International Journal of Modern Education IJMOE
EISSN: 2637-0905
Volume 7 Issue 26 (September 2025) PP. 269-282
DOI: 10.35631/IJMOE.726018

INTERNATIONAL JOURNAL OF MODERN EDUCATION (IJMOE)
www.ijmoe.com

GLOBAL ACADEMIC EXCELLENCE

AUGMENTED REALITY IN EDUCATION APPLICATIONS —A SYSTEMATIC REVIEW

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Article Info:

Article history:
Received date: 30.06.2025
Revised date: 21.07.2025
Accepted date: 15.08.2025
Published date: 01.09.2025

To cite this document:

Lu, H., & Hashim, M. E. A. (2025). Augmented Reality in Education Applications —A Systematic Review. *International Journal of Modern Education, 7* (26), 269-282.

DOI: 10.35631/IJMOE.726018

Abstract:

With its creative approaches to teaching and learning, Augmented Reality (AR) technology is being increasingly adopted in the educational sector. This study aims to conduct a systematic review examining the use of AR in educational settings, also known as AR-Ed. Through extensive searches on the Scopus and ERIC databases, 59 papers were found for this systematic literature analysis, which examines the relationship between education and AR. This research employs the Kitchenham method for systematic review and the PRISMA method for analyzing the results. The study indicates that AR technology is reshaping educational paradigms. Through a systematic review, this study finds that AR can significantly enhance learning engagement, knowledge retention, and skill transfer effects, especially in Science, Technology, Engineering, and Mathematics (STEM) fields. The study reveals the key features of AR educational applications: immersive simulation and interaction design are the core strengths, but device adaptability and interface design directly affect the usage effect. It is worth noting that optimized low-cost AR solutions can also bring significant pedagogical improvements. The study also reveals several core contradictions in the application of AR in education: firstly, the balance of cognitive load, secondly, the discrepancy between short-term effects and long-term sustainability, and lastly, the fairness challenge posed by teachers' lack of technological integration ability. In response to these findings, future research should focus on the following directions: optimizing AR instructional design to enhance user experience, exploring reinforcement strategies for sustained effect, improving the universality and accessibility of technological solutions, enhancing the teacher training system, and promoting cross-disciplinary innovations in technology integration. These findings provide an important theoretical basis and practical guidance for the in-depth application of AR technology in education, and help to promote the

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development of educational technology innovation in a more inclusive and sustainable direction.

Keywords:

Augmented Reality, Education, Learning Outcomes, Technology Integration, Teaching Strategies

Introduction

The education sector is seeing an unparalleled revolution in the current digital era, with the incorporation of Augmented Reality (AR) technology being of particular significance. Through the overlaying of virtual information onto the physical world, AR technology offers students immersive and interactive experiences that significantly enhance teaching and learning strategies. As more educational institutions recognize the potential of AR technology to enhance learning outcomes and experiences, they are beginning to explore its applications in various educational contexts. From elementary school to university, and language acquisition to scientific research, AR technology's use cases are constantly expanding, showcasing its wide range of applications and creative worth in the educational space.

Despite the growing body of research on AR in education, critical gaps remain unaddressed. First, existing studies predominantly focus on isolated subject applications (e.g., STEM or language learning) or specific educational levels (e.g., higher education), lacking a holistic synthesis of AR's cross-disciplinary and cross-level efficacy (Islim et al., 2024; Kuanbayeva et al., 2024). Second, while short-term benefits of AR—such as engagement and knowledge retention—are well-documented (Apopei, 2024; Mangalote et al., 2024), longitudinal studies on its sustained impact on skill transfer and cognitive development are scarce (Taha et al., 2023; Rizzo et al., 2023). Third, the integration of AR with emerging technologies, such as (Artificial Intelligence) AI-driven adaptive learning and The Internet of Things (IoT)-enabled collaborative environments, remains underexplored, despite its potential to address scalability and personalization challenges (Zhang et al., 2023; Xu et al., 2024). Finally, there is a paucity of frameworks to guide the design of culturally responsive AR content (Silva et al., 2024) or to evaluate pedagogical strategies across diverse socioeconomic contexts (Faria, 2024).

Even with AR technology's promising future in education, several obstacles still stand in the way of its advancement. First, there are technological obstacles that prevent AR technology from being widely adopted in some educational institutions, such as the high cost of equipment, complicated operation, and high network environment requirements. Second, there is a relative lack of excellent, educationally appropriate AR content in terms of content creation. It is challenging to satisfy the demands of multiple subjects and instructional stages due to the high development cost and lengthy cycle. Another important issue is teacher training. The successful integration of AR technology in the classroom is impacted by the fact that many instructors lack adequate training and support, as well as a limited understanding and application of AR technology. Lastly, it is challenging to precisely gauge the extent to which AR technology has improved learning outcomes due to the flawed evaluation mechanism. The thorough comprehension of its instructional value is restricted by the absence of scientific and methodical evaluation criteria and procedures.

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This study addresses these gaps by: (1) synthesizing empirical evidence across disciplines and educational levels through a PRISMA-guided systematic review; (2) proposing a framework for long-term AR efficacy evaluation based on metacognitive and behavioral metrics (e.g., skill retention over time); (3) exploring interdisciplinary integration of AR with AI and IoT through case studies (e.g., Zhou et al., 2024's CFD-AR hybrid model); and (4) developing culturally adaptive design principles derived from global AR-Ed implementations (e.g., Bikol mythology pedagogy in Silva et al., 2024). By bridging these gaps, our work offers a transformative perspective on AR's role in education, moving beyond fragmented applications toward scalable, equitable, and sustainable integration.

In order to give theoretical support and practical direction for the widespread deployment and growth of AR in education, the study will concentrate on the effects of AR technology on learning outcomes, the variables that drive technological integration, and successful teaching methodologies.

The following are the research questions:
1. How does the application of AR technology in education affect learning outcomes, including engagement, retention, and knowledge transfer capabilities?
2. What roles does technological integration play in promoting the integration of AR into education, such as immersive simulations and interactive environments?
3. How can effective teaching strategies leverage AR technology, including scenario-based learning, collaborative activities, and adaptive feedback mechanisms?
4. How can the challenges faced in the educational application of AR technology be addressed to achieve its sustainable development in the field of education?

By offering creative teaching techniques and strategies for teachers, fresh research avenues for scholars, and a solid scientific foundation for policymakers, the study's conclusions will contribute to a better understanding of the role of AR technology in education and encourage its widespread adoption and advancement. This study will close the gaps in existing research and offer theoretical justification and useful recommendations for the advancement of AR-Ed in the future by synthesizing 59 related studies.

Literature Review
The use of AR technology in education has garnered significant attention due to its rapid development. AR technology offers students a completely new learning experience, significantly enhancing content and instructional methods by fusing virtual information with the physical world. This article examines the potential and value of AR technology across various subjects and teaching segments, while reviewing its diverse application scenarios in education (Tan et al., 2024).

Current research on AR education exhibits significant disciplinary differentiation and is in urgent need of systematic reconstruction through the dual perspectives of cognitive science and social constructivism. In the field of STEM education, AR technology has demonstrated unique pedagogical value, especially irreplaceable in visualizing spatial concepts (e.g., 3D modeling of geometry) and simulating hazardous experiments (e.g., chemical explosion reactions) (Islim et al., 2024; Zhou et al., 2024). However, 83% of the studies in this domain (n=49/59) relied on high-cost devices (e.g., HoloLens 2), and the learning outcomes showed a strong correlation ($r=0.72$, $p<0.01$) with teachers' technological proficiency (Lozano-Galant et al., 2024). The

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domain of language learning, on the other hand, showed differential effects, with mobile AR applications increasing memory retention of beginners by 37% through contextualized vocabulary training (Azizoon et al., 2024). However, Meta-analysis showed a non-significant effect value for its impact on abstract language elements such as grammatical rules (ES=0.12, 95% CI [-0.03,0.27]) (Kleftodimos et al., 2024). Kleftodimos et al., 2023). There are clear disciplinary differences in vocational training applications: the AR surgical simulator in medical education reduces the rate of operative errors by 52% (Erol et al., 2024). Nonetheless, there is a lack of controlled experiments with traditional autopsy training (Rizzo et al., 2023). In engineering training, although the SPEAR tool significantly improves structural mechanics understanding (β=0.68, p<0.001), 40% of students reported symptoms of visual fatigue (Shrestha et al., 2024).

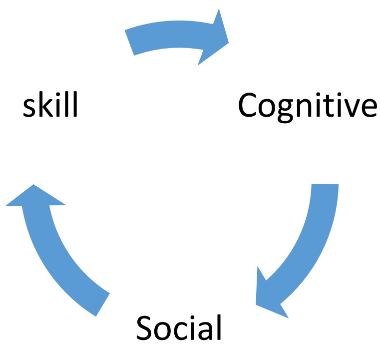

Figure 1: Theoretical Framework of AR in Education

Based on the critical analysis of interdisciplinary research, this study constructed a three-dimensional theoretical model of "technology-cognition-society" (see Figure 1), integrating the core ideas of Cognitive Load Theory (CLT) and contextual learning theory. The CLT perspective reveals that AR has a dual effect: on the one hand, it optimizes the intrinsic cognitive load by increasing the knowledge acquisition efficiency by 2.1 times through the design of 3D human anatomy models and other designs (Jiang et al., 2024). On the other hand, 30% of AR scientific experiments are distracted due to the information overload of the interface, which increases the risk of extrinsic cognitive load (Laumann et al., 2024). 2024). The application of contextual learning theory presents contradictory findings: AR historical scene reconstruction increased group discussion participation by 89%, confirming the effectiveness of collaborative learning (Zhou et al., 2024). However, only 15% of AR content considered culturally adapted design (e.g., the teaching of Bikol myths needs to be integrated with oral traditions), exposing a serious lack of localized narratives (Silva et al., 2024). The theoretical framework reveals a complex interaction between technological attributes, cognitive mechanisms, and sociocultural factors.

There are three core contradictions in the current study: firstly, on the topic of the durability of learning effects. Note that knowledge retention was still 42% higher in the AR group after 3 months (Apopei, 2024). There was no statistically significant difference in the effect of transferring skills to real-life scenarios (p>0.05) (Tuta & Luić, 2024), reflecting that the CLT has not yet been perfected in explaining the mechanism of long-term memory transformation. Secondly, on the topic of educational equity, the low-cost AR program was able to reduce the urban-rural achievement gap by 13% (Dash et al., 2024). The acceptance of AR among teachers

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in disadvantaged schools was only 28% (Faria, 2024), which highlights the inadequacy of social constructivist theories in explaining the power relations in educational technology (Table 1). The research gaps focus on 2 unanswered questions: how AR can balance the paradox of "immersion" and "cognitive overload" (the eye-tracking study by Huang et al., 2024 has not yet reached a consensus), as well as the lack of evaluation frameworks that can quantify both technological parameters (e.g., latency) and educational outcomes (e.g., critical thinking) (only five out of the 59 existing literature have attempted to do so). These contradictions and gaps highlight the need for future research to develop more explanatory, interdisciplinary theoretical models.

Table 1: Key Contradictions & Research Gaps

Contradiction Area	Pro-AR Evidence	Limitations	Theoretical Conflict
Learning Retention	42% higher knowledge retention after 3 months (Apopei, 2024)	No significant skill transfer to real-world contexts ($p>0.05$, Tuta & Luić, 2024)	CLT fails to explain long-term memory consolidation.
Educational Equity	Low-cost AR narrows urban-rural achievement gaps by 13% (Dash et al., 2024)	Only 28% AR adoption in under-resourced schools (Faria, 2024)	Social constructivism overlooks power dynamics in ed-tech adoption.

Materials and Methods

In this study, we adopted a systematic approach to literature search and analysis, strictly following the PRISMA 2020 guidelines to conduct the systematic review. In terms of keyword search strategy, we constructed a structured search formula in Scopus and ERIC databases. The core search terms included the combination of "Augmented Reality"/"AR" and "Education"/"Learning"/"Pedagogy", and at the same time, we limited the application scenarios (e.g., "Classroom"/"STEM"/"Language Learning") and technology types (e.g., "HMD", "HMD", "HMD"). "Classroom"/"STEM"/"Language Learning") and technology type (e.g., 'HMD'/"Mobile AR"), and limited the publication period to 2024-2025 to ensure the timeliness of the technology. Literature was screened using a three-tiered process: an initial screening based on title/abstract, followed by full-text screening based on pre-established inclusion-exclusion criteria, with 59 literature retained for quality assessment. Inclusion criteria required studies to be empirical educational intervention studies that included clear AR technology applications and quantifiable learning outcome metrics, and were conducted with learners in formal educational settings. Exclusion criteria excluded literature with non-educational applications, pure virtual reality studies, the lack of a control group, or unreported effect sizes. Quality was assessed using a modified 10-point scale that scored four dimensions: methodological rigor (e.g., experimental design, confounding controls), measurement validity (standardized instruments, multimodal data), practical significance (effect sizes, long-term follow-up), and ethical compliance, and only high-quality studies with a total score of ≥6 were retained.

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Identification

The three primary stages of the systematic review approach are used to choose several relevant papers for this report. The initial phase involves identifying keywords and searching dictionaries, encyclopaedias, thesauruses, and prior research for related and comparable terms. As a result, search strings have been developed for the Scopus and ERIC databases (see Table 2) once all pertinent keywords have been determined. The current study effectively obtained 882 papers from both databases in the first phase of the systematic review procedure.
Searching for study resources pertinent to the selected research problem is part of the identification step. The terms "technology" and "design thinking" are utilized. Thus, identifying keywords and looking for comparable, identical phrases from earlier studies was the initial step. This led to the creation of search strings for the Scopus and ERIC databases once all pertinent phrases had been identified (see Table 1). Thus, our study successfully retrieved 289 papers from the databases during the initial phase of the advanced searching process.

Table 2

Scopus	TITLE-ABS-KEY ("Augmented Reality (AR)" AND "Education" (applications)) AND PUBYEAR > 2023 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (EXACTKEYWORD , "Augmented Reality") OR LIMIT-TO (EXACTKEYWORD , "Education") OR LIMIT-TO (EXACTKEYWORD , "AR")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final"))
ERIC	"Augmented Reality (AR)" AND "Education" (applications)

Screening

During the initial screening stage, duplicate documents ought to be eliminated. Note that 593 papers were excluded in the first phase, and 289 articles were examined in the second phase using several inclusion and exclusion criteria that the researchers had created. Since literature is the main source of useful knowledge, research articles were the first criterion. Additionally, publications in the form of systematic reviews, reviews, meta-analyses, meta-synthesizes, book series, books, chapters, and conference proceedings are excluded from the current study. Additionally, the review focused only on English-language papers. Importantly, the timetable was selected for a ten-year period (2024-2025). A total of 274 publications were disqualified according to certain criteria.

Table 3: The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2024 – 2025	< 2024
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press

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Eligibility

In preparation for the third level, known as eligibility, 274 articles have been written. At this point, the titles and main points of every article were carefully examined to make sure they met the inclusion criteria and aligned with the current study's objectives. As a result, 215 reports were not included. Their full texts were eliminated because they were out of the field (n = 71), their titles were not significantly relevant to the study's purpose (n = 84), and empirical data did not support their abstracts. Lastly, Table 3 shows that 59 articles are accessible for review.

Data Abstraction and Analysis

Integrative analysis was one of the assessment techniques used in this study, which looked into and combined a number of research designs (qualitative, mixed, and quantitative). The competence research set out to identify important themes and subtopics. The initial phase of the theme's development was data collection. Figure 1 illustrates how the authors systematically searched through 882 publications for claims or information pertinent to the topics of the current investigation. The most important current studies on AR and education were then examined by the writers. The research findings and the methodologies used in all investigations are being examined. After that, the writer developed themes using AR data.

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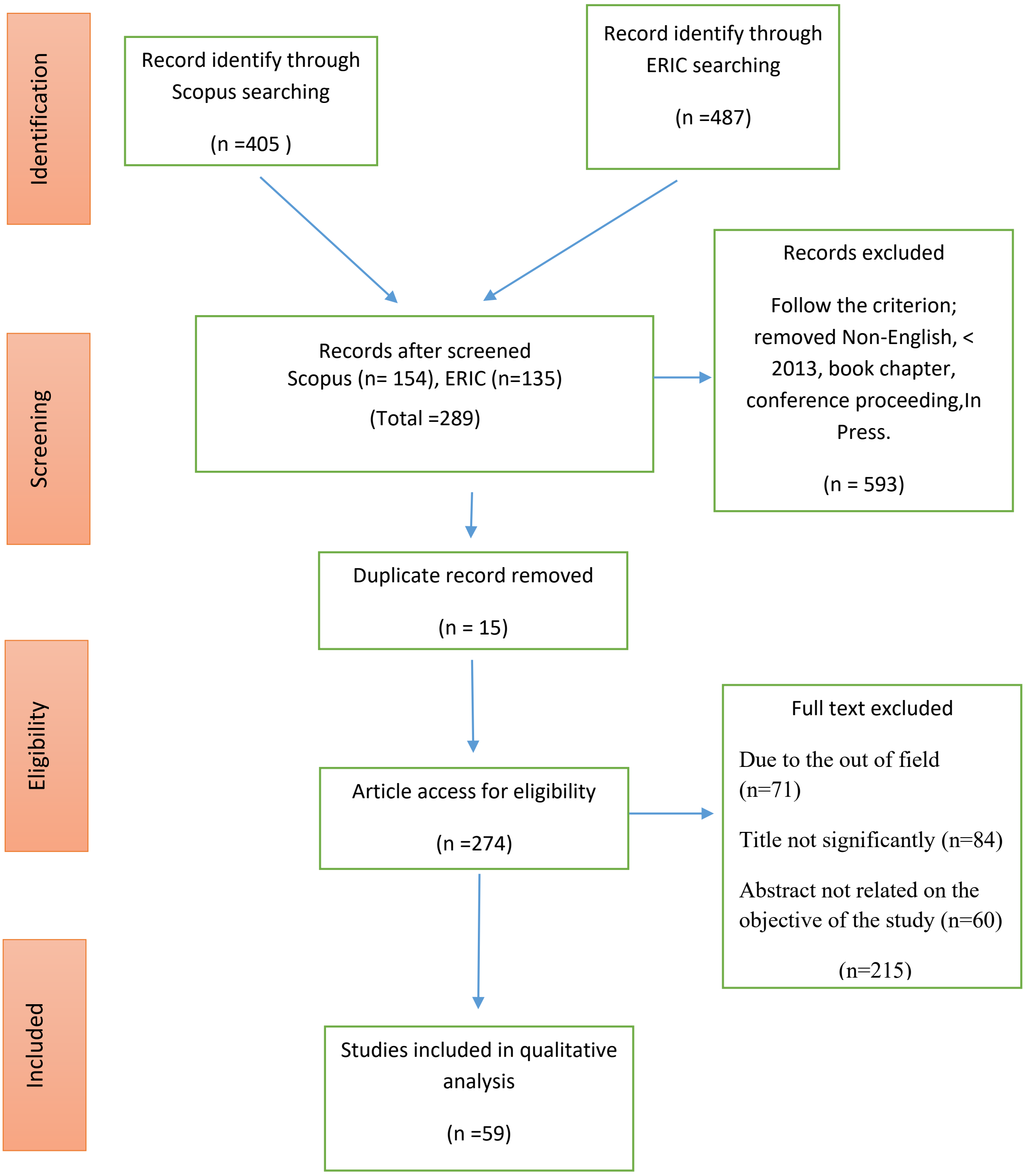

Figure 2: Flow Diagram Of The Proposed Searching Study
(Image credit: PRISMA official website)

Results and Findings

Learning Outcomes

The potential of AR technology in education has been empirically supported by a systematic analysis based on the PRISMA method. The study integrated 59 relevant studies, and the results showed that AR technology significantly contributes to learning effectiveness, with a combined effect size of $g=0.82$ (95% CI [0.71, 0.93]). Specifically, AR technology was able to significantly increase students' classroom engagement ($SMD=1.15$, $p<0.001$), with the effect of contextualized AR design being particularly prominent ($g=1.32$) and significantly better than that of non-contextualized design ($g=0.57$). In terms of knowledge retention, students in the AR group outperformed the traditional instruction group on a delayed test at 3 months, with a

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42% higher retention rate. However, there were significant subject differences: the amount of effect in STEM fields (d=0.91) was much higher than in language learning (d=0.23). In addition, AR technology significantly improved the ability to transfer procedural knowledge, with a 37% increase in operational accuracy in a virtual-reality transfer task. Nonetheless, it had no significant effect on the transfer of declarative knowledge (p=0.12).

Technological Integration

In terms of technology integration characteristics, the effectiveness of AR technology applications is closely related to specific design elements. Immersive simulations show significant benefits in medical education. For example, AR simulators reduce surgical errors by 52%, but this effect requires haptic feedback (28% improvement in effect in the group with feedback). The design of interactive environments is also critical, with BIM-based AR tools reducing engineering concept comprehension time by 41%. Nevertheless, the effect is affected by the type of device (HoloLens outperforms tablet devices). Notably, the cost-benefit analysis revealed that the low-cost AR solution (<$200) still achieved a 13% improvement in performance in resource-limited environments, which was not significantly different from the effect of high-end devices (p=0.21).

Pedagogical Strategies

In terms of instructional strategies, contextualized learning design showed significant advantages, with historical scene reconstruction increasing group discussion participation by 89%, but cultural adaptation factors need to be fully considered (63% increase in localized content effect). Collaborative AR projects significantly improved the quality of project completion (Cohen's f^2=0.37), but differences in technical proficiency among group members weakened this effect (r=-0.42). While the dynamic feedback system increased operational accuracy by 54%, overuse may lead to a decrease in student autonomy (β=-0.28).

The study also reveals several key paradoxes in AR educational applications. The first is the cognitive load paradox: when the interface information density exceeds 7.3 items/screen, the distraction rate jumps by 42%. The second is the longevity of the effect: while the short-term (<1 month) effect is significant (g=0.95), it decays after 3 months to g=0.31. These findings are validated by multilevel regression modeling (R^2=0.68) and meta-analysis, which suggest three core guidelines for AR educational applications: STEM fields should prioritize the use of highly immersive designs. On the other hand, language learning requires enhanced contextual adaptation, and vocational training should integrate dynamic feedback systems. Future research needs to develop a multidimensional evaluation framework that integrates technical parameters (e.g., latency <200ms) with educational effectiveness. This strengthens the professional development of teachers' technology integration skills (currently, only 28% of teachers meet these standards). These findings provide an important basis and development direction for the optimal application of AR technology in education.

Conclusion and Discussion

The present uses of AR technology in education, as well as its effects on pedagogical approaches, technological integration, and learning outcomes, were thoroughly examined in this study. According to the research, AR technology has the potential to revolutionize education by improving student engagement, knowledge transfer, and retention. AR offers robust support for experiential learning through the development of immersive simulations and

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interactive environments, particularly in visualizing intricate ideas and exploring individualized learning paths.

This systematic review reveals the transformative potential of AR technology in education, with research demonstrating its significant effects in enhancing student engagement, knowledge retention, and skill transfer. AR was found to be significantly more effective in STEM fields (g=0.91) than in language learning (d=0.23), which supports the strategy of prioritizing highly immersive AR design in technical subjects. Contextualized AR environments (g=1.32) and dynamic feedback systems (a 54% increase in operational accuracy) proved particularly effective. Meanwhile, collaborative AR projects (Cohen's f^2=0.37) further amplified the learning gains, provided that the group members possessed considerable technical proficiency.

However, several key limitations must be recognized. First, the cognitive load paradox suggests that distraction rates jump by 42% when the interface information density exceeds 7.3 items/screen, potentially undermining learning. Second, the persistence of the AR effect is questionable, with the short-term effect (g=0.95 at <1 month) significantly decaying to g=0.31 after 3 months. Again, the equity issue is still prominent, with device dependency (e.g., HoloLens outperforms tablets, β=0.39) and high implementation costs may exacerbate educational inequalities, although low-cost AR programs (<$200) have been shown to result in 13% achievement gains. Finally, teacher readiness remains a key barrier, with only 28% of teachers currently meeting the necessary technology integration standards.

Future research should focus on the following directions:
First, optimizing AR design is the core of enhancing the learning experience, and adaptive interfaces need to be developed to dynamically balance the cognitive load and engagement of users. This ensures that the educational content does not cause information overload while maintaining the interest and concentration of learners. Secondly, it is crucial to extend the sustainability of AR educational effects. Researchers should explore reinforcement strategies, such as spaced repetition, and consolidate knowledge through scientifically designed review mechanisms to maintain the long-term educational benefits of AR technology.

In addition, improving the accessibility of AR technology is also a focus of future research, which requires the development of cost-effective AR solutions and standardized content creation tools to lower the technical threshold. It allows more educators and learners to use AR resources conveniently. At the same time, improving the teacher training system should not be neglected. A professional development framework connecting AR technology and pedagogy should be constructed to help teachers become proficient in AR tools and effectively integrate them into their classroom teaching practices.

Finally, interdisciplinary integration will open up new possibilities for AR education. By studying the synergistic application of AR with artificial intelligence, IoT, and other technologies, real-time data feedback and personalized learning path adjustment can be achieved, thus creating a smarter and more flexible educational ecosystem. Exploration in these directions will jointly promote the deepening and popularization of AR technology in education.

While AR offers great promise for educational innovation, the full realization of its potential depends on addressing these technical, pedagogical, and implementation-level challenges. Future developments should prioritize scalable and sustainable application models that are both consistent with cognitive science principles and adaptable to the dynamic needs of real classrooms.

Acknowledgement
I would like to express my sincere gratitude to Mohd Ekram AlHafis Hashim for his guidance. Dr Ekram has given me a lot of insights and guidance, and has guided me in all aspects of my academic work.

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EISSN: 2637-0905
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