



MALAYSIAN JOURNAL OF LEARNING AND INSTRUCTION

<https://e-journal.uum.edu.my/index.php/mjli>

How to cite this article:

W. M. F. F. Anuar., N. A. M. Mokmin., S. F. Mohamad Asri., Y. I. Abu Bakar & A. H. Alias. (2026). Augmented reality in education: A systematic review of applications and impacts on student performance. *Malaysian Journal of Learning and Instruction*, 23(1), 139-161. <https://doi.org/10.32890/mjli2026.23.1.7>

AUGMENTED REALITY IN EDUCATION: A SYSTEMATIC REVIEW OF APPLICATIONS AND IMPACTS ON STUDENT PERFORMANCE

¹Wan Muhamad Farid Firdaus Wan Anuar, ²Nur Azlina Mohamed Mokmin,

³Siti Fadziyah Mohamad Asri, ⁴Yasrul Izad Abu Bakar & ⁵Ahmad Hafiz Alias

^{1&2}Centre for Instructional Technology and Multimedia, Universiti Sains Malaysia, Malaysia

^{1,3,4&5}Faculty of Medicine, Universiti Sultan Zainal Abidin, Malaysia

²Corresponding author: nurazlina@usm.my

Received: 27/11/2024

Revised: 21/12/2025

Accepted: 30/1/2026

Published: 31/1/2026

ABSTRACT

Purpose – This study conducts a Systematic Literature Review (SLR) to examine how Augmented Reality (AR) contributes to student performance, with particular attention to engagement, cognitive skills, and academic achievement across different educational contexts. While interest in AR has increased, the evidence remains fragmented, and its impacts on learning outcomes require clearer synthesis.

Methodology – To achieve this, we performed a comprehensive search of scholarly articles using reputable databases like Web of Science (WoS) as well as Scopus, concentrating on studies published between 2020 and 2024. The study followed the PRISMA framework. A total of 30 articles were examined, and the final primary data was assessed.

Findings – The review indicates that AR consistently enhances student engagement and motivation, strengthens cognitive development and problem-solving skills, and provides interactive support for special and inclusive education. However, the impact of AR on academic achievement is mixed, with some studies showing measurable gains while others report only indirect benefits.

Significance – The findings suggest that AR can enrich learning when integrated purposefully into teaching strategies, particularly in STEM and healthcare education. Nonetheless, long-term impacts remain

underexplored, underscoring the need for longitudinal studies and teacher training to maximize its effectiveness.

Originality/Value – This review contributes by mapping AR applications across primary, secondary, and higher education, synthesizing evidence of their effects on student performance, and clarifying conditions under which AR can be most effective for meaningful learning outcomes.

Keywords: Augmented reality, instructional techniques, student engagement, cognitive skills, systematic literature review.

INTRODUCTION

Augmented Reality (AR) has quickly become a ground-breaking tool in education, providing a new, as well as interactive way to learn. By superimposing digital content on real-world environments, AR enhances students' ability to engage with and understand complex concepts, particularly in subjects requiring spatial and visual cognition, such as anatomy, engineering, and architecture. The inclusion of self-organized learning into the syllabus illustrates an increasing need for ground-breaking pedagogical approach which engages with learner's developing needs in a digital age. The growing emphasis on active learning that involves immersion customization of curriculum indicates the importance of AR in tailoring deep engagement and understanding amongst students. In this context, the influence of AR on teaching methods and student achievement represents a space-worthy topic as educators strive to maximize students' learning through high-tech applications. While the prevailing studies indicate a positive impact of AR on student learning in different educational areas, there is still much to be researched. For instance, studies have demonstrated that AR applications may increase student motivation and engagement, as well as improve knowledge retention (AlGerafi et al., 2023; Alzahrani, 2020; Lin & Yu, 2023; Wong et al., 2022). For instance, AR applications in anatomy have already shown positive results in improving spatial skills and concept understanding. This is because the AR applications have made available interactive 3D models which allow for better learning, overcoming the limitations of using traditional educational resources such as the need to reference many textbooks (Ozcakir & Cakiroglu, 2021; Papakostas et al., 2021; Wong et al., 2021). In addition to this, previous research studies have underscored the capability of AR to facilitate problem-solving and critical thinking along with cooperation learning. As a result, students can not only work on digital content in real-time, but they can also enhance their skills in transmuting concepts into reality (Barsom et al., 2016; Daoud et al., 2023; Elsayed & Al-Najrani, 2021; Jdaitawi et al., 2022; Kovoov et al., 2021).

Despite these advances, existing reviews of AR in education often remain fragmented. Many focus narrowly on single domains, such as healthcare, STEM, or language learning, without examining cross-context differences. Others emphasize short-term engagement outcomes while neglecting long-term academic achievement, or they overlook inclusive education altogether. These gaps highlight the need for a systematic synthesis that not only identifies common benefits of AR but also clarifies how its impact varies across educational contexts. Some studies prefer an opportunity for self-directed, unbounded exploration with AR technologies, whereas other works imply that a more structured and directed learning experience produces better outcomes (Wallgrün et al., 2018). In addition, the long-term effects of AR on student performance, beyond immediate engagement and understanding, are still relatively unknown.

Accessibility and affordability of AR technologies are also subject to controversies, especially in low-resource educational contexts (Iskander et al., 2021; Sun et al., 2023). Given these unresolved issues, examining AR across different learning domains, namely specialized education, general education, and inclusive and special education, provides a meaningful framework to evaluate both its impacts and its challenges. Specialized domains often emphasize psychomotor skills, general education focuses on engagement and critical thinking, while inclusive education prioritizes accessibility and adaptability. Differentiating these contexts allows for a more nuanced understanding of AR's contributions.

In the present review, student performance is understood as a multidimensional construct that encompasses learner engagement as follows: motivation, participation, and interaction; cognitive outcomes, such as understanding, problem-solving, and skill development; and academic achievement, for example, as revealed in test scores or formal assessments. While many studies have reported the positive effects of augmented reality on engagement and cognitive processes, these improvements do not necessarily translate directly into measurable academic achievement. Academic outcomes are often influenced by additional factors, such as instructional design, assessment methods, and contextual conditions within learning environments.

Accordingly, the present study was designed to fill these gaps by systematically reviewing how AR would influence student performance across multiple educational contexts. The review sought to synthesize impacts on engagement, cognitive development, and academic achievement, while also examining differences across specialized, general, and inclusive domains. By doing so, it was aimed at providing a clearer understanding of the conditions under which AR had been most effective, and most importantly to inform evidence-based pedagogical practices.

LITERATURE REVIEW

AR opens up immersive learning experiences that mix virtual information with the real world if it can be transformed into an innovative solution for education. Academic performance is reportedly enhanced in terms of student engagement, motivation, and comprehension, which are closely linked to performance outcomes. In general education contexts, AR-based learning enables students to participate actively rather than passively when consuming content, thereby supporting deeper understanding. Research done by Volioti et al. (2023), Cao et al. (2023), and Mokmin et al. (2024) have provided evidence how AR-based learning allows students to participate actively rather than passively when watching slides and interacting with 3D models or digital content. The embedding of AR into the pedagogical practices of the education system has enabled students to attain a better comprehension of complicated topics such as mathematics, science, and engineering. This is because by breaking subjects down into more accessible packages, makes it less tedious and thus, easier for certain students to grasp the subject matter at hand. AR through gamification and real-world application will also enhance the students' motivation. While AR has a long way to go before it is widely adopted in education, one key advantage of using this digital technology is that it can lead students to become more motivated and ultimately produce better creative output, particularly as it relates to writing or language learning. For example, research studies by Li et al. (2023) and Guan et al. (2024), have suggested that AR encourages creative thinking and writing skills. AR has been able to simulate authentic learning environments and promote student engagement, thus, improving

student performance in writing. These findings are consistent with those of Jalaluddin et al. (2024), who examined AR in a flipped classroom model. The study found a significant increase in vocabulary acquisition and overall writing proficiency among rural students. Collectively, these studies highlight AR's potential to foster active learning and bridge educational disparities in general education settings.

In specialized domains such as vocational training and healthcare education, AR has been employed to develop psychomotor and professional skills. Weng et al. (2024) established that students in an AR-integrated gamification approach accomplished better outcomes in psychomotor tasks, while Qin and Bulbul (2023), on the other hand, used AR-based Head-Mounted Displays to assist performance on complex assembly construction. However, the two studies raised the issue of cognitive overload and mental fatigue when AR is used in high-cognitive-demand tasks. The research by Mokmin et al. (2024) supports these findings by suggesting that AR decreases extraneous cognitive load, yet may result in an increased general cognitive demand, which might provoke information overflow among some learners.

AR has also been implemented in healthcare education research, especially for midwifery and nursing education. Gray et al. (2023), as well as Rodríguez-Abad et al. (2023), also emphasized that the ability of AR to help students appreciate physiology-related processes, such as labor and leg ulcer care through interaction with complex medical scenarios. In both the above studies, AR offered specific advantages to students with few clinical exposures by providing a controlled and safe environment in which they can improve their dexterity skills. However, Rodríguez-Abad et al. (2023) reported that though AR could enhance learning outcomes, the application of online AR was limited and should be fully integrated with face-to-face experience-based delivery to be effective. These findings emphasize AR's ability to enhance applied learning outcomes in specialized fields, while also underscoring the importance of addressing cognitive demands posed by the use of AR.

The role of AR in inclusive and equity-focused education has also been highlighted in recent studies. Lin et al. (2023) was a study concerned with these issues and carried out an analysis of how AR might help narrow urban-rural educational gaps. Their study showed that using a dual scaffolding method, AR can be adapted to boost cognitive skills and self-confidence for both urban and rural students. However, challenges like infrastructure and teacher training still need to be addressed for a successful implementation. In contrast, Nasir and Fakhruddin (2023) investigated the impact of AR-based mobile learning on physics education, indicating that using AR in class had led to a considerable increase in students' scores. Nevertheless, a continued focus on the scalability of these innovations in low-resource settings is warranted. Another critical element of AR's effect on education is its role in addressing learning disparities and supporting low-achieving students. Wen et al. (2023) found that AR-based inquiry learning environments increased problem-solving and process integration abilities in low-performing learners. A similar trend was reported by Giancaspro et al. (2024). In their study, a minimal effect size was observed for the overall model; however, compared with no intervention (minimal threshold), AR-assisted learning activities supported students' understanding of complex physics concepts. Together, these findings indicate that AR has strong potential as a tool for educational equity and inclusion.

Despite these promising outcomes in the use of AR in education, significant gaps remain in the literature. A specific weakness is the absence of longitudinal research into whether AR has any long-term effects on student performance. Although short-term gains in engagement and comprehension have been supported

by Mokmin et al. (2024) and Jalaluddin et al. (2024), further research is required in order to find out if AR pedagogy will result in improved academic performance long-term. A further area where gaps persist is in the development of strategies that reduce AR cognitive load, as brought up by Qin and Bulbul (2023) and Chen et al. (2024). Integrating AI-driven scaffolding, as recommended by Chen et al. (2024), also suggest employing AI-based scaffolding. It was suggested that this concern could be addressed by auto-adapting AR content to the cognitive status of each learner. Some possible future avenues of research include examining the combination of AR with other advanced technologies, like Virtual Reality (VR) and AI. The study by Guan et al. (2024) on empathetic VR-based learning indicates how fully immersive technologies can promote empathy and improve writing performance, suggesting that combining AR with VR could offer new avenues for enhancing student outcomes in areas like emotional intelligence and cross-cultural understanding. In addition, incorporating deep learning-based algorithms, as explored by Chen et al. (2024), could enable more adjustment and customization of learning experiences, ensuring that AR applications are adapted to individual learner needs.

In summary, current research demonstrates AR's potential to enhance engagement, cognitive skills, and academic achievement across general, specialized, and inclusive education. However, limitations including inconsistent achievement outcomes, excessive cognitive demands, and the lack of longitudinal studies, restrict our understanding of AR's long-term educational value. The present review sought to address these gaps by systematically synthesizing evidence across the three domains of education, and critically examine AR's impacts on student performance. In doing so, it was aimed at contributing to a more comprehensive and context-sensitive understanding of AR's role in advancing educational practices.

RESEARCH QUESTIONS

This review was aimed at analysing and synthesizing the empirical studies on the use of AR in educational approaches and its impact on student performance. The research questions of the review are as follows:

1. How does the integration of AR affect student engagement, motivation, and cognitive development across educational contexts?
2. What is the impact of AR on academic achievement, and how consistent are these outcomes across specialized, general, and inclusive education settings?
3. In what ways do the challenges and opportunities of AR differ between specialized, general, and special education, and what implications do these differences hold for effective pedagogical practice?

METHODOLOGY

This review adhered to the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)* framework to ensure transparency, replicability, and methodological rigor. The PRISMA flow diagram was applied to illustrate each phase of the review process, including identification, screening, eligibility, and inclusion. This approach ensured that the inclusion and exclusion of articles followed a structured and traceable procedure. Each decision point was documented systematically to maintain the integrity of the data selection process.

Identification

Important procedures from the systematic review approach were utilized in this research to gather a sizable number of relevant materials. After choosing keywords, similar terms were determined by scanning encyclopaedias, thesauri, dictionaries, and previous studies. The search strategy was designed collaboratively by the authors in consultation with two content experts specializing in educational technology and instructional design. These experts validated the accuracy and relevance of the selected keywords to ensure that the search captured a comprehensive range of studies cited in the literature. Once all relevant terms were identified, search queries using the Scopus and Web of Science (WoS) databases were carried out (refer to Table 1). WoS and Scopus are two of the most detailed, as well as prominent academic databases, and their inclusion in the present Systematic Literature Review (SLR) has significantly enhanced the credibility and depth of the research (Goertzen, 2019; Gusenbauer, 2022; Hu et al., 2020). Scopus, which is organized by Elsevier, is the largest abstract and citation database of peer-reviewed literature in a wide variety of fields; from technology to science, medicine to social studies, arts, and humanities. This provides routes to the most reputable and peer-reviewed journals, conference proceedings, and patents - all important for ensuring a review captures research from across these different outputs. In addition, because it covers research articles from around the world systematically, these reviews are more representative and up-to-date than any individual researcher could achieve by other methods (Abdekhoda et al., 2023; Chadegani et al., 2013; Singh et al., 2021). WoS is another mega database, it is operated by Clarivate Analytics and is well known for its stringent indexing standards. It is often preferred for its highly curated content, focusing on high-impact journals. The database provides powerful citation analysis tools that offers up-to-the-minute impact and iteration of important research papers in real-time. It also incorporates specialized indexes, such as the Social Sciences Citation Index (SSCI) and the Science Citation Index Expanded (SCIE), indexes that provide precise research studies of high relevance. Consequently, the use of both databases guarantees that all relevant studies are captured comprehensively and minimizes publication bias. Therefore, it can offer groundwork evidence for analysing research trends or gaps, which is necessary to conduct high-quality systematic reviews. As a result, the first phase of the systematic review identified 466 papers from both databases relating to this issue.

Table 1

The Search String

Scopus	TITLE-ABS-KEY (("learn* approach*" OR "learn* techniques" OR "instructional techniques" OR "teach* strategies") AND ("augmented reality") AND education) AND (LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2024)) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
Wos	("learn* approach*" OR "learn* techniques" OR "instructional techniques" OR "teach* strategies") AND ("augmented reality") AND education (Topic) and 2024 or 2023 or 2022 or 2021 or 2020 (Publication Years) and Article (Document Types) and English (Languages)

Screening

In the screening phase, potentially pertinent studies are assessed to confirm that they meet the predefined research question(s). This stage typically involves selecting research items focused on AR in educational approaches and student performance while removing duplicate entries. Initially, 324 publications were excluded, leaving 142 papers for further review based on specific inclusion, as well as exclusion criteria (refer to Table 2). The first criterion considered was literature, as it serves as the primary source of practical recommendations, such as chapters, books, book series, meta-syntheses, meta-analyses, reviews, as well as conference proceedings that were not covered in recent research. The review focused exclusively on English-language publications from 2020 to 2024. Ultimately, 30 papers were omitted due to duplication.

Table 2

Selection Criteria for Literature Search

Criterion	Inclusion	Exclusion
Language	Articles published in English	Articles published in non-English languages
Time line	Studies published between 2020 until 2024	Studies published before 2020
Literature type	Peer-reviewed journal articles	Review papers, books, and conference proceedings
Publication Stage	Fully published and finalized studies	Articles that are in press or under review

Eligibility

In the third stage, referred to as the eligibility phase, 112 articles were selected for the review. During this phase, the titles and the main content of each article were thoroughly evaluated to ensure that they satisfied the inclusion criteria and were aligned with the research goals. Consequently, 82 articles were excluded due to reasons, such as being outside the relevant field, having irrelevant titles, containing abstracts not aligned with the study's aims, or lacking access to full texts which had empirical evidence. Eventually, 30 articles were retained for further review.

Quality Appraisal

Three experts were chosen to review and validate the 30 articles. The present review utilized the Critical Appraisal Skills Program (CASP) checklist, which includes eight criteria (see Table 3). Experts with more than 10 years of experience in educational technology within academic institutions carried out the quality assessment. The checklist provided a framework for critically evaluating the quality of studies across a variety of evidence (Long et al., 2020). The quality of each article was evaluated based on the following three levels: excellent, good, and moderate. Note that assessments were made based on various criteria, including a clear articulation of research questions, suitability of methods and study design, an appropriate

recruitment strategy, data collection and analytical processes, clarity in presenting findings, as well as the overall significance of the research. All 30 articles were reviewed after the quality appraisal. The results are as summarized in Table 3.

Table 3

The Quality Appraisal

		Yes			No			Total agreement (%)	Comments
		Expert			Expert				
		1	2	3	1	2	3		
Section A: Are the findings valid?	1. Was there a clear statement of the research questions?	/	/	/				100	Excellent
	2. Is a quantitative, qualitative, as well as mixed-method research approach appropriate?	/	/	/				100	Excellent
	3. Was the research design suitable for addressing the research questions?	/	/	/				100	Excellent
	4. Was the recruitment strategy suitable for the research questions?	/	/	/				100	Excellent
	5. Was the data obtained to address the research issue?	/	/	/				100	Excellent
Section B: What are the findings?	6. Was the data analysis appropriately accurate?	/	/	/				100	Excellent
	7. Is there a clear statement of the outcomes?	/	/	/				100	Excellent
Section C: How significant is the research?	8. How significant is the research?	/	/	/				100	Excellent

Data Abstraction and Analysis

This review has adopted a qualitative, integrative systematic review approach rather than a meta-analytic design. Accordingly, findings were synthesized narratively to integrate evidence across diverse study designs, educational contexts, and outcome measures, rather than through statistical aggregation or effect size calculation. This study utilized an integrative analysis as an evaluation approach to review and combine various research designs, with a specific focus on quantitative methods. Here, the aim was to identify subtopics as well as major themes, with the first stage of theme development involving the gathering of data. Table 4 details the authors' in-depth analysis of 30 publications to extract relevant assertions or information related to the study's main focus. Subsequently, the authors reviewed notable studies related to

AR in educational approaches and student performance, examining the methodologies and research outcomes. The authors then worked collaboratively to create themes, bearing in mind our dependence on information relevant to the context of the study. During the data analysis, a log was kept to record analyses, reflections, challenges, and insights related to data interpretation. Finally, the outcomes were examined to spot any inconsistencies in the theme development process. In instances of conceptual disagreements, the authors engaged in discussions to achieve consensus. They also contrasted their outcomes to address any discrepancies that emerged during theme development. Any inconsistencies were resolved through discussion among the authors. Ultimately, the themes were refined to ensure coherence. To validate the identified issues, three experts, two specializing in educational technology and the other in instructional design technology, performed a review. This expert review contributed to clarifying, ensuring the relevance, and confirming the sufficiency of each sub-theme by validating the domain. Correspondingly, modifications were made by the authors in response to expert feedback and suggestions.

Table 4

Summary of Selected Articles

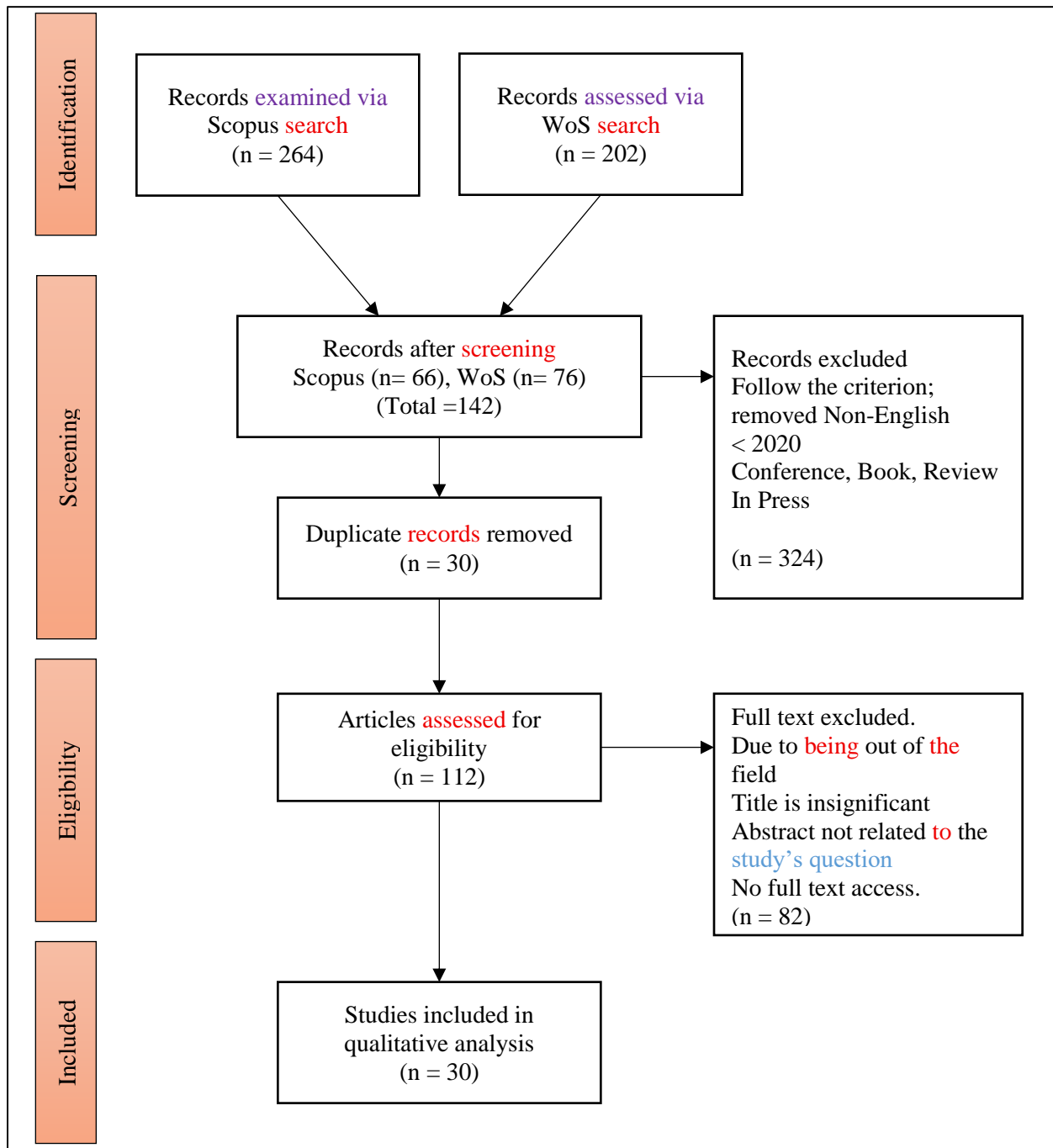
Authors	Year	Journal	Scopus	Web of science
Karayilan et al. (2022)	2022	Journal of Chemical Education	/	
Abdullah et al. (2024)	2024	SN Computer Science	/	
Rogers et al. (2023)	2024	Nurse Educator	/	/
Wen et al. (2023)	2023	Educational Technology Research and Development	/	/
Cagbabanua-Yap et al. (2023)	2023	Journal for ReAttach Therapy and Developmental Diversities	/	
Marcial et al. (2021)	2021	Frontiers in Education	/	
Kotcherlakota et al. (2020)	2020	JMIR Nursing	/	
Abinaya and Vadivu (2023)	2023	International Journal of Advanced Computer Science and Applications	/	
Köse and Güner-Yildiz (2021)	2021	Education and Information Technologies	/	/
Bedewy et al. (2021)	2021	Open Education Studies	/	
Cercenelli et al. (2022)	2022	International Journal of Environmental Research and Public Health	/	/
Opu et al. (2021)	2022	Computers	/	/
Menon et al. (2022)	2022	Clinical Simulation in Nursing	/	

(continued)

Authors	Year	Journal	Scopus	Web of science
Hsieh (2021)	2021	Electronics (Switzerland)	/	/
Balcita and Palaoag (2020)	2020	International Journal of Learning	/	
Alahmari (2023)	2023	International Journal of Information and Education Technology	/	
Ou Yang et al. (2023)	2023	Computers and Education	/	
Garcia (2020)	2020	International Journal of Learning Technology	/	
Volioti et al. (2023)	2023	Computers	/	/
Kamarudin et al. (2023)	2023	Interactive Learning Environments	/	
Czok et al. (2023)	2023	Sustainability (Switzerland)	/	/
Sari et al. (2021)	2021	Education and Information Technologies	/	/
Huang and Musah (2024)	2024	Journal of Pedagogical Research	/	
Rizki et al. (2024)	2024	Journal of Pedagogical Research	/	
Nasir and Fakhruddin (2023)	2023	International Journal of Information and Education Technology	/	
Chou et al. (2022)	2022	Asia-Pacific Education Researcher	/	/
Mccafferty et al. (2022)	2022	Nursing Education Perspectives	/	
Kerr and Lawson (2020)	2020	International Journal of Art and Design Education	/	
Kumar and Rajini (2024)	2024	Salud, Ciencia y Tecnologia - Serie de Conferencias	/	
Wang et al. (2024)	2024	Cogent Education	/	/

Figure 1

Flow Diagram of the Search Process in the Study



RESULTS

This section presents the findings in relation to the study's research questions. For contextual clarity, the results are organized according to the following three educational domains: specialized education, general education, and inclusive and special education; which reflect the differences in learning settings and instructional emphases. Within and across these domains, the impacts of augmented reality are discussed thematically in terms of student engagement, cognitive outcomes, and academic achievement, so as to allow patterns and contrasts to be examined across contexts.

Augmented Reality in Specialized Educational Domains

AR is an excellent way of enhancing highly specialized educational environments in order to provide a more immersive and practical learning experience for students. Many researchers and studies have confirmed that the integration of AR can benefit academic performance significantly, especially with respect to expertise-related skills, particularly in fields such as healthcare, chemistry, and design. Kotcherlakota et al. (2020) examined a study about paediatric asthma management education for nursing students. Their test scores significantly increased after utilizing AR simulations. This innovative augmented simulation gave students the opportunity to engage with clinical scenarios as they happen and, therefore, they were able to learn better about asthma management methods compared to the use of traditional classroom-based techniques. Similarly, McCafferty et al. (2022) found that AR posters had helped nursing students increase their clinical competence and critical thinking skills. These two studies clearly show that AR is a novel learning method to gain competent skills in healthcare education by balancing practical experience and theoretical knowledge. In polymer chemistry education, AR has been employed to address the challenges of distance and virtual learning. According to Karayilan et al. (2022), the shift toward remotely conducted online laboratory experiments during the COVID-19 pandemic prompted educators to re-evaluate traditional laboratory practices. These virtual and AR-based lab simulations ensured that students could access a safer alternative to practical sessions while reinforcing face-to-face learning. The simulations had helped students to delve into intricate synthetic and analytical procedures that they would have to perform in their future work as professionals and academicians. Their paper highlighted how AR had broadened participation in these types of learning spaces while being sustainable by obviating the need for physical materials and laboratory space. Therefore, the successful application of AR in Chemistry education may be a sign of its broader usage in other subjects that involve laboratory work.

AR also has an important place in the teaching of design. Kerr and Lawson (2020) examined the potential of AR to redefine how landscape architecture is taught, allowing opportunities for first-year students to have a more engaging way of both seeing and doing things in their design. In this study, it was found that AR had allowed students to recognize how spatial relationships and design principles were connected in buildings by illustrating them all together as enriched learning techniques, yet related to traditional approaches. The use of AR technology in this manner is great for encouraging creativity and critical thinking, as students can experience intricate designs through interactive storytelling and visual representation. A corresponding study by Kumar and Rajini (2024) likewise showed that AR in maritime education could eliminate some of the traditional theoretical knowledge boundaries while giving students fewer theory lessons. The authors showed that AR was a great way to increase students' readiness for their future maritime career and their preparedness for the real-time experience onboard ships before entering

the workforce. In the medical field, Cercenelli et al. (2022) investigated the combination of AR with 3D-printed models for gross anatomy education. There was no significant gap in test results between the AR and traditional learning groups, but students reported a much higher preference for using AR tools as they were more engaging and made them feel enthusiastic about their classes. The authors suggested that AR had enhanced the retention of memory for more extended periods, as well as 3D apprehension in some anatomical structures, compared to conventional cadaver-based training.

Furthermore, Menon et al. (2022) also concluded that AR could enhance the competency of nursing students in physical assessment skills. Based on psychomotor assessments, the AR students significantly outperformed those in the control group by visualizing overlays of the heart and lungs, as well as the rib cage. This, in turn, reinforces the potential usage of AR technologies as an educational resource in faculty medicine to improve many sought-after practical skills among students.

Lastly, Bedewy et al. (2021) delved into the intersection of AR in STEAM education, where students integrated mathematical knowledge with AR and 3D printing to explore historical architecture. The study showed that AR had turned into an interdisciplinary learning technique by connecting mathematics, history, and engineering, offering students a comprehensive and engaging educational experience. This multimodal learning approach encourages students to have the opportunity to apply what they have learned in real-world contexts, further aiding comprehension and retention of these abstract concepts that would have been missed if strictly employing a traditional lecture-based model. Similarly, Rogers et al. (2023) discovered that 3D AR tutorials in nursing education were found to improve student understanding of pathophysiology by combining visual, auditory, and kinaesthetic learning strategies supporting the enhancement of tailored teaching through AR within specific areas of interest.

These findings address the first and second research questions of the present study by demonstrating how AR enhances both engagement and cognitive skill development in highly specialized disciplines. The evidence supports AR's effectiveness in promoting practical competence and critical thinking, aligning closely with the theoretical foundation discussed in the literature review.

Augmented Reality and Learning Enhancement in General Education

AR has many contributions, but one of its most important impacts is in the field of student engagement and motivation. Indeed, numerous studies have shown that AR significantly improves the interaction of learners with educational content. For instance, Wen et al. (2023) found that the integration of AR and the planets-based QIMS platform made a significant difference in self-directed learning, something called creative thinking among students. In marine education, Hsieh (2021) states that the use of augmented reality in a system called the AR Oyster Learning System can increase student motivation and knowledge gain. That AR is interactive naturally makes it a more practical setting for learning. As Garcia (2020), has noted the immersive storytelling in history education is able to teleport students into the historical world of what was once said and done. These studies, as a whole, underscore the broader impact of AR on increasing students' motivation and engagement across different content domains. From a constructivist perspective, these outcomes show how AR transforms students from being passive recipients to active participants in the learning process. The interactivity and immediate feedback inherent in AR will encourage self-regulation and reflection, which are essential for higher-order learning. This also resonates with the tenets of Self-

Determination Theory, as AR fosters autonomy and competence—two drivers of intrinsic motivation. Another common thread in AR is that it can be a tool to enhance critical thinking and cognitive skills. Many studies show that AR can encourage more advanced learning since people face challenges and need to solve problems. Rizki et al. (2024) reported that an AR-based cooperative model in physics learning significantly improved students' critical thinking and learning motivation. Similarly, Ou Yang et al. (2023) found that employing AR in educational robotics led to pronounced effects on students' computational thinking skills, specifically in algorithm design and efficiency. The results imply that the interactive and immersive aspect of AR can help in developing cognitive skills necessary for solving problems of a more complex nature.

While the effects of AR in many studies are believed to be able to increase motivation and cognitive engagement significantly, its influence on academic achievement is probably weak. For instance, Wen et al. (2023) showed that academic performance did not improve, although both the creative and critical thinking skills of the medical students significantly improved. On the other hand, Nasir and Fakhruddin (2023) showed that using AR technology in mobile learning increased students' physics achievement, which may suggest a possible relationship between studies returning positive results with respect to student academic performance according to subject domain. Given these divergent outcomes of the two studies, there is clearly a great deal more research required to understand why AR worked in some cases, although it did not seem to work in others; before any definitive conclusions on what schooling conditions are necessary for measurable academic improvements using AR can be made. Not only is AR helping people to engage more and develop cognitive skills, it also helps to enhance learning experiences by connecting the most abstract concepts to everyday life. In mathematics, Volioti et al. (2023) assessed that the incorporation of AR in the "Cooking Math" application provided a more interactive and pleasant approach to solving real-world problems. Similarly, Cagbabanua-Yap et al. (2023) highlighted the fact that AR was used in e-learning during the COVID-19 pandemic, which had helped to engage students and facilitate access to digital resources. The results from these studies prove that AR will be a good tool for experiential learning and also provide context awareness, which would create better overall learning experiences in different subjects.

While there have been many positive impacts highlighted in previous studies, there had been few which showcased the dual nature and cognitive load that AR was able to confer. Czok et al. (2023) have noted that while AR may increase motivation and engagement, it can also be cognitively demanding. Nevertheless, these added demands on cognitive resources did not hinder learning, suggesting that the affordances in AR applications, such as heightened engagement, could offset significant challenges for maintaining cognitive load. Concerning AR integration, Huang and Musah (2024) underscore the importance of teacher proficiency in overcoming challenges experienced in such implementation, as there is a role of teachers' readiness for adoption with regard to preparing and executing AR platforms effectively within the classroom. Moreover, the sustained effects of AR integration on learning processes remain largely unexplored. Cagbabanua-Yap et al. (2023) suggest that future work must investigate the persistent impact of AR on learning outcomes in e-learning situations. Correspondingly, Balcita and Palaoag (2020) have highlighted that the instruction-supportive capacities of AR frameworks could be sharpened through future investigations into how to refine such capacity in order to support different learning tactics. These gaps underscore the need for longitudinal studies to determine how AR affects students' learning in the long term.

In general, the literature reviewed indicates how AR can enhance student engagement, motivation, and cognitive skills. Nonetheless, concerning academic success, AR seems somewhat inconsistent, and therefore, further investigation is necessary to delineate the determinants and explain why it works in some educational contexts and surprisingly not in others. Moreover, AR has considerable potential benefits, such as improving the experiential nature of learning and helping learners form abstract concepts. More tangible challenges, such as increased cognitive load and the need for teacher competence, must be met before the utility of AR for educational purposes may be fully materialized.

The outcomes discussed in this section relate to the second and third research questions by highlighting how AR fosters motivation, engagement, and cognitive skills, though its impact on academic achievement overall remains varied across subject areas.

Augmented Reality and Learning Technologies for Special Education and Inclusive Learning

The results discussed in this section respond to the third research question by emphasizing AR's role in inclusive and special education contexts. The studies reviewed illustrate AR's potential to improve attention, engagement, and interaction among diverse learners, reflecting how immersive learning can promote equitable and adaptive educational practices. The study on AR and its use in education highlights its significant potential to enhance learning outcomes, especially for students with special needs and inclusive educational settings. Abdullah et al. (2024) illustrated that AR-based cognitive rehabilitation was very effective for developing attention and concentration for autistic children using 3D objects set in motion and embodied by voice output. The results revealed significant improvements among children who had been classified as mild and moderate in their diagnosis, indicating an AR efficacy across a range of cognitive disabilities. In the same vein, Köse and Güner-Yildiz (2021) are of the view that AR is an effective tool for special needs education as it is a very convenient way of teaching assistive targeted individuals by using portable devices like smartphones or tablets. Both studies clearly illustrate that AR is beneficial for cognitive engagement and can greatly drive the improvement of special education practices. Besides, a study by Abinaya and Vadivu (2023) establishes AR as the one pedagogical tool that can address the concerns about inadequate student engagement and academic performance. The study was undertaken to quantify the benefits of AR in primary school curriculums and reconfirmed that integrated learning outcomes and student engagement improved significantly, which were validated statistically using ANOVA. These results were consistent with the study conducted by Abdullah et al. (2024), which have highlighted the potential of AR for attention and interaction, but within different educational frameworks. Findings from both studies have demonstrated AR to be adaptive, suggesting its capabilities for upending conventional teaching and learning paradigms by creating more dynamic, immersive, and engaging learning environments.

In the machine learning integration context, Opu et al. (2021) revealed that the "Learn2Write" mobile app had combined AR and machine learning to teach writing. This application enabled children to visualize the alphabet in 3D while enhancing their writing skills. This finding that AR and machine learning are compatible has corroborated the findings of the present study and is in line with the conclusions of Köse and Güner-Yildiz (2021). Their study has shown that there were positive effects on learner participation when using effective teaching methods which were supported by AR, compared to non AR traditional education. Both studies showed the potential of AR in special needs education, although "Learn2Write"

itself threw a significant spanner into these works by using artificial intelligence to help improve real-world writing skills. Studies by Alahmari (2023) and Kamarudin et al. (2023) looked at the effect of AR in higher education, as AR has been adopted by staff & students. Alahmari's study revealed that the perceived usability and pedagogical value of the AR significantly influenced if staff would adopt AR in Saudi Arabian higher education. This resonates with Kamarudin et al. (2023) findings, where AR-based e-learning practices during the COVID-19 pandemic had a significant effect on students' cognitive engagement, as well as their intention to engage in learning behaviors. The focus on the use of AR in both studies have highlighted the potential of AR as a modern learning tool that improves teaching and learning, with solid acceptance in different educational domains among educators and learners.

Finally, Wang et al. (2024) have investigated how AR fits with STEM education for preschool children in China. Their findings showed that the students' AR experiences helped them to engage more and improve their capabilities for solving problems. This is consistent with other research studies on special education (Abdullah et al., 2024; Köse & Güner-Yildiz, 2021), which therefore, suggests a broader potential for the improvement of learning outcomes through AR over different age groups and types of educational settings. Thus, the interactive nature of AR, as explored in Wang et al. (2024) research, has helped students to develop a better knowledge of complex concepts, reinforcing AR's role in early childhood education.

DISCUSSION AND CONCLUSION

The findings of this review align with several established educational theories that explain how Augmented Reality (AR) enhances learning. Guided by constructivism, AR enables learners to actively build knowledge through immersive experiences rather than passive observation. Cognitive Load Theory supports the idea that AR can reduce extraneous load by providing multimodal cues, thereby improving comprehension and retention. Moreover, Multisensory Learning Theory highlights how the combination of visual, auditory, and kinesthetic inputs in AR promotes engagement and deeper encoding of information. Framing the findings within these theoretical perspectives helps explain why AR consistently enhances motivation, cognitive skills, and engagement across various educational contexts.

Augmented Reality (AR) has emerged as a transformative educational tool across various sectors, providing immersive and interactive learning experiences. In healthcare education, AR has significantly enhanced students' practical experiences and comprehension. For instance, it has improved clinical readiness in paediatric asthma management. The interactive nature of AR simulations bridges theoretical knowledge and practical scenarios, fostering critical thinking and skill development. In nursing education, integrating AR has led to increased engagement and a deeper understanding of physical assessment techniques. Its value extends beyond clinical fields; AR has proven especially useful during shifts to remote learning, such as in polymer chemistry. AR-based lab simulations offer a safer and more cost-effective alternative to traditional laboratories while providing students with a comprehensive understanding of complex systems. This demonstrates how AR can promote sustainability and expand educational access. These findings reinforce the postulations of Cognitive Load Theory, as AR simulations help learners visualize complex clinical or chemical processes into manageable segments, thereby optimizing working memory use. They also align with the theoretical perspective of Situated Learning Theory, which emphasizes contextual, and authentic experiences. By allowing learners to perform virtual lab or clinical tasks in realistic scenarios,

AR bridges theoretical and practical knowledge — a key principle of experiential learning. The success of AR in subjects like chemistry showcases its broader applicability beyond laboratory settings. AR offers a practical, economical, and efficient solution compared to the costs and effectiveness of using physical resources. In architecture and design education, AR enhances students' ability to visualize and interact with complex spatial concepts, making it easier to grasp relationships and principles. By offering dynamic visual experiences, AR promotes creativity and critical thinking. In real-world training scenarios, such as maritime and landscape architecture, AR has proven more effective than traditional theoretical programs in preparing students for practical experiences. Similarly, in anatomy education, AR provides students with an augmented view of anatomical structures, facilitating 3D comprehension and retention. Traditional teaching methods are effective, but AR serves as an invaluable supplemental tool that enhances students' understanding and psychomotor skills.

AR's integration into STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has connected diverse subjects and applied them to real-world contexts, such as exploring the field of architecture throughout history. By combining visual, auditory, and kinaesthetic learning styles, AR enriches students' understanding of complex concepts across various fields. Research has shown that AR increases student engagement, self-directed learning, and motivation, especially when creative thinking is involved. This is evident in areas like marine education and history, where immersive AR environments have heightened learners' excitement and knowledge retention. The participatory and engaging nature of AR fosters deeper cognitive and emotional involvement, enhancing higher-order thinking skills. Problem-solving is another area where AR demonstrates significant potential. In physics and robotics education, AR encourages exploration of complex concepts, such as algorithm design, leading to enhanced critical thinking and computational skills. However, the effect of AR on academic performance remains mixed. While AR positively impacts cognitive and motivational factors, its direct effect on academic outcomes varies according to context and subject matter. For example, AR has led to improved academic performance in physics through interactive, hands-on learning but has not consistently shown differences in other academic results. This variability suggests the need for further research to identify the conditions under which AR can produce measurable academic benefits.

AR's benefits extend beyond motivation and cognitive skill enhancement; it helps embody abstract ideas and makes learning practical and enjoyable. However, AR may increase cognitive load for learners, though studies indicate this does not significantly impact learning outcomes. The positive aspects of AR generally outweigh potential downsides.

Teacher competency is crucial for the successful implementation of AR in classrooms. Educators must receive adequate training to effectively integrate this technology into their teaching. Understanding the long-term effects of AR on learning, particularly in e-learning, requires more longitudinal research. This will enable the development of AR frameworks that support various learning practices and improve student performance. Studies have shown that AR can also benefit special education, such as cognitive rehabilitation for children with autism. AR's adaptability to varying levels of attention and concentration makes it an effective tool for enhancing cognitive engagement. Portable devices like tablets and smartphones have facilitated AR's integration into special education, improving teaching methods and fostering cognitive involvement. In mainstream education, AR has helped to bridge gaps in student engagement and academic performance, especially when combined with peer-to-peer interaction. This has

proven useful in creating immersive and interactive educational content. Combining AR with other technologies, such as machine learning, has broadened its capabilities, especially in basic education and writing instruction. AR has shown potential for both teaching and learning in higher education. Factors influencing educators' adoption of AR include perceived usefulness and pedagogical benefits, particularly in regions where modern learning technologies are less developed. AR-based e-learning has proven effective for cognitive engagement and positive learning behaviours, particularly in remote education scenarios like those experienced during COVID-19. The integration of AR in early childhood and STEAM education has further highlighted its ability to enhance engagement and problem-solving skills. AR-based modules have promoted deeper understanding and academic performance in various learning environments, including preschools. This underlines AR's ability to transform educational experiences across different contexts by providing an immersive and comprehensive learning approach.

This review contributes novel insights by synthesizing evidence across specialized, general, and inclusive education to provide an integrated understanding of AR's pedagogical value. Unlike previous reviews that had focused on isolated disciplines, this study has highlighted AR's cross-context adaptability and identified the underexplored dimensions of teacher readiness, cognitive load balance, and long-term learning outcomes. The discussion advances the field by clarifying how AR operationalizes multisensory and constructivist learning principles within diverse settings.

Moving forward, future research should employ longitudinal and mixed-method designs to evaluate AR's sustained impact on academic achievement and learner behaviour. Policies should also support professional development for educators, to help them learn how to design AR content which will be aligned with curricular outcomes. By addressing these directions, AR can evolve from an experimental innovation into a mainstream pedagogical framework that transforms educational practice and learning theory.

ACKNOWLEDGMENT

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

- Abdekhoda, M., Ashrafi-Rizi, H., & Ranjbaran, F. (2023). Theoretical issues in medical library and information sciences' articles published in scopus and web of science databases: A scoping review. *Journal of Education and Health Promotion, 12*(1), 244. https://doi.org/10.4103/jehp.jehp_1150_22
- Abdullah, A. S., Karthikeyan, J., Gomathi, V., Parkavi, R., & Rajarajeswari, P. (2024). Enabling technology integrated learning for autistic children using augmented reality based cognitive rehabilitation. *SN Computer Science, 5*(1), 151. <https://doi.org/10.1007/s42979-023-02495-5>
- Abinaya, M., & Vadivu, G. (2023). Transformative learning through augmented reality empowered by machine learning for primary school pupils: A real-time data analysis. *International Journal of Advanced Computer Science and Applications, 14*(12), 1050–1056. <https://doi.org/10.14569/IJACSA.2023.01412107>

- Alahmari, M. (2023). Exploring the influential factors affecting staff willingness to adopt augmented reality. *International Journal of Information and Education Technology*, 13(7), 1078–1084. <https://doi.org/10.18178/ijiet.2023.13.7.1907>
- AlGerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. *Electronics*, 12(18), 3953. <https://doi.org/10.3390/electronics12183953>
- Alzahrani, N. M. (2020). Augmented reality: A systematic review of its benefits and challenges in e-learning contexts. *Applied Sciences*, 10(16), 5660. <https://doi.org/10.3390/app10165660>
- Balcita, R. E., & Palaoag, T. D. (2020). Assisting students learning experiences using an augmented reality model framework. *International Journal of Learning and Teaching*, 6(3), 146–151. <https://doi.org/10.18178/ijlt.6.3.146-151>
- Barsom, E. Z., Graafland, M., & Schijven, M. P. (2016). Systematic review on the effectiveness of augmented reality applications in medical training. *Surgical Endoscopy*, 30(10), 4174–4183. <https://doi.org/10.1007/s00464-016-4800-6>
- Bedewy, S. El, Choi, K., Lavicza, Z., Fenyvesi, K., & Houghton, T. (2021). STEAM practices to explore ancient architectures using augmented reality and 3D printing with GeoGebra. *Open Education Studies*, 3(1), 176–187. <https://doi.org/10.1515/edu-2020-0150>
- Cagabanua-Yap, S. S., Petiluna, G. C., Bunao, C. M., Siaton, I. M. M., Labao, K. E., & Merced, J. J. A. Dela. (2023). Investigating the psychological influence of an augmented reality application on e-learning amid the COVID-19 pandemic: An examination of college students in Asia. *Journal for ReAttach Therapy and Developmental Diversities*, 6(8), 428–437. <https://jrtd.com/index.php/journal/article/view/907>
- Cao, J., Lam, K. Y., Lee, L. H., Liu, X., Hui, P., & Su, X. (2023). Mobile augmented reality: User interfaces, frameworks, and intelligence. *ACM Computing Surveys*, 55(9), 1–36. <https://doi.org/10.1145/3557999>
- Cercenelli et al. (2022). A EducaAR, anatomical education in augmented reality: A pilot experience of an innovative educational tool combining AR technology and 3D printing. *International Journal of Environmental Research and Public Health*, 19(3), 1024. <https://doi.org/10.3390/ijerph19031024>
- Chadegani et al. (2013). A comparison between two main academic literature collections: Web of Science and Scopus databases. *Asian Social Science*, 9(5), 18–26. <https://doi.org/10.5539/ass.v9n5p18>
- Chen, Z. T., Chiappalupi, D., Lin, T., Yang, Y., Beyer, J., & Pfister, H. (2024). RL-LABEL: A deep reinforcement learning approach intended for AR label placement in dynamic scenarios. *IEEE Transactions on Visualization and Computer Graphics*, 30(1), 1347–1357. <https://doi.org/10.1109/TVCG.2023.3326568>
- Chou et al. (2022). Effect of digital learning using augmented reality with multidimensional concept map in elementary science course. *The Asia-Pacific Education Researcher*, 31(4), 383–393. <https://doi.org/10.1007/s40299-021-00580-y>
- Czok, V., Krug, M., Müller, S., Huwer, J., & Weitzel, H. (2023). Learning effects of augmented reality and game-based learning for science teaching in higher education in the context of education for sustainable development. *Sustainability*, 15(21), 15313. <https://doi.org/10.3390/su152115313>
- Daoud, M. K., Alqudah, D., Al-Qeed, M., & Al-Gasawneh, J. A. (2023). Exploring the effectiveness of augmented reality in enhancing brand engagement: A study of digital marketing strategies. *Quality-Access to Success*, 24(196), 75–79. <https://doi.org/10.47750/QAS/24.196.10>

- Elsayed, S. A., & Al-Najrani, H. I. (2021). Effectiveness of the augmented reality on improving the visual thinking in mathematics and academic motivation for middle school students. *Eurasia Journal of Mathematics, Science and Technology Education*, 17(8), em1991. <https://doi.org/10.29333/ejmste/11069>
- Garcia, M. B. (2020). Augmented reality in history education: An immersive storytelling of American colonization period in the Philippines. *International Journal of Learning Technology*, 15(3), 234. <https://doi.org/10.1504/IJLT.2020.112170>
- Giancaspro, J. W., Arboleda, D., Kim, N. J., Chin, S. J., Britton, J. C., & Secada, W. G. (2024). An active learning approach to teach distributed forces using augmented reality with guided inquiry. *Computer Applications in Engineering Education*, 32(2), e22703. <https://doi.org/10.1002/cae.22703>
- Goertzen, M. (2019). Multidisciplinary databases outperform specialized and comprehensive databases for agricultural literature coverage. *Evidence Based Library and Information Practice*, 14(2), 140–142. <https://doi.org/10.18438/eblip29561>
- Gray, M., Downer, T., Hanson, J., Hartz, D., Gao, Y., & Andersen, P. (2023). The impact of three-dimensional visualization on midwifery students' application of knowledge of the third stage of labour to practice: Qualitative findings of a pilot randomized controlled trial. *Women and Birth*, 36(1), e36–e43. <https://doi.org/10.1016/j.wombi.2022.04.009>
- Guan, J. Q., Ying, S. F., Zhang, M. L., & Hwang, G. J. (2024). From experience to empathy: An empathetic VR-based learning approach to improving EFL learners' empathy and writing performance. *Computers & Education*, 220, 105120. <https://doi.org/10.1016/j.compedu.2024.105120>
- Gusenbauer, M. (2022). Search where you will find most: Comparing the disciplinary coverage of 56 bibliographic databases. *Scientometrics*, 127(5), 2683–2745. <https://doi.org/10.1007/s11192-022-04289-7>
- Hsieh, M. C. (2021). Development and application of an augmented reality oyster learning system for primary marine education. *Electronics*, 10(22), 2818. <https://doi.org/10.3390/electronics10222818>
- Hu et al. (2020). Comprehensive database and individual patient data meta-analysis of randomized controlled trials on psychotherapies reducing suicidal thoughts and behaviour: Study protocol. *BMJ Open*, 10(12), e037566. <https://doi.org/10.1136/bmjopen-2020-037566>
- Huang, L., & Musah, A. A. (2024). The influence of augmented reality on creativity, student behavior, and pedagogical strategies in technology-infused education management. *Journal of Pedagogical Research*, 8(2), 260–275. <https://doi.org/10.33902/JPR.202425376>
- Iskander, M., Ogunsola, T., Ramachandran, R., McGowan, R., & Al-Aswad, L. A. (2021). Virtual reality and augmented reality in ophthalmology: A contemporary prospective. *Asia-Pacific Journal of Ophthalmology*, 10(3), 244–252. <https://doi.org/10.1097/APO.0000000000000409>
- Jalaluddin, I., Darmi, R., & Ismail, L. (2024). Implementing mixed augmented and virtual reality in an animated flipped classroom for low-achieving writers in rural primary schools. *Issues in Language Studies*, 13(1), 215–232. <https://doi.org/10.33736/ils.6217.2024>
- Jdaitawi, M., Muhaidat, F., Alsharoa, A., Alshlowi, A., Torki, M., & Abdelmoneim, M. (2022). The effectiveness of augmented reality in improving students motivation: An experimental study. *Athens Journal of Education*, 10(2), 365–380. <https://doi.org/10.30958/aje.10-2-10>
- Kamarudin, S., Shoaib, H. M., Jamjoom, Y., Saleem, M., & Mohammadi, P. (2023). Students' behavioural intention towards e-learning practices through augmented reality app during COVID-19 pandemic in Saudi Arabia. *Interactive Learning Environments*, 31(9), 5715–5731. <https://doi.org/10.1080/10494820.2021.2016863>

- Karayilan, M., McDonald, S. M., Bahnick, A. J., Godwin, K. M., Chan, Y. M., & Becker, M. L. (2022). Reassessing undergraduate polymer chemistry laboratory experiments for virtual learning environments. *Journal of Chemical Education*, 99(5), 1877–1889. <https://doi.org/10.1021/acs.jchemed.1c01259>
- Kerr, J., & Lawson, G. (2020). Augmented reality in design education: Landscape architecture studies as AR experience. *International Journal of Art & Design Education*, 39(1), 6–21. <https://doi.org/10.1111/jade.12227>
- Köse, H., & Güner-Yildiz, N. (2021). Augmented reality (AR) as a learning material in special needs education. *Education and Information Technologies*, 26(2), 1921–1936. <https://doi.org/10.1007/s10639-020-10326-w>
- Kotcherlakota, S., Pelish, P., Hoffman, K., Kupzyk, K., & Rejda, P. (2020). Augmented reality technology as a teaching strategy for learning pediatric asthma management: Mixed methods study. *JMIR Nursing*, 3(1), e23963. <https://doi.org/10.2196/23963>
- Kovoor, J. G., Gupta, A. K., & Gladman, M. A. (2021). Validity and effectiveness of augmented reality in surgical education: A systematic review. *Surgery*, 170(1), 88–98. <https://doi.org/10.1016/j.surg.2021.01.051>
- Kumar, N., & Rajini, G. (2024). Reimagining maritime education and training using latest technologies. *Salud, Ciencia y Tecnología - Serie de Conferencias*, 3, 895. <https://doi.org/10.56294/sctconf2024895>
- Li, M., Chen, Y. T., Huang, C. Q., Hwang, G. J., & Cukurova, M. (2023). From motivational experience to creative writing: A motivational AR-based learning approach to promoting Chinese writing performance and positive writing behaviours. *Computers & Education*, 202, 104844. <https://doi.org/10.1016/j.compedu.2023.104844>
- Lin et al. (2023). Mitigating the urban-rural digital divide: A dual scaffolding-embedded mobile augmented reality learning approach in the post COVID-19 pandemic. *Educational Technology and Society*, 26(4), 108–122. [https://doi.org/10.30191/ETS.202310_26\(4\).0008](https://doi.org/10.30191/ETS.202310_26(4).0008)
- Lin, Y., & Yu, Z. (2023). A meta-analysis of the effects of augmented reality technologies in interactive learning environments (2012–2022). *Computer Applications in Engineering Education*, 31(4), 1111–1131. <https://doi.org/10.1002/cae.22628>
- Long, H. A., French, D. P., & Brooks, J. M. (2020). Optimizing the value of the critical appraisal skills programme (CASP) tool for quality appraisal in qualitative evidence synthesis. *Research Methods in Medicine & Health Sciences*, 1(1), 31–42. <https://doi.org/10.1177/2632084320947559>
- Marcial, D. E., dela Peña, L., Montemayor, J., & Dy, J. (2021). The design of a gamified responsible use of social media. *Frontiers in Education*, 6, 635278. <https://doi.org/10.3389/feduc.2021.635278>
- McCafferty, K. L., Flott, B., & Hadenfeldt, C. (2022). Using augmented reality to foster clinical readiness and critical thinking in nursing education. *Nursing Education Perspectives*, 43(3), 181–183. <https://doi.org/10.1097/01.NEP.0000000000000860>
- Menon, S. S., Holland, C., Farra, S., Wischgoll, T., & Stuber, M. (2022). Augmented reality in nursing education - A pilot study. *Clinical Simulation in Nursing*, 65, 57–61. <https://doi.org/10.1016/j.ecns.2022.01.007>
- Mokmin, N. A. M., Hanjun, S., Jing, C., & Qi, S. (2024). Impact of an AR-based learning approach on the learning achievement, motivation, and cognitive load of students on a design course. *Journal of Computers in Education*, 11(2), 557–574. <https://doi.org/10.1007/s40692-023-00270-2>

- Nasir, M., & Fakhruddin, Z. (2023). Design and analysis of multimedia mobile learning based on augmented reality to improve achievement in physics learning. *International Journal of Information and Education Technology*, 13(6), 993–1000. <https://doi.org/10.18178/ijiet.2023.13.6.1897>
- Opu, M. N. I., Islam, M. R., Kabir, M. A., Hossain, M. S., & Islam, M. M. (2021). Learn2Write: Augmented reality and machine learning-based mobile app to learn writing. *Computers*, 11(1), 4. <https://doi.org/10.3390/computers11010004>
- Ou Yang, F. C., Lai, H. M., & Wang, Y. W. (2023). Effect of augmented reality-based virtual educational robotics on programming students' enjoyment of learning, computational thinking skills, and academic achievement. *Computers & Education*, 195, 104721. <https://doi.org/10.1016/j.compedu.2022.104721>
- Ozcakir, B., & Cakiroglu, E. (2021). An augmented reality learning toolkit for fostering spatial ability in mathematics lesson: Design and development. *European Journal of Science and Mathematics Education*, 9(4), 145–167. <https://doi.org/10.30935/scimath/11204>
- Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2021). Exploration of augmented reality in spatial abilities training: A systematic literature review for the last decade. *Informatics in Education*, 20(1), 107–130. <https://doi.org/10.15388/infedu.2021.06>
- Qin, Y., & Bulbul, T. (2023). Electroencephalogram-based mental workload prediction for using augmented reality head mounted display in construction assembly: A deep learning approach. *Automation in Construction*, 152, 104892. <https://doi.org/10.1016/j.autcon.2023.104892>
- Rizki et al. (2024). Cooperative model, digital game, and augmented reality-based learning to enhance students critical thinking skills and learning motivation. *Journal of Pedagogical Research*, 8(1), 339–355. <https://doi.org/10.33902/JPR.202423825>
- Rodríguez-Abad, C., Martínez-Santos, A. E., Fernández-de-la-Iglesia, J. del C., & Rodríguez-González, R. (2023). Online (versus face-to-face) augmented reality experience on nursing students' leg ulcer competency: Two quasi-experimental studies. *Nurse Education in Practice*, 71, 103715. <https://doi.org/10.1016/j.nepr.2023.103715>
- Rogers, J. L., Reyes, A., & Yang, X. (2023). Development of an interactive 3D visualization tutorial for pathophysiology in graduate nursing education. *Nurse Educator*, 49(2), E68–E73. <https://doi.org/10.1097/NNE.0000000000001496>
- Sari, R. C., Sholihin, M., Yuniarti, N., Purnama, I. A., & Hermawan, H. D. (2021). Does behavior simulation based on augmented reality improve moral imagination? *Education and Information Technologies*, 26(1), 441–463. <https://doi.org/10.1007/s10639-020-10263-8>
- Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics*, 126(6), 5113–5142. <https://doi.org/10.1007/s11192-021-03948-5>
- Sun et al. (2023). Application of virtual and augmented reality technology in hip surgery: Systematic review. *Journal of Medical Internet Research*, 25, e37599. <https://doi.org/10.2196/37599>
- Volioti, C., Orovas, C., Sapounidis, T., Trachanas, G., & Keramopoulos, E. (2023). Augmented reality in primary education: An active learning approach in mathematics. *Computers*, 12(10), 207. <https://doi.org/10.3390/computers12100207>
- Wallgrün et al. (2018). Immersive technologies and experiences for archaeological site exploration and analysis. In W. Cartwright, G. Gartner, L. Meng, & M. P. Peterson (Eds.), *Lecture notes in geoinformation and cartography (LNGC)* (pp. 307–314). Springer. https://doi.org/10.1007/978-3-319-63946-8_48

- Wang, X., Abdul Rahman, M. N., & Nizam Shaharom, M. S. (2024). The impacts of augmented reality technology integrated STEM preschooler module for teaching and learning activity on children in China. *Cogent Education*, *11*(1), 2343527. <https://doi.org/10.1080/2331186X.2024.2343527>
- Wen et al. (2023). Integrating augmented reality into inquiry-based learning approach in primary science classrooms. *Educational Technology Research and Development*, *71*(4), 1631–1651. <https://doi.org/10.1007/s11423-023-10235-y>
- Weng, C., Tran, K. N. P., Yang, C. C., Huang, H. I., & Chen, H. (2024). Can an augmented reality-integrated gamification approach enhance vocational high school students' learning outcomes and motivation in an electronics course? *Education and Information Technologies*, *29*(4), 4025–4053. <https://doi.org/10.1007/s10639-023-11966-4>
- Wong, J., Bayoumy, S., Freke, A., & Cabo, A. (2022). *Augmented reality for learning mathematics: A pilot study with WebXR as an accessible tool*. In Proceedings of the SEFI 50th Annual Conference of The European Society for Engineering Education: Towards a new future in engineering education, new scenarios that European alliances of tech universities open up (pp. 1805–1814). Universitat Politècnica de Catalunya. <https://doi.org/10.5821/conference-9788412322262.1216>
- Wong, J., Yu, K., & Giacaman, N. (2021). Scaffolding spatial ability with augmented reality and virtual reality. *International Journal of Mobile Learning and Organisation*, *15*(1), 50. <https://doi.org/10.1504/IJMLO.2021.111597>