. The established narrative review methodology for this study was shaped by recommendations from prevailing narrative review frameworks and drew inspiration from numerous studies that have effectively employed this approach, resulting in favorable outcomes in their conducted reviews [22–28].

A complete literature review was undertaken by exhaustively investigating primary databases, such as Web of Science, Scopus, PubMed, ACM Digital Library, IEEE, Google Scholar, Educational Resources Information Center (ERIC), and the National Library of Medicine NIH, which were searched from the past ten years up to the date of the search, and manual searching of the reference lists was conducted. A literature review that delves into research conducted a decade ago serves as a significant academic endeavor with multifaceted benefits. By collating studies spanning this substantial timeframe, such analyses offer a panoramic synthesis of the evolution of knowledge on a specific subject.

The search terms used were a combination of keywords and terms related to "Augmented Reality", "Virtual Reality", "AR/VR in Education", "Augmented Technology in STEM", "K-12 Education Using VR and AR", "Metaverse in Education", "AR/VR Platforms for Distance Education", "Medical Education with AR and VR", "Professional Training with Augmented Technologies", and other related concepts. Additionally, the references in the relevant studies were searched manually using interrelated concepts, such as ICT in education, AR/VR gamification for education, reviews on AR and VR in higher education, virtual and augmented reality in primary education, recent developments in AR and VR for education, and mobile augmented reality application for teaching and learning.

2.2. Inclusion and Exclusion Criteria

The review was conducted according to specific inclusion criteria. Studies were included if they focused on AR and VR technologies within educational contexts and reported empirical findings concerning learning outcomes, educational experiences, or learner attitudes toward AR/VR technologies in education. Studies reporting student or teacher participation across different age groups in education were included. The review also considered studies that underwent a peer-review process and conference proceedings or book chapters written in English.

2.3. Study Selection

The study selection process involved two stages: (1) title and abstract screening and (2) full-text review. Two independent reviewers conducted the initial screening based on the inclusion and exclusion criteria. In cases where the abstract lacked sufficient information for the area of interest, the reviewers would thoroughly examine the entire article to ensure accuracy and relevance. Any discrepancies were solved through discussion or consultation with a third reviewer if necessary. The studies selected for the review require a case study, an experimental or a quasi-experimental design focusing on examining the learning outcomes of using AR/VR in an educational setting. The review included studies that presented interventions of AR/VR with participants divided into either the treatment or control group. Figure 1 shows a flowchart of literature inclusion.

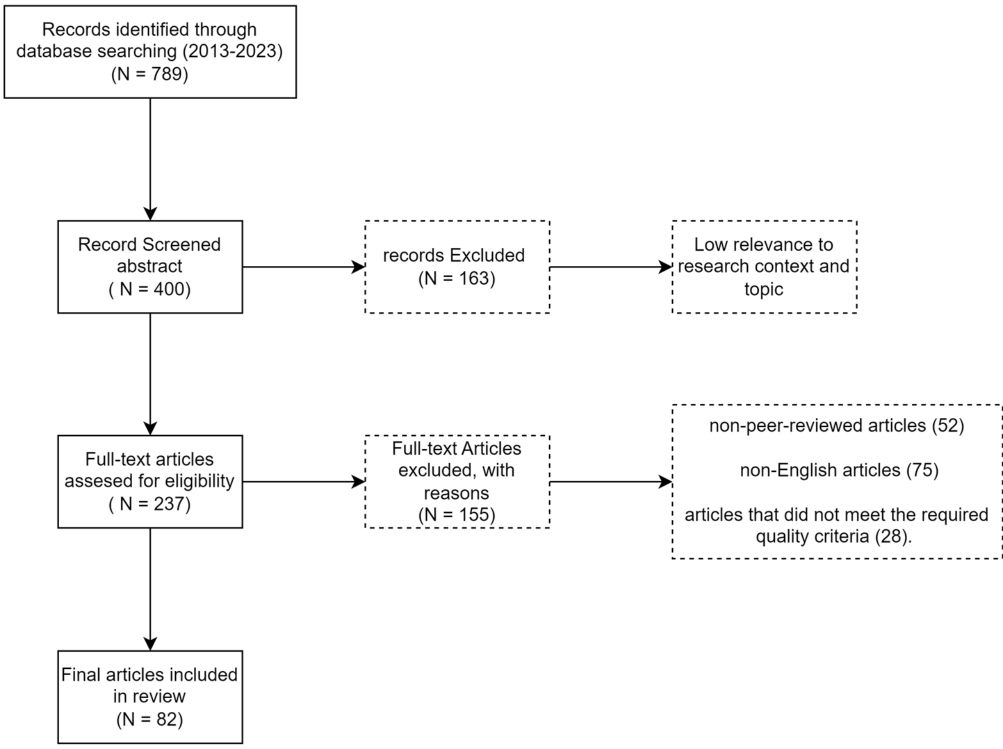

Figure 1. A flowchart of literature inclusion.

A total of 789 literature sources from the past ten years (2014–2023) were initially screened, focusing on AR/VR implementation from a broader perspective. The literature sources have been primarily identified from Web of Science, Scopus, PubMed, ACM Digital Library, Google Scholar, and IEEE and Educational Resources Information Center (ERIC). After reviewing the abstracts and availability, 400 studies were considered for further assessment. This subset identified studies specifically addressing AR/VR implementation in education, with distinct focus areas such as K-12 education, distance education, medical education, higher education, professional training, and language learning, resulting in 237 studies for further consideration. Subsequently, the subset underwent a thorough quality assessment to identify peer-review studies, excluding preprints or papers with only abstract availability.

Additionally, literature in languages other than English was excluded. The rigorous screening process led to the exclusion of a total of 155 articles, comprising non-peer-reviewed articles (52), non-English articles (75), and articles that did not meet the required quality criteria (28). For the final selection, the review included 82 articles that met the inclusion criteria and were meticulously analyzed to extract valuable insights.

2.4. Data Extraction

A standardized extraction approach was followed to ensure systematic data collection from the chosen studies. This process facilitated the extraction of the following information. Figure 2 highlights the data extraction process undertaken for the review.

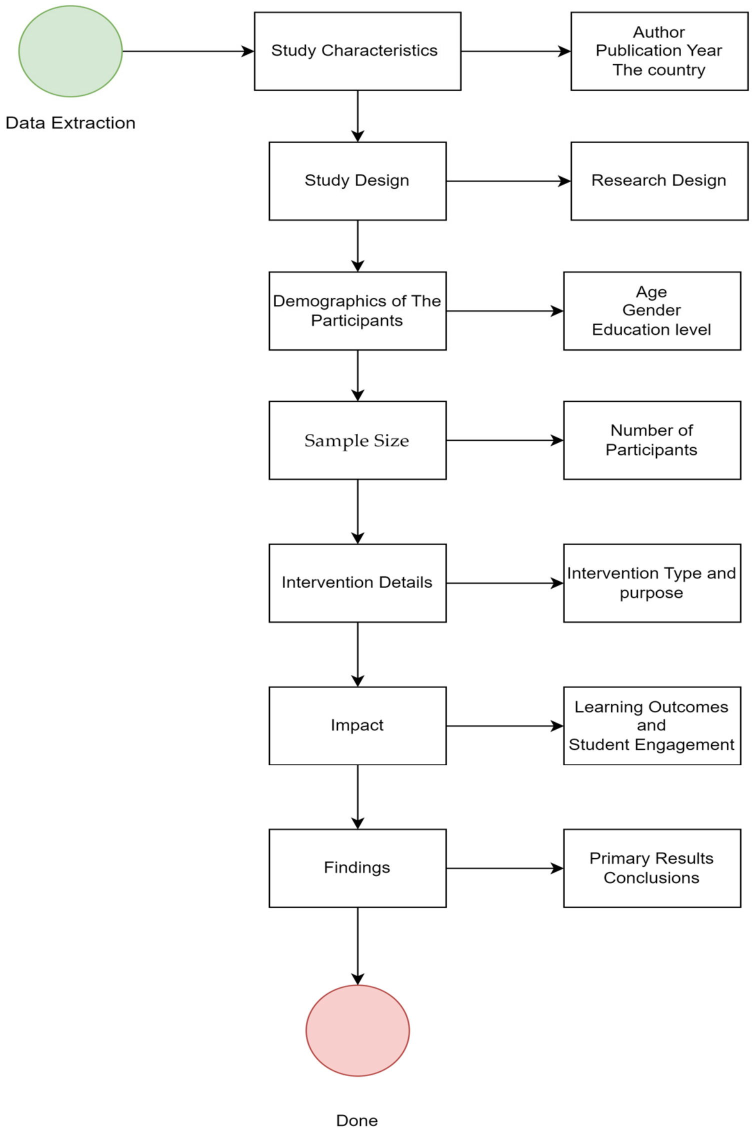

Figure 2. A flowchart of the data extraction process.

(a) Study Characteristic:
- Author(s) of the study;
- Publication year of the study;
- The country where the study was conducted.

(b) Study Design:
- Describing the research design such as randomized controlled trial or quasi-experimental.

(c) Demographics of The Participants:
- Information regarding the characteristics of the study gender, such as gender, age, and education level.

(d) Sample Size:
- Number of participants involved in the study.

(e) Intervention Details:
- Details about AR or VR application used in the study and its purpose and implementation type.

(f) Impact on learning outcomes and student engagement

(g) Key Findings:
- The primary results and conclusions drawn from the study regarding the impact of AR and VR intervention.

2.5. Data Synthesis

Due to expected heterogeneity in study designs and outcomes, a narrative approach was adopted. This involved qualitatively summarizing data from included studies to identify trends, common themes, and patterns related to the effectiveness of AR and VR technologies in education.

2.6. Bias Evaluation

A clear and well-defined approach was established to eliminate bias in the review, encompassing the research question, inclusion and exclusion criteria, and data extraction method. This approach ensures to maintain transparency and reduces selective reporting risks. An extensive and unbiased search was conducted across multiple databases and supplemented by hand-searching techniques to minimize publication bias and ensure comprehensive inclusion of studies. To address conflicts and discrepancies during the review process, an additional reviewer facilitated open discussions and resolved any issues. This collaborative approach enhanced the robustness and objectivity of the review. The review prioritized transparency in presenting its findings.

3. Findings

Researchers and educators have shown significant interest in integrating AR and VR technologies across various educational contexts. This study comprehensively reviews the literature on AR/VR in different educational settings while exploring its effects on learning outcomes, student engagement, and instructional practices. Each section delves into distinct educational contexts, examining the effectiveness and outcomes of the studies that have employed AR and VR in their respective domain. The findings analyze the research question and present various distributions of the studies identified during the review.

3.1. Distribution According to Educational Levels

Figure 3 showcases the distribution of studies utilizing AR/VR technologies in education across different educational settings. Upon analyzing Figure 3, it becomes evident that over the past ten years (2014–2023), most AR and VR interventions have been implemented in higher education. Following closely behind are postsecondary, secondary, and elementary education settings. However, as the educational level decreases to the junior levels, the research focusing on immersive technologies for education at these levels notably declines. These findings suggest that immersive technologies are more suitable for mature learners who better understand technology applications. At junior levels, the effectiveness of such technologies might not be as pronounced, and they could be perceived more as recreational interventions rather than educational tools.

Over the past five years, from 2019 to the present, there have been notable fluctuations in the number of studies focusing on AR and VR technologies. However, the analysis demonstrated a consistent and sustained interest in applying these technologies in higher education and postsecondary settings. On the other hand, other relevant areas have remained similar, with limited variations in the published studies. Nevertheless, it is crucial to recognize that some of the fluctuations observed in the published studies can be attributed to the impact of the pandemic during the period under evaluation. In addition, the use of AR and VR for junior learners, including kindergarten, preschool, and specialized areas like adult education, remains relatively sparse. Figure 4 illustrates the number of studies in the past five years and the education levels.

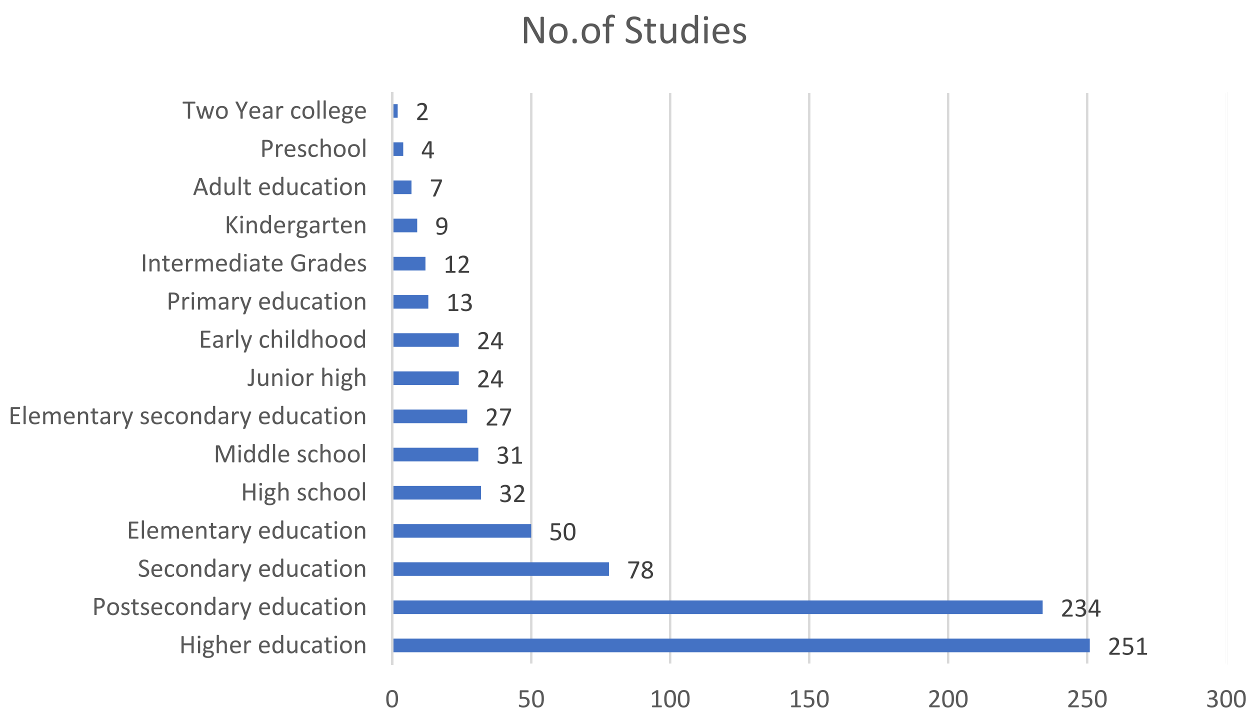

Figure 3. Educational levels and the number of studies (since 2014).

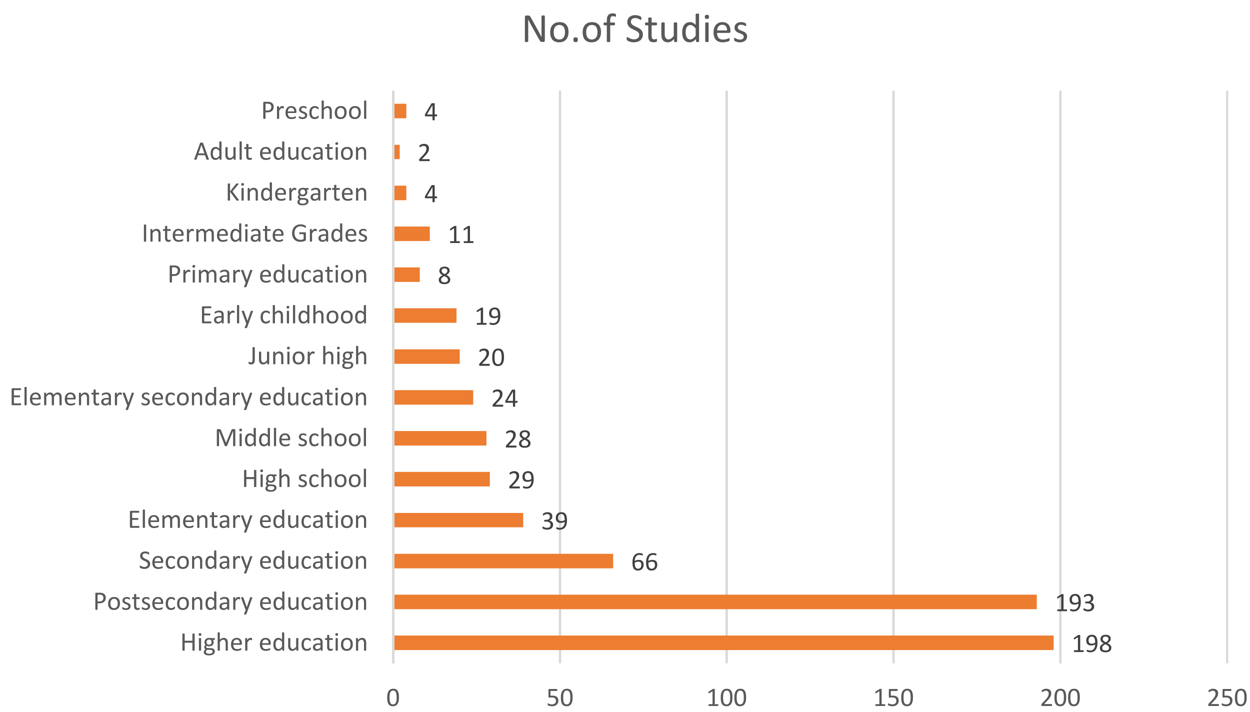

Figure 4. Educational levels and the number of studies (past five years since 2019).

3.2. Distribution of Study According to Publication Year

Upon analysis, it becomes evident that there has been a steady number of studies conducted during the past decade.

The period from 2014 onwards for the past ten years shows a broader perspective considering the use of immersive technologies in education, resulting in more published studies. However, in 2019, there was a significant drop in the number of studies due to the impact of pandemic. In the subsequent years of 2022 and the current year, 2023, a satisfactory number of peer-reviewed articles have been published, although it is comparatively lower than in previous years. This downward trend is due to technological advancements that has led to shifted focus from AR/VR in education alone toward hybrid approaches that can include the advantages of modern technologies with the benefits of AR/VR and address different problem areas of using technology in education.

This information is depicted in Figure 5.

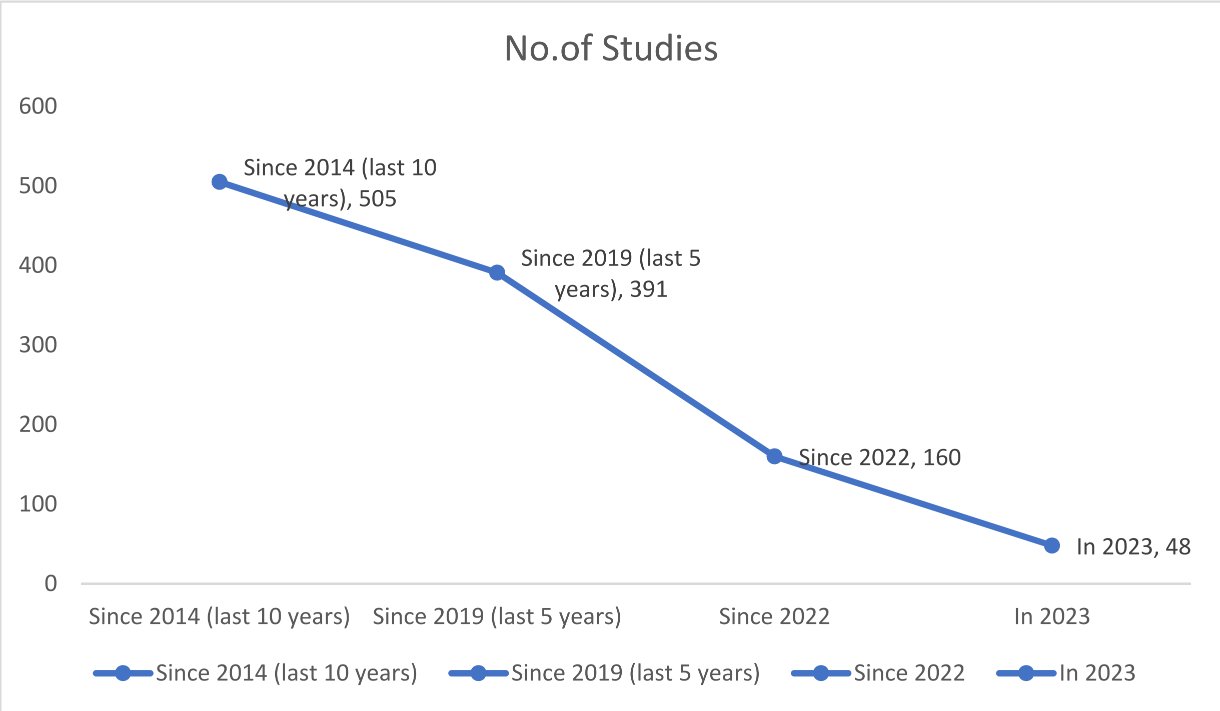

Figure 5. Study distribution by year.

3.3. AR/VR for Distance Education

The recent pandemic and the rapid evolution of immersive technologies have amplified the demand for online distance education, allowing students and teachers to engage in educational learning from the comfort of their homes. However, online education has faced criticism due to specific limitations related to practical courses, where traditional teaching methods are challenging to replicate. Distance learning requires students to rely heavily on their imagination for certain aspects of the learning process, and the absence of in-person guidance and real-time feedback from teachers can hinder the quality of knowledge transfer. Furthermore, technological issues such as screen size, camera angles or clarity, and volume or delayed feedback impeded learners' ability to grasp knowledge and concepts. This situation underscores the significance of AR and VR technologies in distance education to overcome time constraints and face-to-face interactions, enabling teachers and students to engage in interactive learning experiences without physical presence limitations [29]. To gain a better understanding of the impact, Table 1 highlights the studies that have utilized AR/VR for distance education and assesses their overall influence on learning outcomes and student engagement.

Table 1. Findings on AR/VR in distance education.

Author and Publication Year	Study Design	Demographics of Participants	Sample Size	Country	Intervention Details	Purpose	Impact of Learning Outcomes	Impact of Engagement	Key Findings
Li et al. [29]	Mixed-method	Male = 77 Female = 75	*N* = 152	China	Oculus Quest2 VR equipment, painting teaching application, and virtual calligraphy painting application	Distance learning to teach Calligraphy	Positive	High	There is a need to improve the understanding of teaching content using VR and enhance the design of VR-based education and learning initiatives.
Coban and Goksu [30]	Quasi-experimental	Experimental = 21 Control = 20	*N* = 41	Turkey	vAcademia and Adobe Connect	Distance learning environment to motivate and socialize undergraduates	VR environment: High W	High	Inability to provide a completely realistic environment. It also requires the responsibilities of tutors and learners to be considered for such intervention.
Rawson et al. [31]	Experimental	n/a	*N* = 75	UK	Low-immersive VR (Seekbeak platform)	Summative assessment for postgraduate environmental management online module	Promising	High	The response rate was lower than anticipated. There is a need to explore student views and competence further.
Birt et al. [32]	Quasi-experimental	Nonsimulation: Male = 31 Female = 49 Simulation: Male = 24 Female = 31	*N* = 159 (enrolled)	Australia	Mobile mixed reality simulation	Paramedical distance education	Improved	High	Difficulties in transitioning from AR to VR. Additionally, there were challenges related to ease of use in the context of heads-up display positioning.

Table 1. *Cont.*

Author and Publication Year	Study Design	Demographics of Participants	Sample Size	Country	Intervention Details	Purpose	Impact of Learning Outcomes	Impact of Engagement	Key Findings
Lee et al. [33]	Experimental	Male = 13 Female = 7	*N* = 20	Korea	IVR-based distance education system	Remote sensing, sharing, and experiencing Solar Dynamics Observatory via streaming using VR in real-time	Promising	High	A small proportion of the participants reported concerns regarding the headset's weight as the session duration increased.
Gatullo et al. [34]	Experimental	Students = 48 (study1) Students = 36 (study2)	*N* = 84	Italy	Mixed reality application	Supporting laboratory lectures in STEM distance education	Promising	Moderate	Students' engagement was low due to a lack of visually captivating design elements, while other participants provided recommendations for improving the content, device, interaction, and GUI.
Claman [35]	Quasi-experimental	Synchronous method: 10 Asynchronous method= 11	*N* = 21	USA	Multi-user virtual world environment	Assessing student engagement to improve learning outcomes of nursing students in online learning mode	Improved	High	The study encompassed a limited sample size, predominantly comprising female participants. The study encountered hardware and technical skill challenges among the participants. The user proficiency was constrained due to the lack of study materials tailored to the immersive environment's curriculum. Additionally, as all students used their hardware, the study faced reliability issues concerning speed, connectivity, and computational power.

3.4. AR/VR for K-12 Education

The adoption of AR/VR in K-12 education has gained momentum. Nevertheless, emerging challenges require attention and resolution before widespread implementation can be fully realized. AR and VR have been found to promote active learning, leading to increased engagement and motivation. Moreover, AR and VR empower students to learn independently and engage with subjects through interactive activities, facilitating a deeper understanding and retention of knowledge [36].

MacDowell et al. [37] presented a case study with panel discussions focused on AR/VR integration in K-12 and higher education. The findings emphasized the need for immersive learning experiences aligned with education goals. Practical recommendations included tangible curriculum resources and innovative instructional strategies and considering the availability of the technology at a viable cost. Despite challenges, an implementation was performed for implementing AR/VR in a Grade 8 science class. The results demonstrated enhanced engagement, knowledge retention, and understanding of abstract concepts. The research also highlighted AR/VR's effectiveness in childhood learning environments, fostering open-ended play and collaboration to deepen understanding of real-world topics. Lindgren et al. [38] conducted a study with 113 seventh-grade students randomly assigned to experimental (N = 58) and control (N = 55) groups. Using various levels, an interactive simulation game was employed to teach students about object movement in space. The experimental group showed significant cognitive and motivational improvements in learning, higher engagement levels, and a positive attitude toward science learning when using immersive technology. Ewais and Troyer [39] studied the impact of AR technology on female seventh-grade students' attitudes toward science and technology. The study involved seventh-grade students from a Palestinian primary school, and a mobile AR application was used in the experiment. The results indicated that all participants (N = 50) developed a positive attitude toward using AR technology in their learning process. The findings suggest that AR has the potential to positively influence students' perceptions and attitudes, even those who may initially show less interest in science and technology. Additional research indicates that disengaged middle and high school students experienced increased engagement and motivation when mobile AR simulation was integrated into their learning process [40]. Similarly, elementary students reported greater attention, self-confidence, and satisfaction when using AR concept map applications compared to AR alone [41].

A study was conducted in Hong Kong with a class of four to five-year-old children (N = 30), their class teacher, and two parent volunteers. This study investigated the impact of AR on early art education for children. Evaluations were performed through semi-structured interviews with parents, teachers, and the principal, while children's responses were collected using a survey. The findings indicate that children have control over the AR application's design and interaction elements and objects, and stakeholders supported technical intervention. However, the principal, teachers, and parents raised concerns about the potential side effects of using AR technology in early childhood education [42]. In the context of junior high school students, comprehending complex concepts related to microstructures in chemistry is challenging due to their limited imaginative abilities. A study implemented AR as an intervention tool for junior high school chemistry students in Shenzhen, China. The results demonstrated a significant impact as a learning tool, particularly for low-achieving students. Overall, students exhibited a positive attitude toward learning using the AR-enabled application [43]. The most notable advantage of immersive technologies is creating immersive hybrid learning environments that integrate digital and physical objects. This approach allows students to develop critical thinking, problem-solving, and communication skills through interdependent collaborative activities [44]. A mixed-method study assessed ninth-grade students' perception of AR technology, motivation, and its impact on vocabulary development. The sample comprised 130 students, divided into experimental (N = 64) and control (N = 66) groups. Pre- and post-test instruments were utilized to analyze performance. The findings revealed significant interest in AR integration among students. However, no significant differences were observed in vocabulary learning performance between the experimental and control groups [45].

Experimental studies with control groups have revealed that students exhibit a positive attitude and have developed a strong preference for haptic-based AR devices and AR-based games as a preferred learning tool over traditional classroom lessons [46]. Additionally, compared to conventional teaching methodologies, AR tools fostered greater motivation and learning interest. Moreover, haptic AR devices effectively teach complex physics concepts in a virtual environment [47]. AR-based gamified learning and storytelling are effective for intrinsic motivation and linking abstract concepts to real-world applications. Laine et al. [48] developed the Geometry game to teach geometry to fifth-grade students in a virtual environment at a Korean elementary school. The study introduced the Android-based Science Spots AR (SSAR) platform for story-driven learning games in this mixed-method approach. Results showed strong positive responses, particularly in problem-solving eagerness and communication among friends. The study recommends Incorporating multiple difficulty levels to maintain interest and encourage long-term use. Another experimental research study investigated the impact of AR-based applications on a science course focusing on electric vehicles involving 15 third-grade students. The application consists of 15 h of pre- and post-tests. The collected results indicated a significant increase in student success rates, attitudes, and achievements [49].

Limited studies have investigated the impact of VR in K-12 education, resulting in limited information about the benefits and challenges in such educational settings. To address this, a mixed-method quasi-experimental approach implemented VR (Oculus Quest) and non-immersive VR (3D Website) for ninth-grade social studies classroom teaching. The qualitative data analysis did not reveal a statistically significant improvement in knowledge development and classroom engagement upon using VR. However, qualitative data indicated positive learning benefits and increased classroom engagement. Notably, the improvement was observed to have developed due to historical empathy through VR [50]. In recent times, the implementation of AR/VR has been extended to K-12 teachers for their professional development programs. A study investigated the use of AR/VR for online personal development courses in a European nation. The research amalgamates pedagogically informed approaches such as inquiry-based learning and digital storytelling. Results derived from the mixed-method research highlighted that AR/VR can be seamlessly integrated into regular teaching practices. However, the authors contend that further development programs utilizing such technology are essential, as only a limited number of adept teachers can quickly excel without facing any difficulties and substantial support [51,52].

Similarly, in academic settings, using AR and VR for training and mentoring is perceived as a method to enhance the instructional proficiency of educators and foster competency-based skills while promoting cognitive development. Concurrently, this strategy holds the potential to curtail the time and financial investments associated with instructor training and mentoring. As a result, a multitude of institutions are adopting AR and VR technologies to establish more immersive learning for training instructors [53]. Some of the key findings are summarized in Figure 6.

The findings underscore the immense potential of integrating AR/VR technologies in K-12 education. Prominent areas identified from the AR/VRs impact analysis include greater participant satisfaction, particularly among students. Teachers and parents also exhibited a positive attitude, but concerns about potential side effects were expressed. Notably, self-confidence was significantly improved, especially for low-achieving students, while strong academic performers did not consistently demonstrate significant changes in comprehension abilities. Immersive virtual environments proved beneficial for children in different grades of K-12 education, fostering improved communication and teamwork skills. Literature also highlighted the effectiveness of immersive technologies in teaching abstract science and technology concepts, resulting in heightened attention, engagement, and knowledge retention. However, in existing studies, limited focus was given to effectiveness, knowledge retention, and skill development. Challenges such as hardware requirements, complex environments, and the need for innovative instructional strategies have been common challenges in adopting virtual learning. Other notable areas of impact included the development of a positive attitude toward learning with technology, increased learner motivation, and higher levels of engagement. Overall, the findings emphasize AR/VR technologies' promising opportunities for enhancing K-12 education while acknowledging the need to address the challenges to explore further research avenues. The findings on feasibility in this area of AR/VR in K-12 education are discussed in Table 2.

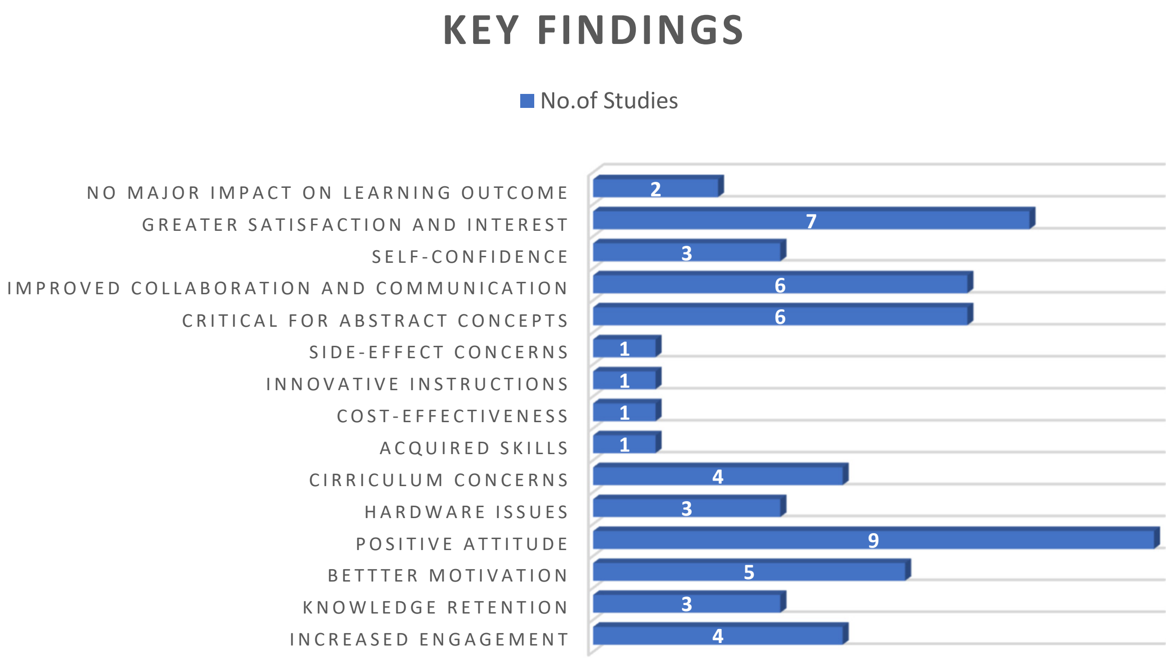

Figure 6. Key findings from relevant literature.

3.5. AR/VR for Higher Education

AR and VR technologies significantly impact higher education, revolutionizing the traditional learning experience. These immersive tools provide students with engaging and interactive learning environments to intuitively explore complex concepts. A recent study examined university-level chemistry students' motivation and technology acceptance using AR/VR environments. The study includes pre- and post-test designs with the control group. Students in the experimental group used an AR application, while the control group used 2D pictures to develop models of carbon bonds. Academic achievement increased for those using the AR application, while no motivation scores showed significant differences between the groups [54]. AR environments are also preferred in higher education as they allow students to modify elements in their surroundings and promote active engagement [55]. Higher education students show a positive attitude toward AR and VR because of the their experimental learning (learn by doing) approach, which enhances the understanding and retention of complex concepts compared with traditional teaching methods [56].

Furthermore, AR demonstrated a positive emotional impact on students, improving their cognitive processes and overall performance [57]. Additionally, virtual environment students experience a lower cognitive load than with traditional methods [58]. A recent study utilized a quasi-experimental research design to assess the effectiveness of three distinct learning methods: traditional, wearable AR, and wearable hybrid AR/VR. The participants consisted of 105 students distributed randomly into three groups. The findings revealed that the wearable hybrid AR/VR group displayed notably elevated situational interest and learning performance compared to the traditional learning group. Additionally, the same group exhibited significantly higher engagement levels when contrasted with other approaches. The study's findings highlight that wearable hybrid AR/VR is more effective in enhancing situational awareness and interests, engagement, and overall learning experience in the context of physical laboratory courses [59].

Table 2. Findings on the feasibility of AR/VR in K-12 education.

Feasibility Aspects	Description
Conceptual	The concept must align with the needs, educational requirements, and targeted users.
Motivational factor	Long-term use should be encouraged, considering the effectiveness of the technology and its challenges. On the other hand, to increase motivation, the virtual environment must incorporate elements that continue to motivate and challenge the student to continue using the environment for skill development.
Pedagogical factor	Learning content for teachers and students must be pedagogically designed, focusing on delivering positive learning outcomes.
Technical factor	Cost-effective hardware and bandwidth requirements must be considered before developing immersive technologies for K-12 education, as affordability is crucial. In addition, the systems or applications must be robust, scalable, and extensible with appropriate security measures.
Interface	The interface must be simple and user-friendly as complex user-interface have demonstrated that participants lose interest and tend to switch off from the environment.
Reusability	With a significant investment required to integrate such technologies, these applications or platforms must enable reusability in the context of resources for sustainability.
Behavioral	The level of student comprehension differs across different learners. Therefore, the virtual environment needs different elements that can adapt according to the learners' needs.

The utilization of AR/VR has the potential to motivate and engage advanced learners in essential fieldwork practices and techniques. These interactive environments foster critical visual literacy skills and enhance employability prospects for students [60]. Another recent study examined the potential of VR for pedagogical applications in geography for postgraduate courses. The study involved implementing a VR field trip to the Auschwitz-Birkenau State Museum using the high-immersive Inside Auschwitz guided documentary. The performance was evaluated from the surveys and interviews, which revealed VR technology acting as an inhibitor and facilitator, offering a sense of social and temporal freedom. This VR experience was identified to have generated curiosity and is an effective spatial prompt mechanism, inspiring new questions for students already engaged in developing geographical understandings and imagination of different sites [61]. An experimental study demonstrated that VR technology led to a better understanding of complex concepts and provided practical experience for third-year students in geo-education from Abai Kazakh National Pedagogical University. The experimental research involving sixty students revealed that VR could form the basis for effective and high-quality training with a focus on practice and productivity. The students' subjective assessment of the educational process changed from the desired quality of education to the expected quality after the AR training experience [62]. The researchers conducted a study to examine the impact of a 3D VR reality game on English and foreign language students' development of vocabulary and cultural knowledge. Twenty-five students participated in the VR-gamed-based language learning experiment, while a control group of twenty-four students followed the regular curriculum of the university. The feedback was collected through a questionnaire and an online survey to assess student perception and attitude. The findings suggest that VR-gamed-based learning is promising and effective in enhancing students' vocabulary and cultural knowledge [63]. A qualitative case study was conducted with 23 high school teachers to explore their perceptions of AR and VR in English language teaching and learning activities. The data were collected through semi-structured interviews. The findings include positive and negative themes related to integrating AR and VR in English education. Some positive perceptions include effective language learning, student engagement, and active learning, whereas the negative themes include time-consuming and health-related concerns [64].

A free-to-use AR-based mobile application called Nucleophile's Point of View (NuPOV) has been developed to address the limitations of using two-dimensional media to represent chemistry-based concepts in a particular manner that is easy to comprehend. With NuPOV, users can view chemistry concepts in AR and interact with them through hands-on activities. This individualized and self-directed learning experience enables users to understand the subject matter better. The findings suggest increased confidence in solving difficult questions and developing a positive attitude and interest in studying challenging courses [65]. Another experimental study employed a VR program to teach introductory computer hardware courses to first-year students from two universities in China. The program covered critical concepts on the history of computers, computer components, computer assembly, and hardware workflow. The student's behavior was analyzed to understand differences among various groups. The results showed increased students' curiosity and improved understanding of the concepts. On average, the students who engaged in the VR environment scored 27.2% higher than those in the traditional teaching group [66]. A recent study investigated the application and evaluation of VR in civil engineering education for infrastructure management. The study focused on a bridge inspection module for the study using the Projection VR system at NED University. The effectiveness of VR was assessed through the performance and feedback of 69 senior-year undergraduates. The structured rubrics-assessments revealed that the participants demonstrated heightened concentration levels in the VR environment and enhanced learning experience with increased exposure to practice using VR technology. However, a notable limitation is the absence of structural components that represent real-world scenarios concerning the appropriate representation of damages in the bridge inspection module [67].

Xiao investigated the implementation of digital multimedia VR courses in classrooms and analyzed the roles of students' and teachers' feedback that influence the implementation. The study reported a correlation between the execution of such courses and various influencing factors. Despite progress in digital multimedia, VR-enabled teaching has shortcomings, such as insufficient art digital multimedia curriculum focusing on VR, limitations of contemporary requirements in the course, gaps between implementation and the developmental stages of teaching methods, and limited teacher proficiency in digital multimedia using VR [68]. A similar study assessed students' experience with VR tool and their comprehension of 3D vectors in a university physics course. The experimental research design included experimental and control groups to gauge pre-post-test performance. The experimental group was also evaluated based on their perception of VR uses, learning objectives, and experiences of VR as a learning tool. The findings indicate that the experimental group outperformed the control group concerning items that required visualization. Additionally, the students had a positive attitude toward the VR-based learning tool, as it was identified as being able to enhance their learning experience, particularly in categories of course content involving visualization, 3D visualization, identification, and understanding [69]. The focal point of most of the immersive technology intervention studies was centered on learning achievement, motivation, and attitude, but there is a dearth of qualitative investigations in the domain [70]. The prevalent research trend involves contrasting student learning outcomes between VR and alternative methodologies such as AR, hands-on experiences, and conventional education. Emerging findings suggest that VR demonstrates enhanced efficacy for visual educational content, while AR exhibits superiority for auditory learning [71]. The key findings of this section are depicted in Figure 7.

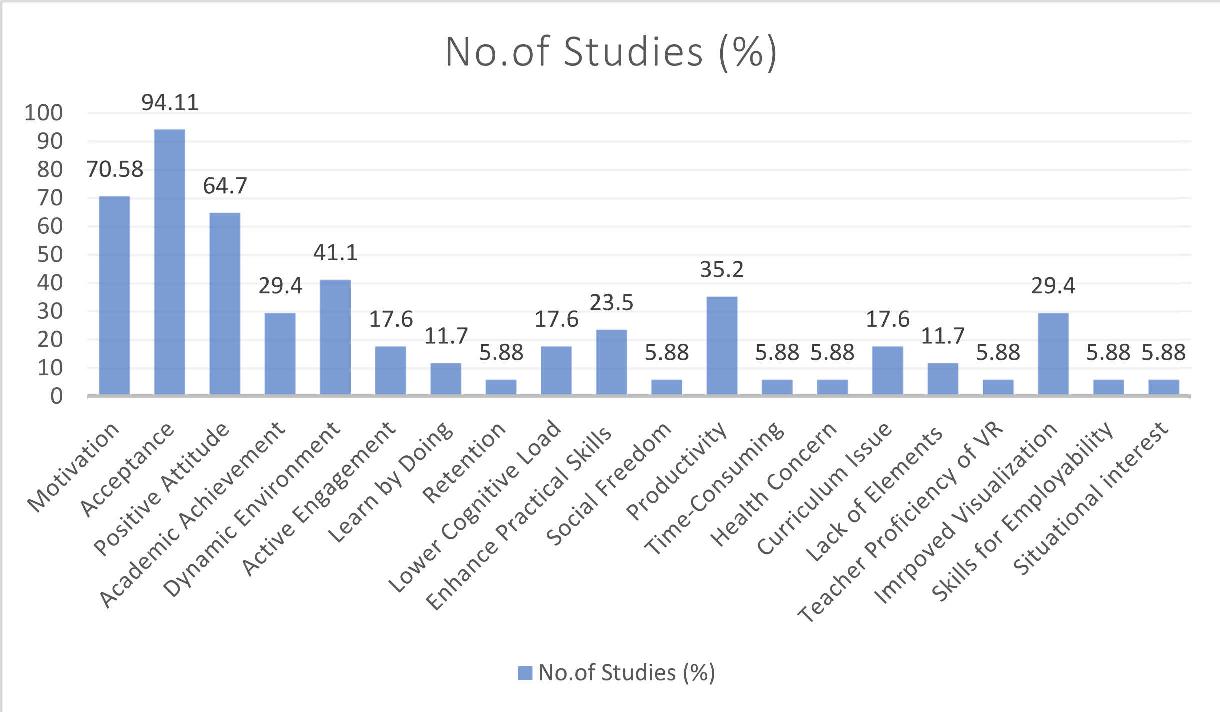

Figure 7. Findings from the literature on AR/VR in higher education.

Among the various factors identified and evaluated in the studies, acceptance stands out as the most crucial element, with a significant weight of 94.11%. This highlights the paramount importance of students and educators embracing the integration of AR and VR technologies in higher educational settings. Conversely, certain factors have not received adequate emphasis. While motivation (64.7%) and positive attitude (64.7%) have been recognized, academic achievement (29.4%) and visualization experience (29.4%) are areas that may warrant greater attention. Additionally, dynamic environment (41.1%), productivity (35.2%), and enhanced practical skills (23.5%) demonstrate notable relevance, factors like active engagement and learning by doing, which are curriculum issues, were lacking elements in the virtual environment, and with the subject in consideration for teaching are areas that could potentially benefit from enhanced consideration in the context of AR/VR integration. The feasibility aspects are outlined in Table 3.

3.6. AR/VR for Medical Education

AR and VR technologies have significantly transformed medical education by offering innovative and immersive learning experiences. Medical students and professionals benefit from these technologies in various ways, such as anatomy visualization, telementoring of new medical professionals, surgical training, diagnostic simulations for reasoning and making accurate diagnoses, and remote learning to enable students and professionals to participate in virtual surgeries and other medical procedures conducted elsewhere, and facilitating collaborative learning environments to discuss cases and share experiences from different locations. A study at the University of Dundee was conducted with medical students who had different experience levels. The study involved the assessment of preliminary VR anatomy resources. Students were introduced to the 3D anatomical models in a VR environment to gauge the potential and acceptance of the technology for anatomy education. The findings indicate promising results in the effectiveness of the technology, particularly for better visualization of annotations. However, students reported technical issues regarding bugs, which disrupted the procedure [72]. Similar research delved into the impact of digital anatomy learning tools, encompassing an intricate tablet-based depiction of anatomical systems using AR-based applications. The application superimposes 3D anatomical structures onto the digital mirror image of students. This study involved 236 students pursuing healthcare courses, where their performances were evaluated against traditional methods. The findings revealed that AR-based anatomical educational tools enhanced the learning experience, especially considering the enjoyment, motivation, and inclination to recommend. However, the study emphasized that male participants exhibited more positive learning experience scores than female participants. Additionally, no significant differences were observed in performance and knowledge retention [73]. In anatomical education within immersive environments, Moro et al. [74] propose that VR and AR can serve as effective methods in medical education without negatively affecting student performance. The research highlights these technologies as having a favorable influence on students' spatial comprehension abilities and a deeper understanding of 3D-based anatomical structures.

Table 3. Feasibility factors to consider.

Feasibility Aspect	Description
Curriculum	The alignment of AR/VR experiences with a specific curriculum designed for the virtual environment is essential for successful implementation.
Side effects	Significantly, few studies have addressed potential health concerns upon long-term uses of the technology. This requires addressing potential physical or psychological issues arising from prolonged AR/VR uses, especially for higher education, where advanced concepts require spending more time in the virtual environment.
Educator proficiency	Educators' competence in effectively utilizing AR/VR tools for instruction and guidance is critical in learning. Hence, educators must be provided with supplementary curriculum and virtual environment training.
Improved visualization	Much research has indicated a lack of visual appeal, leading to a mixed reaction. Although the attitude is positive toward the technology, using AR/VR for advanced higher education concepts requires improved visual capabilities to gain a deeper understanding of complex concepts in less time.
Knowledge retention	AR/VR implementation has to address the primary factor related to knowledge retention. To date, the focus on knowledge retention is significantly limited.
Dynamic and diverse environment	AR/VR environments must adapt to evolving technology and education trends and cater to diverse educational needs. Moreover, the focus must be adapting to different learning environments using technology for students from diverse locations.

Conversely, contrasting findings from another study suggest a different perspective. This study indicates that while VR might enhance learners' anatomy knowledge, AR may have a detrimental impact on performance compared to traditional 2D anatomy teaching methods [75,76]. An experimental study was developed to create and assess a prototype tool for medical education in human anatomy, using AR technology and a tangible 3D printed model. The primary objective was to facilitate 3D and topographical learning experiences. The tool named Anatomical Education and Augmented Reality (AEduCAR) was integrated and subsequently evaluated with 62 second-year medical students from the University of Bologna's School of Medicine and Surgery. The experimental and control group test results indicated no significant distinction between the two learning methods. Conversely, the questionnaire responses highlighted tremendous enthusiasm and interest in students. The AR tool was considered to boost student motivation, enhance long-term retention, and foster better 3D comprehension of anatomical structures [77].

An investigation was conducted to assess the usability of a VR application for training practical skills among dental students. The authors validated the VR application's effectiveness using the System Usability Scale (SUS) and analyzed the data collected on participants' perceptions. Overall, the VR training in dental education yielded positive outcomes, with participants finding the learning experience enjoyable and repeatable without extra costs [78]. A randomized trial was recently conducted at Kermanshah University of Medical Sciences, Iran. The study included 60 sixth-year dental students, randomly assigned to experimental (N = 25) and control (N = 25) groups. The performance was evaluated based on the usability of the VR technology, and student satisfaction was assessed via a questionnaire. Results indicated that all faculty members found VR usable in dental education. Most students (76%) expressed higher satisfaction with the VR integration into their learning. The mean score for students in the experimental group was higher than in the control group [79].

A randomized controlled multicenter trial assessed VR's effectiveness in teaching students about surgical site infection and its preventive measures. This study included third-year medical students at Grenoble Alpes University, Imperial College London, and the University of Heidelberg. Students were randomly assigned VR teaching or control groups, and the measure was the difference in scores achieved in the IPC exam at the end of the year. This intervention highlights critical areas where VR could be implemented for better medical education outcomes [80]. A mobile app, NitLabEduca, incorporating AR technology, was developed to study the spinal cord. The app offers an interactive exploration of 3D rotating models, theoretical content, animations, and simulations related to its physiology. To assess the impact, 80 participants with and without neuroanatomy knowledge were divided into control and experimental groups. SUS was implemented for usability checks. Notably, both groups showed better test results ($p > 0.001$) when combining the app usage with text. The SUS results indicated promising usability and learning outcomes. The authors suggest that the AR environment enhances learning compared to printed material [81]. Similarly, another research study underscores the versatility of immersive VR tools in health sciences. These tools are lauded for their customizability and hands-on capabilities. Notably, VR is experiencing growing traction in health sciences due to adequate visualization provisions for procedural simulation, surgical skill refinement, surgical planning, and in-depth gross anatomy education [82]. Bifulco et al. [83] examined AR's effectiveness as an educational aid for untrained individuals lacking medical expertise. The researchers devised an AR system that enabled individuals to perform ECG assessments using a head-mounted display with pointers, text boxes, and audio. Following the simulation on a mannequin, participants were capable of executing an authentic ECG on a volunteer. The authors suggested that the average electrode positioning errors were acceptably comparable to the placement errors of trained medical professionals. Additionally, the researchers highlighted that the application could be implemented to support other medical equipment and perform telemedicine tasks using a tablet or a smartphone. Tai et al. [84] proposed an all-encompassing AR lobectomy in a training system for thoracoscope surgery, incorporating visual and haptic modeling to investigate the possible advantages of the technology. The content comprised an immersive AR visual rendering constructed using the cluster-based extended position-based dynamics algorithm for soft tissue physics. AR haptic rendering systems were also integrated with a model architecture consisting of multitouch interaction points, including kinesthetic and pressure-sensitive points. The authors developed an AR interactive VATS surgical training platform based on the theoretical framework. Twenty-four volunteers evaluated the proposed system based on tactile sense, visual sense, scene authenticity, and simulator performance. The results demonstrated that the simulator effectively enhances surgical skills for novices and can be retrained after a specific time. Huang et al. [85] employed a method for cannulating the internal jugular (IJ) vein by utilizing AR glasses on a manikin. The AR group performed the Central Venous Catheter (CVC) insertion procedure, while an instructional simulation was projected onto their glasses. Despite the identical procedure time for both the control and AR groups, the AR group exhibited greater compliance with the procedure checklist ($p = 0.003$).

Dias et al. [86] implemented an AR-aided video laryngoscopy, wherein they contrasted the endotracheal intubation process of ICY nurses using direct and indirect video laryngoscopy. A comparison of intubation success rates revealed that the direct group achieved a rate of 32%, whereas the indirect group and the AR-based groups achieved 72% and 71%, respectively ($p < 0.001$). Likewise, the direct group had an esophageal intubation rate of 27%, while the indirect and the AR group had no instances of esophageal intubation. AR can aid healthcare providers in critical care procedures such as central line placement and intubation. The results were evident in the study conducted by Alismail et al. [87] consisting of 32 ICU trainees of whom 15 were assigned to the AR group. This group utilized AR glasses while performing endotracheal intubation on a training doll. The remaining participants were assigned to the interventional group. The necessary measures for the process were exhibited in the head-mounted display. Considering the results, the AR group was more time-efficient than the interventional group, as the latter required more intubation time despite having greater compliance with evidence-based intubation. Most recently, a study conducted by Kok et al. [88] emphasizes the implementation of AR in radiation oncology education. The authors reveal that commercial AR environments for radiotherapy training are unavailable. However, software prototypes have been developed to insert a fully 3D version of a radiotherapy linear accelerator into a real-life environment, such as the radiotherapy clinic or a patient's living room. As such, this integration would hypothetically facilitate a learning experience for expert personnel and patients who are unfamiliar with a radiotherapy machine to familiarize themselves with it. Chen et al. [89] presented a study that explores the utilization of AR in localizing supratentorial lesions imperative for preoperative planning. The evaluation of AR's effectiveness involved the implementation of a 3D slicer to retrieve lesion information. Additionally, registration was accomplished utilizing the anatomical landmarks and fiducial markers. The central areas of the lesion on the scalp were pinpointed using the proposed mobile AR system and the conventional neuron avigation system, respectively. The authors assert that the mobile AR system may provide a cost-efficient option for image-guided neurosurgery planning. The key findings on AR/VR for medical education are summarized in Figure 8.

Figure 8. Findings on AR/VR in medical education.

An essential factor highlighted in the studies is the "Acceptance" of AR/VR technology, with 14 studies focusing on this aspect. Better visualization and effectiveness also garnered significant attention, with studies exploring their impact. On the other hand, certain factors seem to be underemphasized, such as spatial comprehension, hardware issues, and technical issues being addressed by limited studies. At the same time, several aspects like motivation, enjoyable experience, positive impact on performance, and positive learning experience received moderate attention across the literature. Factors such as the negative impact on performance, long-term retention, and 3D comprehension have been explored in a limited number of studies. Other aspects, such as practical skills, higher satisfaction, time efficiency, and cost-effectiveness, were examined from two to seven studies, indicating a varying degree of emphasis in these areas. Critical responses and findings from the studies contribute essential insights into the feasibility aspect, as outlined in Table 4.

Table 4. Feasibility aspects of AR/VR in medical education.

Feasibility Aspects	Description
Improved and enjoyable experience	AR/VR platforms and applications must incorporate enjoyable learning compared to textbook study. New learning methods enable a better understanding of complex concepts better.
Employability	Most students prefer the second or third year, while an equal number of participants prefer the whole course. Therefore, careful evaluations must be performed to understand user needs and employ AR/VR for those learning requirements.
Upgradability	As AR/VR applications are meant to be used for a specific duration during lessons/sessions, there should be features that allow students to capture image sections and zoom in and out according to comfort. Other upgradable features include improving resolution when focusing on these applications in medicine and adding annotations, labels, and quizzes that help test learners about their knowledge retention after each module. Moreover, blurry images are common when using these medical education applications.
Technical factors	Recent findings highlight hardware and software problems considering AR/VR applications. There is a need for consistent updates to remove bugs and other faulty technical issues. These applications require providing learners with a seamless experience to prevent disruptions during sessions.
Side effects	There is a need to highlight any side effects of the prolonged use of these technologies. Limited studies have focused on potential health concerns regarding AR/VR technologies. Therefore, careful evaluation is required before proper implementation.

4. Discussion

Integrating AR and VR in education underscores immersive technologies' transformative potential for learning environments [90,91]. The literature on AR and VR applications in education spans a broad spectrum, encompassing various educational contexts. In the K-12 educational context, AR technologies have garnered more attention, and implementations are higher than VR technologies [92]. Conversely, literature on VR applications in higher education often lacks explicit reference to foundational learning theories. Experimental studies have predominantly focused on measuring learner attitudes, engagement levels, and usability [93]. Additionally, AR and VR application development assessment has primarily revolved around gauging learners' perception of specific application features. As a result, there is shortage of empirical research regarding the comparative analysis of the educational outcomes stemming from the implementation of AR and VR technologies [72].

The current landscape of teaching and learning is undergoing dynamic transformations, propelled by the rapid development and widespread adoption of information technology. As a result, pedagogical practices are continuously evolving, with a notable trend being the exploration of immersive virtual technologies. Yet, amidst this surge, ascertaining the precise impacts of Virtual Reality (VR) remains an intricate challenge [94]. Nevertheless, a dearth of comprehensive insights into application design elements and architecture and the absence of underlying theories remain noticeable. This can be primarily attributed to the cost of developing such technologies, leading to some studies adopting existing solutions like AR mobile applications or VR head-mounted devices [95].

In STEM education, the bulk of exploration resides within K-12 educational settings, where studies have spanned across science, technology, language, art, and music domains [70]. While the adoption and application of AR/VR in STEM education show promising potential, several challenges and considerations highlighted in various studies underscore the need for further development, refinement, and a more comprehensive approach to addressing user needs such as personalized learning materials, cost of hardware and software, usability, interaction and kinesthetic learning, and educational theories [96]. Similarly, the studies on professional development programs using AR/VR exhibited limitations in their scope. Insufficient attention was directed toward intervention attributes, evaluation metrics and learning outcomes [97]. Within K-12 education, a predominant focus was directed toward customized curricula for educators to cater to student requirements, assessment methods to address transfer of performance skills, and elevated cognitive processes. Additionally, inadequate provisions were observed for educators and administrators at the district and state tiers to cultivate knowledge foundation and attitudes that is essential to improve the quality of teaching [98]. Similarly, health considerations pertaining to children using AR/VR technologies were observed from the feedback of parents and educators [65].

The integration of practical and versatile development software, including prominent platforms, such as Unity, Blender, and Houdini SideFX, plays an indispensable and multifaceted role in the domain of animation. These software applications transcend their conventional usage as tools solely for interactive engagement, assuming a foundational and transformative role in the comprehensive process of animation creation. Unity, distinguished for its adaptability beyond gaming contexts, emerges as a dynamic platform enabling creators to orchestrate immersive visual narratives. Its capabilities extend to real-time rendering, fostering interactive environments that imbue animations with experiential depth. On a parallel note, Blender, a comprehensive open-source 3D creation suite, spans the gamut of animation production. Its diverse toolset facilitates not only modeling and texturing but also intricate animation processes, rendering, and simulation, engendering a comprehensive ecosystem for seamless visual development. Furthermore, the inclusion of Houdini SideFX amplifies the array of software choices, offering an advanced framework for procedural animation and intricate visual effects. This software's procedural paradigm empowers animators to meticulously craft intricate visual sequences that bear a profound semblance to real-world dynamics. Collectively, these software platforms transcend their conventional utility, evolving into fundamental instruments that enable the transformation of creative concepts into captivating, multisensory animations. Their integration ushers in a new era of dynamic interactivity, effectively bridging the gap between static visual content and immersive animated experiences.

There is a more advanced landscape in medical education, with applications utilized for surgical and anatomy education, yielding positive outcomes. Nevertheless, a substantial number of these studies remain within experimental phase or are limited to prototype designs primarily intended for training. Consequently, the genuine influence of immersive technologies in medical education is frequently left unexplored [99]. Furthermore, a study has brought to light that students participating in e-learning platforms that incorporate a range of technological integrations for medical education, especially in distance learning settings, have conveyed discomfort with the platform and demonstrated reluctance in accepting its integration. Moreover, students have faced difficulties related to understanding medical instruction and learning materials. Consequently, the study suggests that students need to be effectively acquainted with this new teaching environment before adopting new technologies for medical education [100].

Delving into VR applications across various educational settings, two significant areas come to the forefront: user interaction within the immersive environment and interactions with the hardware. Within these domains, notable concerns emerge, as learners have reported issues related to communication, object manipulation, and interruptions within the virtual environment. Technical glitches, such as bugs and crashes, have also hindered a seamless learning experience [92,101].

Moreover, critical aspects like potential side effects on users and image resolution, including the need for blur-free images and zoom-in and out features, demand more substantial consideration to enhance user comfort. In educational settings, the principles of reusability and scalability are essential for ensuring the long-term sustainability of technological implementations [102]. Focusing on these critical factors is increasingly important as we integrate innovative tools like Augmented Reality (AR) and Virtual Reality (VR). Reusability means designing educational content and applications in a way that allows them to be adapted and reused in different contexts, courses, and learning objectives [103]. This optimizes resources and ensures consistency in delivering compelling learning experiences. Scalability is equally essential and involves developing solutions that can accommodate a growing number of users without compromising quality or functionality. Scalable AR and VR applications can meet the evolving needs of education, expanding student populations, and dynamic curriculum changes. By paying more attention to reusability and scalability, educators and technologists can ensure that the benefits of AR and VR are not limited to isolated cases but are woven into the fabric of education, promoting lasting innovation and improved learning outcomes.

While few studies have reported a lower cognitive load, there is no in-depth information on cognitive load theory. Research outcomes have yielded a blend of results, with some investigations offering overreaching assertions regarding reduced cognitive load. One particular study has underscored the hurdle linked to AR applications, particularly concerning lower-order cognitive aptitudes, potentially impeding cognitive advancement through AR-based learning [104]. In a distinct examination, it has been emphasized that the recurrent utilization of immersive environments might lead to cognitive overload owing to the substantial time and attention required to grasp the educational content [105,106]. In general, cognitive load can differ based on the inherent complexity of a task or concept. In contrast, other load forms involve cognitive demands imposed by a presentation of content and often stemming from suboptimal instructional materials [107].

Similarly, limited information has been presented considering the participants' ability for long-term retention. Therefore, the simplistic assumption of lower cognitive load based on an enjoyable and unique immersive experience is insufficient. Past literature has indicated that immersive VR burdens working memory, leading to cyber sickness [108,109]. Additionally, design deficiencies may also have a substantial impact on the surge of cognitive load. Likewise, cybersickness is a widely discussed limitation of VR environments [110]. However, this issue has been probed through several hypotheses with no potential remedies for this concern. Spatial understanding is another context that has limited focus. In this context, it is crucial to understand the participants' spatial associations with objects in the environment, as varying levels of spatial ability can determine the participants' performances in the virtual environment.

Furthermore, divergent information exists regarding the optimal duration of these studies. While most studies have centered around shorter durations, emerging evidence suggests that a learner's impact is more comprehensively discerned through extended sessions. Simultaneously, it has been reported that shorter sessions with breaks can effectively mitigate fatigue and the potential onset of motion sickness [111]. These findings underscore the imperative for further comprehensive assessments before integrating technology into education.

Recommendations for Practical Implications

The advent of AR and VR promises to transform the education landscape, ushering in immersive and captivating learning platforms and experiences for students. The implications of these technologies are multifaceted and can be expounded upon as follows:

1. A tangible curriculum with practical instructional strategies for educators is critical as it can heighten interest in students by delivering the subject matter in a way that creates sustained student engagement.
2. Integrating AR/VR developmental training for educators is imperative, accompanied by thorough research that underscores teachers' learning experiences and compares them with students' learning experiences in the same environment. Doing so can effectively identify and address any disparities or challenges, ensuring a well-rounded and optimized learning environment for educators and students.
3. Captivating visuals and interactive platforms with auditory cues must be incorporated to foster long-term interest and prevent confusion on how to engage within the virtual environment and its objects.
4. Educational content must be designed to suit diverse environments, educators, and students with a user-friendly interface to enable a comprehensive grasp of the materials being taught.
5. Equitable access to AR and VR is critical for ensuring that all learners can benefit from the innovative tools. As these tools are considered for educational settings, addressing potential disparities in access is essential. Equitable access ensures that students with diverse backgrounds, including those with disabilities and varying economic circumstances, have an equal opportunity to engage with AR/VR experiences. Achieving this goal can involve various strategies, such as making AR/VR experiences accessible in public institutions, schools, and libraries and ensuring the availability of suitable assistive technologies for students with disabilities under the required guidance of specialists.
6. Collaboration among educational institutions, technology providers, and other community organizations is pivotal in extending AR/VR resources to marginalized communities.
7. Educators and policymakers can collaborate to leverage the capabilities of AR/VR for every learner.
8. Cost-effective hardware and software are critical in adopting these technologies in an educational setting.
9. The results have indicated that these technologies favored the confidence and retention of low-achieving students over high achievers. Therefore, AR/VR must be tailored for students, as they have varying levels of comprehension.

5. Conclusions

AR and VR technologies are poised to reshape the educational landscape, offering students more engaging, dynamic, and immersive experiences. While the potential benefits of AR and VR are evident across various educational levels, key aspects warrant attention as these technologies become more integrated into learning environments. Despite significant strides taken sto explore the benefits of AR and VR, challenges remain, such as cognitive load, cybersickness, cost, equitable access, curriculum challenges, and instructional strategies. The literature lacks a strong foundation in learning theories, with many studies focusing on usability without establishing a robust theoretical framework. Bridging this gap by infusing pedagogical theories can enhance the effectiveness of these applications in addressing specific learning objectives. As the field evolves, it is crucial to foster dialogue, share best practices, and develop guidelines that prioritize an inclusive learning environment with features specifically designed to address the educational needs of different students. AR and VR technologies continue to evolve, and educators, researchers, and policymakers have an exciting opportunity to shape the future of education by addressing various gaps, challenges, and limitations, such as theoretical foundations, application design, impact on learning, side effects, and the full potential of AR/VR technologies to create transformative learning experiences that prepare students for the challenges and opportunities of the modern world.

6. Limitations

While this study contributes new insights and recommendations for future research, it is not exempt from several limitations. Given the expeditious advancement of AR/VR technologies, the evaluation may not cover the most recent improvements or applications, potentially leading to inadequate comprehension of current educational potential. The heterogeneity in interventions, lack of architectural designs, different study designs, lack of foundational learning theories, and varying methodologies add complexity to cross-study comparisons, which may reduce the generalizability of findings. Furthermore, selecting studies only in English may present a publication bias resulting in skewed findings. The review's scope can be further constrained by factors such as the primary focus on usability, varying measurement approaches, the lack of long-term studies, limited research reporting negative findings or limitations of their research concerning the AR/VR intervention, or emphasis on unfavorable outcomes. The effectiveness of AR/VR is context dependent, and geographical and cultural variations compound its complexity. Therefore, such reviews provide perspectives, but their limitations must be recognized to ensure a nuanced interpretation of the findings.

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