Integrating Augmented Reality into Education: Applications, Benefits, Challenges, and Opportunities

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HOW TO CITE:

Sharmila Sure, Kavita Choudhary (2026). Integrating Augmented Reality into Education: Applications, Benefits, Challenges, and Opportunities. International Journal of Special Education, 41(16s), 362-379

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ABSTRACT:

This review thoroughly explores the incorporation of Augmented Reality (AR) into the educational sector, focusing on its uses, advantages, obstacles, and future prospects across various fields. By superimposing digital elements onto physical surroundings, AR provides engaging and interactive educational experiences that boost spatial visualization, active learning, motivation, and teamwork. The review traces AR's journey from its initial concepts to sophisticated wearable devices, highlighting its transformative role in areas like medical education, engineering, architecture, science, mathematics, language acquisition, arts and design, vocational training, and fashion education. Although AR enhances student involvement and academic success by aligning with constructivist, experiential, and cognitive learning theories, its implementation encounters major hurdles such as technical limitations, high expenses, lack of faculty training, infrastructural challenges, content creation difficulties, accessibility problems, and ethical issues. Importantly, the review points out research gaps in less-explored domains like fashion education, long-term educational outcomes, teacher professional development, and inclusivity. Future directions focus on AI-driven adaptive AR environments, WebAR for increased accessibility, wearable spatial computing devices, collaborative multi-user AR platforms, integration of learning analytics, creation of discipline-specific content, and sustainable implementation methods. By compiling existing knowledge and addressing these gaps, this review offers a comprehensive framework for educators, developers, and policymakers to fully utilize AR's potential, promoting engaging, effective, and equitable educational experiences that cater to the needs of 21st-century learning.

Keywords: Augmented Reality, Education, Students Engagement, Inmmersive Learning

1.1 Introduction

Augmented Reality (AR) signifies a groundbreaking development in computer science, enhancing how users engage with their physical surroundings by incorporating computer-generated visuals, sounds, and text

(Azuma, 1997). Emerging from early literary concepts and advancing through technological breakthroughs since the 1960s, AR has evolved into a refined tool that seamlessly integrates virtual components with real-world settings (Lee, 2012; Woods, 2014). The swift progress of AR technologies, such as mobile apps and wearable gadgets, has broadened its reach and utility across multiple fields, particularly in education (Radianti et al., 2020).

AR's significance in education stems from its ability to craft immersive, interactive learning experiences that go beyond conventional teaching methods. It enhances spatial visualization, supports experiential learning, and aids in acquiring contextual knowledge, which is especially beneficial in fields that require a mix of cognitive and practical abilities (Bacca et al., 2014; Billinghurst & Dünser, 2012). By providing multi-sensory interaction and real-time engagement, AR caters to various learning preferences, boosts motivation, and promotes collaborative learning (Kerawalla et al., 2006; Videnov et al., 2018). These features align with contemporary educational objectives that prioritize critical thinking, creativity, and student-focused learning, establishing AR as a vital facilitator of 21st-century skills (Kunnathodi, 2024; Vas, 2025). Although there is increasing interest and promising uses of AR in education, a significant gap remains for thorough reviews that compile existing knowledge on its integration, advantages, challenges, and future prospects. Current studies often concentrate on particular fields like medicine, science, and design, with limited investigation into AR's wider educational potential and the practical aspects of its implementation (Akçayır & Akçayır, 2017; Moro et al., 2017). Furthermore, differences in technological infrastructure, teaching frameworks, and user preparedness across various educational settings highlight the need for a detailed understanding of AR's role in diverse learning environments (Alzahrani, 2020; Sakr & Abdullah, 2024). A comprehensive review is crucial to pinpoint gaps, assess empirical evidence, and guide educators, developers, and policymakers in effectively using AR technologies. The main goals of this review are to thoroughly explore AR's applications in education, clarify its educational benefits, critically evaluate the obstacles to its widespread adoption, and emphasize new opportunities for future research and practice. This review intends to incorporate insights from different educational domains, including science, mathematics, language, medical, and design education, to offer a comprehensive view of AR's transformative potential (Bacca et al., 2014; Chang et al., 2020; Christopoulos et al., 2022).

Additionally, it aims to address the pedagogical and technological factors affecting AR implementation, such as cognitive load, usability, and motivation, thereby providing a detailed framework to guide effective AR integration (Buchner et al., 2022a; Eccles & Wigfield, 2002; Keller, 1987). In doing so, this review seeks to contribute to the ongoing discussion on immersive learning technologies and support the informed adoption of AR in educational practices globally.

1.2 Evolution of AR in Education

Since its initial conceptualization, AR has undergone substantial development, significantly impacting educational practices. The origins of AR date back to the 1960s, highlighted by groundbreaking inventions such as Morton Heilig's Sensorama in 1962, which offered multisensory experiences, and Ivan Sutherland's 1968 "Sword of Damocles," the first head-mounted display system that merged virtual and real environments (Berner, 2020; Lee, 2012). The phrase "augmented reality" was introduced in 1990 by Caudell and Mizell at Boeing, describing AR as the real-time integration of virtual elements with the physical world in a three-dimensional context (Azuma, 1997). These early technologies paved the way for later innovations, including the creation of marker-based tracking systems like ARToolKit in 1999 (Kato & Billinghurst, 1999) and the rise of mobile AR applications in the early 2000s (Mohring et al., 2004; Reitmayr & Schmalstieg, 2001). The 2010s saw a rapid increase in AR's educational applications, fueled by the growing availability of smartphones and

wearable technology. AR's ability to offer immersive and interactive learning experiences has been utilized in various fields such as science, medicine, mathematics, and design education (Akçayır & Akçayır, 2017; Bacca et al., 2014). In science education, AR aids in visualizing intricate biological and physical processes, thereby improving conceptual understanding and motivation (Gregorčič & Torkar, 2022; Radu & Schneider, 2019). Likewise, AR enhances spatial reasoning and collaborative problem-solving in mathematics and design disciplines (Salinas & Pulido, 2016; Topal & Sener, 2015). Educational institutions globally have increasingly adopted AR tools to engage students who are digital natives, aligning with their preference for experiential and technology-driven learning (Vas, 2025; Videnov et al., 2018).

Recent technological progress has significantly enhanced the educational capabilities of AR. Advanced AR software development kits (SDKs) like ARCore, ARKit, and Vuforia have facilitated the development of cross-platform AR experiences, both marker-based and marker-less, with superior tracking and environmental comprehension (Apple, 2026; Google, 2024; PTC, 2026; Unity Technologies, 2024). The emergence of wearable AR devices such as Microsoft HoloLens and Google Glass has brought about hands-free, spatially aware learning methods, enabling users to engage with 3D holograms in real-world environments (Flavián et al., 2019; Wright & Steele, 2024). Moreover, the combination of 5G networks and cloud computing supports low-latency, real-time AR experiences, while Web AR technologies lower entry barriers by allowing AR content to be accessed via standard web browsers without the need for specialized hardware (Orlosky et al., 2017; Qiao et al., 2019). These advancements have increased AR's accessibility and practicality, promoting its integration into various educational contexts and boosting the scalability of immersive learning solutions.

1.3 AR Applications Across Educational Disciplines

1.3.1 Medical Education

AR has transformed medical education by offering engaging, interactive experiences that improve spatial comprehension and practical abilities. Through AR tools, students can observe intricate anatomical structures in three dimensions, going beyond the constraints of textbooks and dissections (MacCallum & Jamieson, 2017). Platforms like Microsoft HoloLens enhance anatomy education by enabling the exploration of organs such as the heart, which boosts academic achievement and motivation (Christopoulos et al., 2022). In surgical training, AR provides simulated settings that decrease both learning duration and mistakes (Heinrich et al., 2021; Logishetty et al., 2019). Additionally, AR assists in patient education by visually demonstrating procedures, which helps to alleviate anxiety (Calle-Bustos et al., 2017; Raith et al., 2022). Despite these advantages, there are still challenges related to technical constraints and the need for long-term efficacy research (Moro et al., 2017; Raith et al., 2022).

1.3.2 Engineering

In the realm of engineering education, AR significantly boosts spatial visualization, practical abilities, and teamwork. By superimposing virtual models onto real-world settings, AR connects theoretical concepts with practical applications, creating genuine design experiences (Billinghurst et al., 2015). It enhances comprehension of intricate geometries and aids in iterative design processes, allowing for early error identification and shortening assembly durations (Mourtzis et al., 2018). Research indicates AR's success in manufacturing education by promoting experiential learning and enhancing communication between learners and educators (Lai, 2017). Nonetheless, technical difficulties and the necessity to integrate with current curricula continue to hinder its widespread implementation (Akçayır & Akçayır, 2017)

1.3.3 Architecture

In the realm of architecture education, AR addresses the limitations of conventional teaching methods by enhancing spatial awareness, student engagement, and collaborative efforts (Hajirasouli & Banihashemi, 2022). It allows learners to engage with and visualize three-dimensional architectural models within real-world settings, thereby deepening their comprehension of spatial qualities and design concepts (Birt et al., 2017; Riera et al., 2015). Location-based AR tools are instrumental in urban planning education, as they incorporate geo-located models (Milovanovic et al., 2017). Additionally, AR fosters experiential learning and constructivist teaching methods, encouraging active knowledge building and teamwork (Hajirasouli & Banihashemi, 2022; Santos et al., 2013). Although feedback is generally positive, students have identified challenges such as the steep learning curve of the software and managing workloads (Riera et al., 2015).

1.3.4 Science

AR enhances science education by transforming abstract ideas into concrete experiences and fostering inquiry-based learning. It aids in visualizing intricate biological systems, like the circulatory system, thereby enhancing conceptual comprehension (Gregorčič & Torkar, 2022).

In physics, AR tools help students grasp electromagnetism by making unseen phenomena such as magnetic fields visible (Radu & Schneider, 2019). Chemistry education is enriched through AR games that boost student engagement and simplify the visualization of molecules (Boletsis & McCallum, 2013; Olim et al., 2024). Additionally, AR provides interactive and multisensory learning opportunities for students with special educational needs (Delgado-Rodríguez et al., 2023). Effective AR integration relies heavily on comprehensive teacher training (Delgado-Rodríguez et al., 2023).

1.3.5 Mathematics

AR is utilized in mathematics education to enhance spatial reasoning, alleviate anxiety, and promote positive attitudes. Through AR tools, students can interactively visualize geometric concepts like conic sections, bridging the gap between abstract algebraic definitions and their visual counterparts (Salinas & Pulido, 2016). For students with special educational needs, AR-enhanced multi-touch systems provide contextualized learning experiences for monetary concepts, leading to notable improvements in engagement and knowledge acquisition (Cascales-Martínez et al., 2016). Collaborative AR applications stimulate creativity and problem-solving in open-ended tasks, fostering divergent thinking and teamwork (Pratiti et al., 2019). These studies confirm AR's contribution to enhancing mathematical understanding and motivation (Rashevska et al., 2020).

1.3.6 Language Learning

In language education, AR applications enhance vocabulary learning, communication abilities, and student motivation. Mobile AR offers immersive and contextually rich settings that promote genuine language practice (Parmaxi & Demetriou, 2020). Research indicates that AR-based vocabulary instruction outperforms traditional flashcards by incorporating visual and spatial elements, which boost retention and engagement (Ibrahim et al., 2018). For learners of English as a Foreign Language (EFL), AR creates simulations of real-world situations, which help lower anxiety and increase proficiency (Chang et al., 2020). This technology encourages active involvement and situational learning, which are crucial for language learning, and proves effective for a variety of learners, including junior high and special needs students (Chang et al., 2020).

1.3.7 Arts and Design

In the realm of arts and design education, AR plays a crucial role in enhancing spatial visualization, fostering creativity, and promoting experiential learning. By allowing students to engage with three-dimensional digital prototypes within real-world settings, AR enriches the exploration of materials and supports iterative design processes (Alzahrani, 2020; Radianti et al., 2020). In fields such as architecture, interior design, and product design, AR applications boost spatial awareness, increase motivation, and

encourage collaboration (Gürçınar & Esen, 2018; Hajirasouli & Banihashemi, 2022). Mobile AR tools provide students with the ability to instantly visualize different layout options, which aids in decision-making and enhances communication (Chang et al., 2020; Maulana et al., 2023). Studies emphasize AR's potential to underpin constructivist and experiential teaching methods, thereby nurturing creativity and facilitating peer learning (Ibáñez & Delgado-Kloos, 2018).

1.3.8 Vocational Education

AR enhances vocational education by offering practical, risk-free learning settings that connect theoretical knowledge with practical application. It replicates industrial operations and technical tasks, thereby improving skill development and minimizing mistakes (Akçayır & Akçayır, 2017). AR caters to various learning preferences by providing contextualized teaching and instant feedback, which are crucial in vocational education (Bacca et al., 2014). This technology encourages collaborative learning and boosts learners' confidence (Lai, 2017). Nonetheless, the complexity of the technology, the need for robust infrastructure, and the preparedness of instructors present major challenges to its broad adoption (Akçayır & Akçayır, 2017; Alzahrani, 2020).

1.3.9 Fashion Education

Fashion education, which combines creativity, spatial reasoning, and hands-on skills, is increasingly incorporating AR to improve the learning experience. AR tools enhance understanding of garment design, pattern creation, and textile visualization by offering interactive 3D models (Borisova et al., 2021; Videnov et al., 2018). Research indicates that AR increases student engagement, motivation, and the retention of technical knowledge (Elfeky & Elbyaly, 2021; Mohamed & El-Nahas, 2021). However, the use of AR in fashion education is still limited, particularly in developing nations like India, due to challenges related to infrastructure and curriculum (Singh & Rani, 2025). Studies highlight the importance of aligning AR tools with educational frameworks to maximize their effectiveness, especially in studio-based learning settings (Videnov et al., 2018).

1.4 Benefits of Augmented Reality in Education

AR provides numerous educational advantages by boosting student engagement, motivation, academic performance, spatial visualization, active learning, and collaboration. Together, these advantages lead to more impactful and significant educational results.

1.4.1 Student Engagement

AR engages students by crafting immersive and interactive educational settings that enhance focus and stimulate curiosity. In contrast to conventional techniques, AR integrates digital elements into real-world environments, making abstract or intricate ideas more concrete and relatable (Bacca et al., 2014; Videnov et al., 2018). This sensory-rich experience motivates learners to actively explore and engage with the material, resulting in increased participation. For example, in science classes, AR tools enable students to see biological processes or physical phenomena in three dimensions, greatly boosting their interest and involvement (Gregorčič & Torkar, 2022; Radu & Schneider, 2019). The novelty and impressive impact of AR also help maintain engagement, particularly among students who are accustomed to technology-driven learning settings (Keengwe & Georgina, 2013; Vas, 2025).

1.4.2 Motivation

AR boosts student motivation by making learning materials more engaging, pertinent, and easy to access. Keller's ARCS model suggests that motivation is influenced by factors such as attention, relevance, confidence, and satisfaction, all of which are enhanced by AR's immersive visualizations and interactive elements (Fang et al., 2024; Keller, 1987). By providing context to educational content, like simulating real-life situations in language or medical training, AR enhances perceived value and boosts learner confidence (Chang et al., 2020; Christopoulos et al., 2022). Additionally, AR encourages intrinsic motivation by allowing students to manage their learning speed and actively engage with the

material, which is in line with student-centered teaching methods (Delgado-Rodríguez et al., 2023; Videnov et al., 2018). The motivational increase from AR is associated with greater persistence and more positive attitudes towards difficult subjects such as mathematics and science (Rashevska et al., 2020; Salinas & Pulido, 2016).

1.4.3 Academic Performance

Research has shown that AR enhances academic performance by enabling a more profound grasp and retention of information. The interactive and visual characteristics of AR aid cognitive functions by minimizing cognitive overload and fostering meaningful learning experiences (Buchner et al., 2022a; Delgado-Rodríguez et al., 2023). In the realm of medical education, AR has been demonstrated to improve spatial understanding of anatomy, which translates to higher test scores and enhanced clinical reasoning skills (Christopoulos et al., 2022; Moro et al., 2017). Likewise, AR tools in physics and chemistry assist students in comprehending abstract ideas through visualization and simulation, leading to better assessment outcomes (Cai et al., 2021; Olim et al., 2024). Nonetheless, the success of AR is contingent upon careful instructional design and alignment with educational objectives to prevent distractions or shallow learning (Alzahrani, 2020; Sakr & Abdullah, 2024).

1.4.4 Spatial Visualization

AR offers a notable benefit by enhancing spatial visualization skills, which are essential in fields like science, engineering, architecture, and design. By enabling learners to interact with 3D models within real-world settings, AR effectively connects two-dimensional depictions with a concrete understanding of space (Billinghurst et al., 2015; Hajirasouli & Banihashemi, 2022). In the realm of mathematics education, for instance, AR aids students in visualizing geometric figures and conic sections, thereby linking abstract equations to tangible spatial forms (Salinas & Pulido, 2016). Similarly, in design and fashion education, AR improves the understanding of fit, proportion, and construction by allowing engagement with virtual prototypes (Borisova et al., 2021; Videnov et al., 2018). These features not only enhance conceptual understanding but also encourage creativity and innovation.

1.4.5 Active Learning

AR fosters active learning by prompting learners to physically and mentally interact with educational material. In contrast to merely absorbing information passively, AR compels students to investigate, manipulate, and experiment with virtual components embedded in their surroundings, thereby supporting inquiry-based and experiential learning (Ibáñez & Delgado-Kloos, 2018; Santos et al., 2013). This interactive method is consistent with constructivist teaching approaches, where understanding is developed through experience and reflection (Hajirasouli & Banihashemi, 2022). In fields like science and vocational training, AR simulations offer secure settings for skill practice and experimentation, allowing for trial and error along with immediate feedback without the dangers of the real world (Akçayır & Akçayır, 2017; Mourtzis et al., 2018). Engaging with AR in active learning has been associated with higher student satisfaction and a more profound grasp of intricate concepts (Lam et al., 2023; Radu & Schneider, 2019).

1.4.6 Collaboration

AR enhances collaborative learning by offering shared visual experiences that improve communication and interaction among peers. In group environments, AR allows learners to collectively engage with 3D models or simulations, promoting social constructivism and cooperative problem-solving (Akçayır & Akçayır, 2017; Pratiti et al., 2019). For example, in design education, AR tools enable teams to collaboratively create and evaluate virtual prototypes, which aids in decision-making and boosts collective creativity (González, 2018; Topal & Sener, 2015). Likewise, collaborative AR applications in mathematics and science stimulate discussion and joint problem exploration, enhancing teamwork skills crucial for 21st-century education (Delgado-Rodríguez et al., 2023; Pratiti et al., 2019). These interactions not

only improve learning outcomes but also develop social skills and motivation.

To conclude, AR enhances education by deeply involving students, inspiring continuous learning, boosting academic results, aiding spatial comprehension, promoting active involvement, and facilitating teamwork. These advantages underscore AR's ability to shift conventional educational models into vibrant, student-focused settings that equip learners for intricate real-world issues.

1.5 Challenges of Augmented Reality in Education

While AR holds the promise of revolutionizing education, it encounters numerous substantial obstacles that hinder its successful implementation and broad acceptance. These challenges span technical, financial, pedagogical, infrastructural, content-related, accessibility, and ethical domains.

1.5.1 Technical Issues

Technical difficulties continue to be a significant obstacle to the integration of AR in educational environments. AR systems frequently encounter issues such as tracking inaccuracies, unstable software, and hardware constraints, all of which interrupt the flow of learning and diminish user engagement (Akçayır & Akçayır, 2017). The use of head-mounted displays (HMDs) and AR applications can lead to high cognitive demands due to overwhelming visual and auditory inputs, making it challenging for learners to assimilate information efficiently (Buchner et al., 2022). Users also face frustration from camera delays, slow visualizations, and restricted fields of view, particularly in intricate subjects like physics, where accurate timing and visualization are essential (Vidak et al., 2024). Moreover, marker-based AR relies on the dependable detection of visual markers, which can be compromised by lighting and camera quality, whereas marker-less AR requires advanced simultaneous localization and mapping (SLAM) algorithms that may not perform consistently in all settings (Borisova et al., 2021).

1.5.2 Cost

The financial commitment necessary for implementing AR technology poses a significant challenge. The cost of high-end AR devices, like Microsoft HoloLens or sophisticated AR glasses, remains prohibitive, restricting their availability to numerous educational institutions, especially in developing nations (Akçayır & Akçayır, 2017; Singh & Rani, 2025). Although mobile AR applications are comparatively cheaper, they still require compatible smartphones or tablets, which may not be accessible to every student. Expenses are not limited to hardware; they also include software licenses, upkeep, and updates, which can burden financial resources. Additionally, creating custom AR content that aligns with specific curricula requires considerable time and expertise, further increasing costs (Alzahrani, 2020).

1.5.3 Faculty Training

Successful integration of AR in education is largely contingent upon the preparedness and skill level of faculty members. A significant number of educators are not adequately trained to effectively incorporate AR into their instructional methods (Delgado-Rodríguez et al., 2023). In the absence of comprehensive professional development, educators might either fail to fully utilize AR tools or use them in a superficial manner, which can result in less effective learning experiences (Alzahrani, 2020). The lack of familiarity and intricacy of AR technology can be daunting for faculty, necessitating continuous support and training to enhance their confidence and teaching proficiency (Sakr & Abdullah, 2024). Additionally, the task of aligning AR applications with educational objectives requires instructional design capabilities that many educators have not yet acquired (Akçayır & Akçayır, 2017).

1.5.4 Infrastructure

Implementing AR effectively demands a strong technological foundation, which is frequently absent, particularly in educational settings with limited resources. AR tools necessitate reliable internet access, adequate bandwidth, and compatible devices, yet these are not always

readily accessible (Alzahrani, 2020). Numerous schools and colleges in developing areas encounter obstacles like inconsistent power, obsolete equipment, and inadequate network reach, hindering AR adoption (Singh & Rani, 2025). Additionally, incorporating AR into current IT frameworks and learning management systems calls for technical know-how and institutional dedication, which might be lacking (Akçayır & Akçayır, 2017).

1.5.5 Content Development

Creating AR content that is both high-quality and educationally effective involves significant complexity and resource demands. It is essential for educational AR materials to be meticulously crafted to meet curriculum standards, cater to the varied needs of learners and achieve learning goals (Bacca et al., 2014). If AR content is poorly designed, it may inundate learners with unnecessary information, thereby increasing cognitive load and diminishing understanding (Buchner et al., 2022a). Furthermore, the development of such content requires collaboration across disciplines, involving subject matter experts, instructional designers, and AR developers, which can be challenging to organize and finance (Alzahrani, 2020). The absence of scalable and reusable content libraries restricts educators' capacity to broadly implement AR and tailor experiences effectively (Akçayır & Akçayır, 2017).

1.5.6 Accessibility

Although AR holds potential for fostering inclusive education, accessibility issues persist. The technology often demands costly equipment and digital literacy, which are not uniformly available to all students (Alzahrani, 2020). This disparity in access could worsen educational inequalities, especially for those in economically disadvantaged or rural regions. Furthermore, unless AR interfaces are specifically equipped with accessibility features, they may not be entirely usable for students with disabilities like visual or motor challenges (Delgado-Rodríguez et al., 2023). Additionally, language and cultural differences can impact the effectiveness and applicability of AR content, requiring efforts in localization and adaptation(Akçayır & Akçayır, 2017).

1.5.7 Ethical Concerns

Integrating AR into education presents ethical challenges concerning privacy, data security, and user health. AR tools frequently gather and analyze user data, such as behaviour, place, and biometric details, which raises issues about obtaining consent and data protection (Kakade et al., 2025; Sakr & Abdullah, 2024; Werner et al., 2025). The immersive experience of AR can also lead to physical discomfort, including eye strain, fatigue, or motion sickness, especially with extended use (Alzahrani, 2020; Łowcewicz et al., 2026; Yego et al., 2025). Additionally, if AR is not thoughtfully incorporated, its novelty might result in distraction or shallow learning, potentially affecting educational quality (Buchner et al., 2022; Garzón & Acevedo, 2019; Radu, 2014; Radu & Schneider, 2019). Therefore, ethical use demands user education and clear policies. To protect learners' rights and well-being continuous oversight is necessary.

To sum up, although AR offers significant potential to improve education, it is crucial to tackle these complex challenges for its long-term and fair implementation. Key actions include overcoming technical barriers, offering thorough training for educators, enhancing infrastructure, creating high-quality content, guaranteeing accessibility, lowering expenses, and addressing ethical issues. Achieving AR's complete educational potential will require careful planning, institutional backing, and cross-disciplinary cooperation.

1.6 Application of Learning Theories to Augmented Reality Research in Education

Incorporating AR into education is significantly shaped by diverse learning theories, which offer structures to comprehend the ways AR improves educational experiences. These theories direct the creation, execution, and assessment of AR tools, making sure that the technology supports educational objectives. The subsequent analysis examines the application of major learning theories in AR research and practice, emphasizing their significance and influence.

1.6.1 Constructivism

Constructivism suggests that knowledge is actively built by learners through their experiences and reflections, rather than being passively absorbed (Prakash Chand, 2023; Tynjälä, 1999). AR complements constructivist ideas by allowing learners to engage with virtual elements within real-world settings, thus promoting active knowledge creation. Studies in architecture and design education highlight this synergy, showing how AR aids students in handling 3D models and participating in genuine problem-solving activities (Hajirasouli & Banihashemi, 2022; Santos et al., 2013). For instance, AR tools enable students to project digital prototypes onto actual environments, encouraging exploration and iterative learning that aligns with constructivist teaching methods (Radianti et al., 2020). This hands-on involvement enhances comprehension and critical thinking, as learners experiment and obtain immediate feedback in relevant contexts.

1.6.2 Experiential Learning

Experiential learning focuses on acquiring knowledge through firsthand experiences and subsequent reflection (Kolb, 1984). AR enhances this type of learning by placing students in dynamic settings where they can actively engage in skill practice and witness the outcomes immediately. In the realm of medical education, AR simulations offer a risk-free platform for students to delve into anatomical studies or perform surgical techniques, thereby providing practical experience that bolsters skill development (Christopoulos et al., 2022; Logishetty et al., 2019). Likewise, in fields such as vocational and design education, AR facilitates interaction with virtual tools and resources, effectively linking theoretical knowledge with practical application (Ibáñez & Delgado-Kloos, 2018; Mourtzis et al., 2018). This engaging form of interaction promotes reflection and adjustment, which are fundamental to experiential learning, allowing learners to grasp concepts through active participation rather than passive observation.

1.6.3 Cognitive Theory of Multimedia Learning (CTML)

According to CTML which is proposed by Mayer, optimal learning occurs when information is delivered via both visual and auditory means, which helps to minimize cognitive overload and improve integration (Mayer, 2020). AR applications naturally integrate various modalities, such as 3D visuals, sound, and text, thereby aligning with CTML principles. Research in science and language education indicates that AR's multimodal presentations enhance understanding and memory by offering coordinated visual and verbal signals (Gregorčič & Torkar, 2022; Ibrahim et al., 2018). For example, AR chemistry games employ animations and narrations to clarify molecular structures, promoting dual-channel processing and encouraging effective learning (Olim et al., 2024). This multimodal strategy aids learners in constructing coherent mental models by connecting verbal descriptions with visual depictions.

1.6.4 Cognitive Load Theory

Cognitive Load Theory (CLT) emphasizes the importance of managing working memory demands to enhance learning (Sweller, 1988). Research on AR recognizes that although AR can improve comprehension, it might also elevate extraneous cognitive load if not designed effectively (Buchner et al., 2021, 2022; İbili, 2019). Successful AR applications limit unnecessary distractions and deliver information in digestible portions. For instance, Buchner et al. (2022) demonstrated that well-organized AR content alleviates cognitive overload, allowing learners to concentrate on crucial information. In the context of medical education, AR instructional designs that scaffold content and offer interactive support help balance intrinsic and extraneous load, thereby enhancing learning outcomes (Delgado-Rodríguez et al., 2023). Consequently, CLT guides AR development by prioritizing simplicity, clarity, and appropriate pacing to avoid overwhelming learners.

1.6.5 Situated Learning

According to situated learning theory, acquiring knowledge is most effective when it occurs in genuine settings through social interaction and active participation (Lave & Wenger, 1991). AR facilitates situated learning by integrating virtual components with real-world environments, thereby embedding content within the learners' physical context. For instance, AR applications that are location-based in fields like architecture and history education allow students to investigate urban areas or historical locations enriched with digital data, promoting contextual comprehension and engagement (Challenor & Ma, 2019; Riera et al., 2015). This integration within the context aligns with social constructivist learning principles, as students engage in collaboration and discussion about their observations in real-world environments, thereby improving the applicability of the knowledge gained.

1.6.6 Keller's ARCS Model

Keller's ARCS Model, which stands for Attention, Relevance, Confidence, and Satisfaction, serves as a motivational framework in instructional design (Keller, 1987). AR naturally draws attention by offering engaging and unique experiences, which are essential for motivation. Studies that integrate the ARCS model with AR-enhanced learning indicate that AR boosts learner engagement by making the content both relevant and interactive (Chang et al., 2020; Fang et al., 2024). For example, in the context of language learning, AR situational scenarios increase relevance by mimicking real-world communication, thereby enhancing confidence and satisfaction through successful interactions (Chang et al., 2020; Parlar & Sütçü, 2025; Shadiev & Liang, 2024). Additionally, AR's provision of immediate feedback and the ability to control the learning pace further bolster learner confidence and satisfaction, effectively aligning with the principles of the ARCS model.

1.6.7 Expectancy-Value Theory

According to Expectancy-Value Theory, motivation is determined by learners' success expectations and the importance they place on tasks (Eccles & Wigfield, 2002). AR applications boost expectancy by offering clear visual representations of learning objectives and progress, thereby enhancing learners' confidence in their ability to achieve success. The value aspect is reinforced by AR's capacity to place learning in context and illustrate its practical significance, particularly evident in fields like medical and design education where AR clarifies complex ideas and real-world applications (Christopoulos et al., 2022; Videnov et al., 2018). Research shows that the immersive and interactive qualities of AR enhance both expectancy and value, resulting in greater persistence and more positive attitudes towards difficult subjects (Mohammadhossein et al., 2024; Salinas & Pulido, 2016).

1.6.8 Technology Acceptance Model (TAM) / Unified Theory of Acceptance and Use of Technology (UTAUT)

TAM and UTAUT examine the elements that affect the adoption of technology, such as perceived usefulness, ease of use, social influence, and facilitating conditions (Venkatesh et al., 2003). In AR research, these frameworks are utilized to explore how educators and learners accept AR tools. Research indicates that performance expectancy and effort expectancy are crucial factors influencing the adoption of AR in educational settings (Acikgul & Sad, 2026; Graser & Böhm, 2024). Institutional backing and peer influence are also significant in promoting AR integration, particularly in fields like fashion education where faculty preparedness is essential (Singh & Rani, 2025). These models inform strategies to enhance AR acceptance by addressing usability issues and ensuring AR tools meet user requirements.

In conclusion, AR's effectiveness in education is strongly backed by its alignment with established learning theories. Constructivism and experiential learning emphasize AR's active and immersive engagement, while CTML and CLT guide its cognitive design. Situated learning underscores the importance of authentic context, and motivational and technology acceptance theories direct learner engagement and adoption. These

theoretical bases ensure that AR is not just a technological novelty but a pedagogically robust tool that improves learning outcomes across various disciplines.

Table 0.1 Application of Learning Theories to Augmented Reality Research in Education

Learning Theory	**Key Concepts**	**Application to AR in Education**
Constructivism	Learners actively construct knowledge through experience and reflection.	AR enables learners to interact with virtual objects in real contexts, fostering active knowledge construction and authentic problem-solving (Hajirasouli & Banihashemi, 2022; Santos et al., 2013).
Experiential Learning	Learning through direct experience and reflection.	AR provides students with the opportunity to engage in interactive environments, where they can practice skills and observe the immediate effects of their actions, thereby enhancing their learning experience (Christopoulos et al., 2022; Mourtzis et al., 2018).
Cognitive Theory of Multimedia Learning (CTML)	To minimize overload, information is best absorbed when delivered through both visual and auditory means.	By integrating 3D images, sound, and written content, AR facilitates dual-channel processing, which enhances both understanding and memory retention (Gregorčič & Torkar, 2022; Ibrahim et al., 2018).
Cognitive Load Theory (CLT	Managing working memory load to optimize learning.	By organizing content and providing scaffolding, AR design reduces unnecessary cognitive load, thereby avoiding overwhelming learners (Buchner et al., 2022; Delgado-Rodríguez et al., 2023).
Situated Learning	Knowledge is best acquired in authentic contexts through social interaction and participation.	By superimposing virtual components onto actual settings, AR facilitates learning experiences that are contextualized and encourages collaborative efforts (Challenor & Ma, 2019; Riera et al., 2015).

Keller's ARCS Model	Motivation driven by Attention, Relevance, Confidence, Satisfaction.	AR draws interest by offering immersive experiences, makes content more relevant by incorporating real-world situations, builds confidence by providing instant feedback, and elevates satisfaction levels (Chang et al., 2020; Fang et al., 2024).
Expectancy-Value Theory	Motivation depends on expectancy of success and value assigned to tasks.	AR boosts expectancy by making learning objectives clearer and raises value by placing content in context, which in turn enhances persistence and attitudes (Eccles & Wigfield, 2002; Videnov et al., 2018).
Technology Acceptance Model (TAM) / Unified Theory of Acceptance and Use of Technology (UTAUT)	Adoption influenced by perceived usefulness, ease of use, social influence, and facilitating conditions.	The acceptance of AR is influenced by how educators and learners perceive its practicality and simplicity, along with the backing from institutions and the impact of social factors (Acikgul & Sad, 2026; Graser & Böhm, 2024; Venkatesh et al., 2003)

1.7 Research Gaps

The body of work on AR in the educational sector highlights several distinct research gaps, emphasizing the importance of a thorough review. One major gap is the limited research on design-oriented fields, with fashion education being particularly overlooked. Although AR's use in disciplines such as medicine, engineering, and architecture is well-documented, its application in fashion education has not been extensively studied (Borisova et al., 2021; Singh & Rani, 2025; Videnov et al., 2018). This is a crucial gap, considering the dependence of fashion education on spatial reasoning and tactile creativity, where AR could significantly enhance learning experiences. Secondly, there is a scarcity of longitudinal research investigating the prolonged effects of AR on educational outcomes. The majority of studies concentrate on immediate or short-term impacts, which leaves gaps in understanding regarding skill retention, transferability, and sustained motivation (Delgado-Rodríguez et al., 2023; Moro et al., 2017) . Conducting such research is crucial to confirm the lasting educational advantages of AR and to guide strategies for its integration into curricula. Thirdly, evidence from developing nations, such as India, is scarce, where unique infrastructural, curricular, and cultural elements impact the adoption and success of AR (Singh & Rani, 2025). The absence of empirical data specific to these regions limits comprehension of the contextual challenges and opportunities, thereby obstructing fair technology distribution.

Moreover, there has been a lack of focus on the professional development of teachers concerning AR. Successful integration of AR demands that educators have both the necessary technological expertise and pedagogical understanding. However, studies on faculty training,

preparedness, and continuous support are limited (Delgado-Rodríguez et al., 2023; Sakr & Abdullah, 2024). Additionally, the absence of standardized tools for assessing AR learning experiences poses challenges for comparing studies and conducting meta-analyses (Buchner et al., 2022). To build strong evidence bases, uniform measures for engagement, cognitive load, motivation, and academic performance are essential. Although the potential of combining AR with artificial intelligence (AI) to customize learning experiences and enhance educational results is significant, this area remains largely unexamined (Acikgul & Sad, 2026).

In conclusion, there is a scarcity of research focused on accessibility and inclusive design in AR, which poses challenges for fair access among students with disabilities and those from disadvantaged backgrounds (Alzahrani, 2020; Delgado-Rodríguez et al., 2023). Bridging these gaps is essential to fully harness AR's capabilities as an inclusive educational resource.

1.8 Future Directions

Future investigations into the use of AR in education should tactically focus on bridging current gaps by pursuing several crucial paths that improve accessibility, customization, collaboration, and sustainability. A particularly promising direction involves creating AI-driven adaptive AR learning settings. By combining artificial intelligence with AR, it is possible to offer personalized learning experiences that automatically modify content difficulty, speed, and feedback according to each learner's profile, thus enhancing engagement and results (Egunjobi & Adeyeye, 2024; Lampropoulos, 2023; Tursunova et al., 2024). This integration could address the limitations of a one-size-fits-all approach and cater to the varied needs of learners across different fields.

Another important future direction is enhancing accessibility through WebAR technologies. By providing AR experiences directly through standard web browsers, WebAR removes the necessity for specialized hardware or app installations, thus greatly reducing entry barriers for both students and educators, particularly in environments with limited resources (Qiao et al., 2019; Zaifri et al., 2023). This method supports the demand for affordable and scalable AR solutions, promoting wider adoption in developing nations and institutions with fewer resources (Singh & Rani, 2025).

The progress in spatial computing and the development of wearable AR technology, including devices like Microsoft HoloLens and new lightweight AR glasses, offers the potential for more engaging and hands-free educational experiences. These technologies facilitate intuitive engagement with three-dimensional holograms in real-world settings, thereby enriching experiential and context-based learning (Flavián et al., 2019; Wright & Steele, 2024). Future research should focus on enhancing ergonomics, improving usability, and aligning with educational objectives to fully realize their potential in learning environments.

Another crucial domain is the development of collaborative multi-user AR learning environments. These platforms enable real-time interaction between students and teachers in shared AR settings, promoting social constructivism, peer learning, and teamwork skills that are crucial for education in the 21st century (Pratiti et al., 2019). Future research should aim at creating scalable systems that accommodate various group sizes and facilitate interdisciplinary collaboration. By combining learning analytics with AR, educators can gain immediate insights into student behavior, engagement, and performance, allowing for data-informed instructional modifications and tailored support (Sakr & Abdullah, 2024). Achieving this integration necessitates the creation of standardized metrics and tools specifically designed for AR environments.

Developing AR content that is specific to each discipline is essential to meet distinct educational requirements, such as the focus on spatial reasoning and tactile creativity in fashion education (Borisova et al., 2021; Videnov et al., 2018). Custom AR resources can improve both relevance and effectiveness, especially in fields that are less represented. In addition, future

studies should concentrate on strategies for implementing AR that are both sustainable and cost-effective. This involves using affordable hardware, open-source software, and modular content design to ensure fair access and long-term integration, especially in developing areas(Alzahrani, 2020; Singh & Rani, 2025). By addressing these areas, AR can be significantly advanced as an inclusive, adaptable, and influential educational technology.

1.9 Conclusion

This review underscores the transformative impact that AR can have on education, highlighting its ability to improve spatial visualization, foster active learning, boost motivation, and encourage collaboration across various fields. The progression of AR from its initial concepts to advanced, wearable devices has broadened its use in education, especially in areas that demand intricate spatial and practical abilities, such as medical, engineering, architecture, and design education. By incorporating AR into these fields, traditional teaching limitations are addressed through immersive, interactive, and context-rich learning experiences that resonate with constructivist and experiential learning theories. However, despite its potential, the adoption of AR encounters significant obstacles, including technical limitations, high costs, the need for faculty training, infrastructural challenges, complexities in content development, accessibility issues, and ethical considerations. These challenges are particularly pronounced in developing regions and less-explored areas like fashion education, where empirical research is limited. The review emphasizes the importance of focused research to bridge these gaps, including long-term studies on sustained learning outcomes, the development of standardized evaluation metrics, and the investigation of AR's integration with AI for personalized learning.

Future directions point to the advancement of AI-powered adaptive AR environments, expanding WebAR for greater reach, developing wearable spatial computing gadgets, creating multi-user collaborative AR systems, and incorporating learning analytics. Developing content tailored to specific disciplines and devising sustainable, cost-efficient implementation plans are essential to fully leverage AR's educational potential and ensure inclusivity. In summary, this review brings together existing insights on AR's uses, advantages, and obstacles, providing a detailed framework for educators, developers, and policymakers. It emphasizes the need for strategic AR integration to create engaging, effective, and fair learning environments that equip students for the challenges of the 21st century.

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