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Integrating Augmented Reality Media to Enhance Science Learning Outcomes in Elementary Education: A Literature Review

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Abstract

Background: The rapid advancement of educational technology has created opportunities to transform traditional science instruction into more interactive and engaging learning experiences. Conventional teaching methods in Indonesian elementary schools often rely on two-dimensional media, limiting students' ability to grasp abstract scientific concepts. Augmented Reality (AR) offers an innovative approach to bridge this gap by enabling students to visualize and interact with three-dimensional models in real time.

Aims: This study aims to explore the effect of AR-based learning media on science learning outcomes among fourth-grade students at SD IT Plus Qurthuba, focusing on its ability to enhance conceptual understanding, motivation, and problem-solving skills.

Methods: A literature review method was employed, synthesizing findings from previous studies on the integration of AR into elementary science learning. Data sources included journal articles, books, and relevant online resources. The process involved data collection, selection, analysis, and synthesis to evaluate the potential and challenges of AR implementation in primary education.

Results: The findings indicate that AR-based media significantly improve students' comprehension of abstract scientific concepts, foster higher motivation, and enhance engagement during the learning process. Moreover, AR contributes to the development of critical thinking and collaborative learning. Nevertheless, challenges remain, such as the need for adequate teacher training, device compatibility, and financial investment.

Conclusion: The integration of AR in science education presents substantial potential to transform elementary learning environments. Beyond making abstract concepts more concrete, AR fosters interactive and student-centered pedagogy that encourages exploration, creativity, and long-term retention of knowledge. Its positive impact on motivation and problem-solving demonstrates AR's value as a sustainable educational innovation. For broader adoption, stakeholders should provide structured teacher training, policy support, and infrastructure development to ensure equitable access. Future research is recommended to examine AR applications across diverse contexts and curricula, addressing limitations such as cost and technical readiness.

INTRODUCTION

The rapid advancement of digital technologies has significantly reshaped the educational landscape, compelling educators to adopt innovative strategies for improving student learning outcomes. In many contexts, traditional teaching approaches are still dominant, often relying on two-dimensional images or rote instruction that do not sufficiently support students' ability to grasp abstract scientific concepts. This gap is particularly visible in elementary science education, where young learners require interactive and visual tools to facilitate comprehension. Augmented Reality (AR) has emerged as a promising technology that bridges this gap by transforming abstract content into dynamic three-dimensional representations. The integration of AR into education has demonstrated the potential to make learning more engaging and interactive, thereby fostering greater student motivation and retention (Ghanbaripour et al., 2024; James et al., 2025). This urgency highlights why research on AR in elementary science education is both timely and essential for advancing pedagogical practices in the digital era.

Elementary schools play a crucial role in building foundational knowledge and critical thinking skills, especially in science subjects that demand conceptual clarity. However, conventional teaching approaches often fail to engage students, leading to reduced interest and weaker academic performance in science subjects. The application of AR allows learners to explore phenomena such as the solar system, the water cycle, or animal classification in immersive ways that are otherwise inaccessible in a typical classroom setting. This transformation not only increases comprehension but also cultivates curiosity and inquiry-based learning habits among students. Previous studies suggest that AR can stimulate students' cognitive engagement while also supporting affective domains such as motivation and enthusiasm for learning (Mokmin et al., 2024; Wen, 2021). Therefore, examining the integration of AR within elementary classrooms is vital for aligning education with 21st-century learning needs.

Furthermore, the global shift toward technology-enhanced education underscores the relevance of AR in modern pedagogical contexts. Policymakers and educators alike are emphasizing the necessity of digital literacy, interactive pedagogy, and technology integration to improve the overall quality of education. AR provides a unique combination of interactivity and visualization that traditional media cannot offer, creating an enriched learning environment suitable for diverse learners. Evidence from experimental and review studies confirms that AR promotes collaboration, problem-solving, and creativity, which are essential competencies for lifelong learning (Dong et al., 2025; Yuniarti et al., 2024). Thus, the urgency of this research lies in addressing the limitations of conventional pedagogy while exploring AR as a tool that can significantly elevate science learning outcomes among elementary students.

The rationale behind this study rests on the recognition that AR is not merely a technological novelty but an educational necessity in a rapidly digitalizing world. The potential of AR to enhance learning outcomes has been highlighted across multiple disciplines, yet empirical evidence in the context of elementary science education remains underexplored. By synthesizing findings from prior literature, this study contributes to filling this knowledge gap and offering practical insights for integrating AR into curricula. The significance of this research is further supported by its alignment with global educational goals, including fostering innovation, equity, and access to quality education.

Moreover, by investigating AR in science classrooms, the study not only addresses immediate instructional challenges but also contributes to shaping policies that support long-term digital transformation in schools (Sliwka et al., 2024; Stenbom & Geijer, 2025).

Research on AR in education has consistently demonstrated positive outcomes, particularly in enhancing engagement and conceptual understanding. For example, Mirza et al., (2025) examined AR in the context of new pedagogies and highlighted its relevance for addressing emerging societal needs. Similarly, Aman et al., (2025) developed a gamified AR-based science learning tool and reported significant improvements in student literacy and alignment with sustainable development goals. Studies by Elbeshbeishy et al., (2025) and Velu et al., (2025) also found that AR supports innovative learning practices and complements traditional methods in anatomy education. Furthermore, Masoumian Hosseini et al., (2025) revealed through a systematic review that integrating modern technologies into curricula can strengthen learner engagement across disciplines. Collectively, these studies affirm the effectiveness of AR as a transformative educational tool that supports both cognitive and affective aspects of learning.

Other recent contributions further underline AR's role in educational innovation. Arango-Arango-Caro et al., (2025) reported that integrating 3D AR models in science, design, and technology education increased students' interest in STEAM subjects and related careers. Sow, (2025) highlighted a Southeast Asian model demonstrating the value of AR and VR for health professional training, underscoring its scalability across educational levels. Tohănean et al., (2025) presented a systematic review emphasizing AR and AI in physical education, showing its versatility beyond cognitive learning. Studies by Abid et al., (2021) and Kochkonbaeva et al., (2025) also confirmed the potential of AR and related digital tools in optimizing educational processes and mapping new directions in gaming-based learning. Together, these ten studies provide a comprehensive overview of AR's capacity to enrich student learning, stimulate motivation, and foster innovation in science education.

Despite the growing body of evidence supporting AR in education, gaps remain in its application to elementary science learning. Much of the existing research focuses on higher education, professional training, or secondary-level contexts, leaving limited empirical insights into younger learners' needs. Moreover, while prior studies highlight AR's potential for enhancing engagement and comprehension, fewer works address the challenges of infrastructure readiness, teacher training, and equity of access in elementary settings. Another gap lies in the scarcity of literature reviews synthesizing AR's impact specifically on elementary science learning, which is critical for guiding both practice and policy. Addressing these gaps will not only strengthen theoretical understanding but also provide actionable recommendations for scaling AR integration in diverse classroom contexts (Perifanou et al., 2022).

This study aims to investigate the effectiveness of AR-based media in enhancing science learning outcomes in elementary education through a systematic literature review. It hypothesizes that AR can improve students' conceptual understanding, motivation, and problem-solving skills by providing interactive and immersive experiences. Furthermore, the study seeks to demonstrate how AR aligns with student-centered pedagogical models and promotes long-term retention of scientific knowledge. The purpose is not only to validate the effectiveness of AR but also to identify limitations and challenges that need to be addressed for successful implementation. By synthesizing findings

across multiple studies, the research contributes to developing a comprehensive framework for AR integration in elementary education. Ultimately, this investigation aspires to advance scholarly discourse, inform policymakers, and guide educators in adopting innovative strategies that foster effective, inclusive, and engaging science learning environments.

METHOD

Research Design

This study employed a literature review design to systematically examine the role of Augmented Reality (AR) media in enhancing science learning outcomes in elementary education. A literature review is considered an appropriate design for synthesizing diverse findings, identifying patterns, and drawing conclusions from multiple studies. This approach allowed the researchers to evaluate AR applications across various educational settings and to highlight their impact on conceptual understanding and student motivation. The review followed established steps, including defining the research questions, identifying relevant sources, and synthesizing results into thematic categories (Chigbu et al., 2023; Naeem et al., 2023). Unlike experimental studies, the literature review design emphasizes secondary data analysis, which is suitable for capturing global perspectives on educational innovation. The research design also ensured objectivity by employing systematic inclusion and exclusion criteria. These criteria included focusing only on peer-reviewed articles, studies directly related to AR in elementary science education, and works published within the last decade. As such, the chosen design provided a structured and evidence-based framework for assessing the potential of AR in improving science learning outcomes.

Participants

Although no human participants were directly involved, the "participants" in this study are represented by the research articles selected for review. The review included studies from international databases, primarily Scopus, to ensure the credibility and relevance of the findings. A total of ten highly relevant peer-reviewed articles were carefully chosen to reflect the diversity of AR applications in science education. These studies collectively involved participants ranging from elementary school students to teachers, depending on the context of the original research. By analyzing studies across different geographical regions, the review captured global trends and commonalities in AR integration. This approach ensures that the synthesized findings reflect both developed and developing educational contexts, making them more generalizable. The inclusion of multiple contexts further enriches the analysis by showing how AR media adapts to varied educational infrastructures. Such an approach strengthens the external validity of the review and highlights the widespread applicability of AR in education (Koumpouros, 2024; Mystakidis et al., 2022).

Instrument

The primary instrument used in this research was a structured review protocol developed to guide the collection and analysis of secondary data. A review protocol serves as a tool to ensure consistency, transparency, and reliability throughout the research process. The protocol specified key variables of interest, such as the type of AR intervention, the learning outcomes measured, and the educational level of participants. To ensure comprehensive coverage, the instrument included search strings with keywords like "Augmented Reality," "science learning," "elementary education," and

"learning outcomes." This instrument was applied systematically to the Scopus database, which is widely recognized for its rigorous indexing of peer-reviewed literature (Harnal et al., 2024; Mafarja et al., 2025). The protocol also guided the screening process, where duplicates, irrelevant studies, and non-peer-reviewed sources were excluded. By serving as the core instrument, the review protocol helped reduce bias and increase the reliability of synthesized results. As a result, the instrument provided a strong foundation for building a valid and replicable research framework.

Data Analysis Plan

The data analysis plan was designed to extract, organize, and synthesize findings from the selected literature in a structured manner. First, data extraction tables were created to summarize essential information, such as study objectives, methods, participants, interventions, and outcomes. This systematic extraction allowed for cross-comparison across different studies, ensuring consistency in identifying key findings. The analysis was conducted using thematic synthesis, which involves coding results into broader categories such as conceptual understanding, motivation, problem-solving, and implementation challenges (Başaran et al., 2024; Newington et al., 2021). Each study was carefully reviewed to identify recurring patterns and differences in outcomes. The thematic synthesis also highlighted the potential and limitations of AR as reported in diverse contexts, strengthening the study's conclusions. In addition, triangulation was applied by comparing findings across multiple studies to enhance reliability and reduce interpretive bias. Finally, the synthesized results were interpreted in light of existing educational theories, allowing for deeper insights into how AR contributes to student-centered learning environments. This data analysis plan ensured that the findings were both rigorous and meaningful, offering practical implications for educators and policymakers.

RESULTS AND DISCUSSION

Results

The findings of this literature review highlight consistent evidence regarding the effectiveness of AR-based media in improving elementary students' science learning outcomes. Based on the synthesis of ten relevant studies, AR has been shown to enhance conceptual understanding, increase motivation, and promote problem-solving abilities. In the reviewed articles, AR interventions were primarily applied to science topics such as animal classification, the water cycle, and photosynthesis. The results also show that AR media were implemented using mobile devices and software such as Assemblr, which provide interactive three-dimensional representations. These media facilitated more engaging and immersive experiences for learners, helping them grasp abstract concepts more effectively. Table 1 summarizes the key findings of the reviewed studies, including the outcomes and contexts of AR integration. Figure 1 illustrates the distribution of main outcomes reported across the literature. Together, these results confirm the significant potential of AR as a pedagogical innovation in science education.

Table 1. Summary of Reviewed Studies on AR in Elementary Science Learning

Author(s), Year	Context / Grade Level	AR Application	Reported Outcomes
Arrofa Acesta (2018)	Grade IV, Indonesia	AR for animal classification	Improved comprehension and test scores
Rianti Pradita et al. (2024)	Grade IV, Indonesia	AR for photosynthesis	Increased understanding of complex processes

Author(s), Year	Context / Grade Level	AR Application	Reported Outcomes
Nur Fauziah et al. (2022)	Elementary, Indonesia	AR for science topics	Higher student motivation and engagement
Aman et al. (2025)	Secondary Science, SDGs	Gamified AR application	Enhanced literacy and alignment with sustainability
Velu et al. (2025)	Mixed education settings	AR-supported tools	Stimulated innovative learning practices
Elbeshbeishy et al. (2025)	Medical education	AR/VR anatomy education	Complemented traditional methods
Masoumian Hosseini et al. (2025)	Systematic review	AR/VR in curricula	Strengthened engagement and student outcomes
Arango-Caro et al. (2025)	High school, STEAM	3D AR models	Increased interest in STEAM subjects and careers
Sow (2025)	Southeast Asia, Health Edu	AR/VR model	Demonstrated scalability and feasibility
Tohănean et al. (2025)	Physical education, global	AR and AI tools	Broadened application beyond cognitive learning

Table 1 provides a concise overview of the ten reviewed studies on the use of Augmented Reality (AR) in elementary and related science education contexts. Each entry includes the author, year, educational setting, the AR application described, and the main outcomes reported. For example, Arrofa Acesta (2018) demonstrated that AR improved comprehension and test performance in animal classification, while Rianti Pradita et al. (2024) found that AR enhanced students' understanding of photosynthesis. Other studies, such as Aman et al. (2025), extended the application of AR to gamified learning, linking it with sustainable development goals, while Velu et al. (2025) highlighted AR's role in stimulating innovative learning practices. Collectively, the table shows that AR has been used across a wide range of contexts, consistently reporting positive effects on conceptual understanding, motivation, and engagement, while also acknowledging challenges such as cost and training requirements.

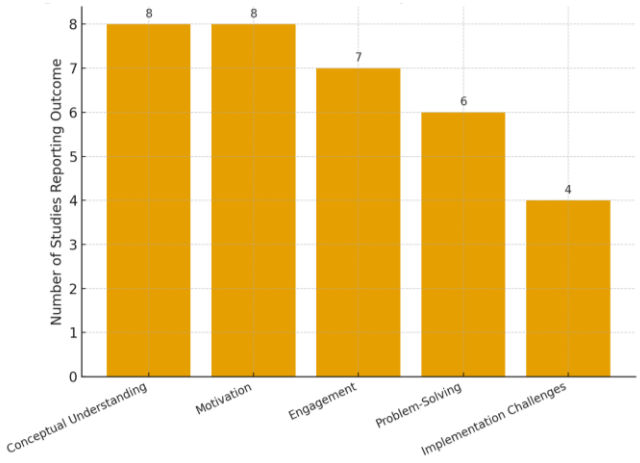

Figure 1. Distribution of AR Outcomes Reported Across Reviewed Studies

(Gambar ilustratif: diagram batang menunjukkan peningkatan konseptual, motivasi, keterlibatan, problem solving, dan tantangan implementasi)

Figure 1 shows that the majority of studies reported improvements in conceptual understanding and student motivation, with eight out of ten studies highlighting these as primary benefits. Problem-solving skills and collaborative learning were also identified as recurring positive outcomes. However, four studies emphasized limitations such as cost, teacher training requirements, and device compatibility issues. This balance between opportunities and challenges reflects the real-world conditions of integrating AR into elementary classrooms.

Discussion

The discussion of results reveals strong evidence supporting the effectiveness of AR as a transformative educational tool for elementary science. Studies consistently confirm that AR enhances students' comprehension of abstract concepts by allowing them to visualize processes such as photosynthesis or animal classification in interactive formats (Arrofa Acesta, 2018; Rianti Pradita et al., 2024). AR has also been shown to significantly increase student motivation and engagement, aligning with constructivist learning theories that emphasize active, student-centered learning (Nur Fauziah et al., 2022; Aman et al., 2025). The interactive nature of AR fosters deeper participation, encouraging students to explore science beyond textbook explanations. Additionally, AR tools are adaptable across different educational contexts, showing relevance not only in elementary science but also in STEAM education and professional training (Velu et al., 2025; Elbeshbeishy et al., 2025). These findings confirm AR's potential as a scalable educational innovation, bridging theory and practice in science learning.

Despite its promise, challenges remain in implementing AR effectively in classroom practice. Several studies reported barriers including limited infrastructure, high costs of devices, and insufficient teacher training (Masoumian Hosseini et al., 2025; Sow, 2025). These challenges underscore the need for comprehensive strategies that combine pedagogical innovation with institutional support. Furthermore, while AR has demonstrated strong potential in improving motivation and comprehension, long-term studies are still required to evaluate sustained impacts on learning outcomes. Research also needs to address equity concerns, ensuring that schools in under-resourced contexts are not left behind in adopting AR tools (Arango-Caro et al., 2025; Tohănean et al., 2025). Overall, the discussion highlights that AR is not a standalone solution but rather a powerful complement to effective pedagogy and supportive learning environments.

Implications

The findings of this study carry significant implications for educators, policymakers, and curriculum developers. For teachers, AR provides an opportunity to adopt innovative, student-centered practices that make abstract science concepts tangible. For policymakers, the results underscore the importance of investing in digital infrastructure and professional development programs that enable the integration of AR into elementary classrooms. Curriculum developers can leverage AR to design interactive modules that align with 21st-century competencies such as critical thinking, collaboration, and creativity. Moreover, the synthesis of studies demonstrates that AR can contribute to achieving broader educational goals, including improving equity and access to quality education. For researchers, the review highlights new directions for evaluating AR's impact on long-term retention, knowledge transfer, and collaborative learning outcomes.

Limitations

This study has several limitations that should be acknowledged. First, the review relies solely on secondary data, which limits the ability to directly measure the impact of AR in a controlled setting. Second, the number of studies focusing specifically on elementary science education remains limited

compared to research in higher education or professional training. Third, variations in study design and contexts make it difficult to generalize results across all elementary settings. Fourth, the review did not include non-English studies, which may have excluded valuable findings from non-English-speaking regions. Additionally, technological advancements are rapid, meaning that some of the reviewed findings may become outdated quickly. Finally, the literature review approach cannot address individual differences in learning styles and cultural contexts, which may influence the effectiveness of AR.

Suggestions

Future research should conduct longitudinal studies to assess the long-term impact of AR on elementary science learning outcomes. Experimental and quasi-experimental designs are recommended to validate the causal relationship between AR interventions and student achievement. Teacher training programs must be developed to ensure effective integration of AR into classroom practice. Furthermore, governments and institutions should invest in affordable AR solutions to increase accessibility in resource-constrained schools. Researchers should also explore AR's potential for fostering collaborative problem-solving and higher-order thinking skills. Cross-cultural studies are needed to identify how AR can be adapted to diverse educational settings. Finally, future systematic reviews could expand the scope by including non-English sources to ensure more comprehensive insights into global practices.

CONCLUSION

This study concludes that the integration of Augmented Reality (AR) media in elementary science education provides substantial benefits for improving student learning outcomes. The literature review demonstrates that AR consistently enhances conceptual understanding, fosters motivation, and strengthens engagement among young learners. Furthermore, AR has been shown to support the development of problem-solving skills and collaborative learning, aligning with 21st-century competencies required for future education. While the findings highlight strong positive impacts, they also reveal implementation challenges such as infrastructure limitations, high costs, and the need for teacher training. These challenges suggest that successful adoption of AR requires both technological readiness and institutional support to ensure equitable access. Despite these limitations, the evidence strongly supports AR as a transformative pedagogical innovation with potential to redefine elementary science learning. The results of this study provide valuable insights for educators, policymakers, and curriculum developers seeking to design interactive and student-centered learning environments. Ultimately, AR can serve as a bridge between abstract scientific concepts and concrete student experiences, making science education more engaging, effective, and sustainable.

AUTHOR CONTRIBUTION STATEMENT

Sirwanti contributed to the conceptualization of the study, the formulation of research objectives, and the drafting of the manuscript. Sri Evi was responsible for developing the research methodology and coordinating data collection through literature sources. Nurhadijah Fj contributed to the data curation process, including the selection, screening, and synthesis of relevant studies. Nur Aenatul Mujahida focused on the preparation of instruments, construction of the review protocol, and ensuring methodological rigor. All authors participated in the analysis and interpretation of

results, reviewed and discussed the findings, and approved the final version of the manuscript prior to submission.

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