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Effectiveness and Challenges of Implementing Augmented Reality (AR) Technology in Science Learning in Elementary Schools: A Literature Study

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A B S T R A C T

In the era of digital technology advancement, education is also evolving rapidly. This provides a great opportunity for teachers to improve the quality of the teaching and learning process, especially in teaching media. One of the emerging technologies is augmented reality (AR) which combines the real world with digital elements to provide a more interactive and visual learning experience. This article aims to explore the effectiveness of using AR in learning science in elementary schools, especially in improving the understanding of abstract concepts that are difficult to understand. Through a literature review of previous studies, this article highlights the benefits of AR such as increased student understanding, learning engagement, and motivation. However, challenges such as limited infrastructure, high costs, and teacher readiness still hinder its implementation. This study concludes that AR has great potential to transform science learning, although it requires appropriate implementation strategies, including adequate infrastructure, teacher training, and relevant content development. Based on the literature review, the development of curriculum-appropriate AR applications and their long-term implementation is still not widely explored and can be the focus of future studies.

1. Introduction

Advances in digital technology have significantly transformed educational practices, particularly in the development of innovative learning media. One emerging technology that has gained considerable attention is Augmented Reality (AR), which integrates real-world environments with interactive digital elements. In educational contexts, AR enables learners to visualize abstract concepts through three-dimensional representations and interactive simulations. Previous studies indicate that AR can enhance students' immersive learning experiences,

particularly in science education at the elementary level (Karang et al., 2024; Riyanti et al., 2024). Through dynamic visualization, AR facilitates the explanation of abstract scientific concepts such as the solar system, photosynthesis, and the water cycle, which are often difficult to comprehend using conventional instructional approaches (Saputri & Susilowati, 2022). Furthermore, AR-based learning media have been shown to increase students' motivation and active participation by creating engaging and interactive learning environments (Setyawan et al., 2019).

Despite its potential, the implementation of AR in elementary schools is not without challenges. Limited technological infrastructure, insufficient teacher training, and lack of curriculum integration remain significant barriers to effective adoption (Fearn & Hook, 2023). In many primary school contexts, access to adequate digital devices and stable internet connectivity is still uneven. Moreover, teachers may experience difficulties in integrating AR into pedagogical practices due to limited technological competence and instructional design skills. While AR has demonstrated promising outcomes in improving conceptual understanding, its sustainable and systematic application in elementary science classrooms requires further investigation. Empirical evidence suggests that AR-assisted multimedia improves students' conceptual understanding (Febriyanti & Andriani, 2025), while curriculum-aligned AR modules further enhance learning through immersive visualization (Syahrir et al., 2025). However, these findings also highlight the need for comprehensive evaluation regarding long-term implementation and contextual challenges in primary education settings.

Science learning at the elementary level continues to encounter difficulties, particularly when addressing abstract processes that are not directly observable. Conventional teaching methods often rely heavily on textbooks and static images, which may limit students' conceptual comprehension. AR technology offers an alternative instructional approach by enabling students to interact with virtual three-dimensional objects embedded in real-world environments. This interactive visualization supports deeper cognitive processing and experiential learning. Nevertheless, the effectiveness of AR integration is influenced by several contextual factors, including infrastructure readiness, teacher competence, and institutional support (Suryaning et al., 2022). Additional challenges such as high development costs, limited access to digital devices, and insufficient professional training further constrain its widespread implementation (Alzahrani, 2020; Yulia, 2024).

A number of studies have examined the educational benefits of AR technology. Research by Purnama et al. (2024) demonstrates that AR facilitates students' understanding of difficult scientific concepts through interactive visualization. Similarly, Winarni and Purwandari (2023) report increased student motivation when AR is integrated into science instruction. Inquiry-based AR media have also been found to enhance both conceptual understanding and learning motivation (Sudarno et al., 2025). In addition, broader literature reviews confirm that interactive media, including AR, positively impact science learning effectiveness in elementary schools (Prayoga et al., 2025). While these studies consistently

highlight the cognitive and motivational benefits of AR, relatively limited research has comprehensively examined the combined aspects of effectiveness and implementation challenges within the context of elementary science education in Indonesia.

From a theoretical perspective, the application of AR in science learning can be understood through several foundational frameworks. Constructivism Theory emphasizes that knowledge is actively constructed through direct interaction with the environment. AR aligns with this perspective by enabling experiential and interactive learning processes (Wahyuningsih, 2021). Cognitive Theory of Multimedia Learning (CTML) suggests that learning is more effective when information is presented through integrated visual and verbal channels, a principle strongly reflected in AR-based multimedia environments (Riyanti et al., 2024).

Cognitive Load Theory (CLT) further explains that instructional design should minimize unnecessary cognitive burden; AR may reduce cognitive overload by presenting complex scientific phenomena in simplified visual forms (Suryaning et al., 2022). Additionally, the Technology Acceptance Model (TAM) provides a framework for understanding teachers' and students' acceptance of AR technology, which is influenced by perceived usefulness and ease of use (Fearn & Hook, 2023). These theoretical foundations collectively support the pedagogical relevance of AR in elementary science education.

Although prior studies have established the benefits of AR in improving learning outcomes and motivation, gaps remain regarding systematic evaluation of both its effectiveness and the practical challenges of implementation within primary school contexts. Many studies focus primarily on short-term experimental outcomes without sufficiently addressing sustainability, infrastructural readiness, teacher preparedness, and curriculum alignment. Consequently, a comprehensive synthesis of existing research is necessary to provide a clearer understanding of how AR can be effectively integrated into elementary science education while addressing contextual constraints.

Therefore, this study aims to examine the effectiveness and challenges of implementing Augmented Reality (AR) technology in elementary school science learning through a systematic literature review approach. Specifically, this study seeks to analyze the extent to which AR enhances students' conceptual understanding and learning motivation in science subjects, and identify key implementation barriers, including infrastructure limitations, teacher readiness, and curriculum compatibility. By synthesizing findings from previous research, this article is expected to contribute theoretically to the development of educational technology studies and provide practical recommendations for educators, curriculum developers, and policymakers in optimizing the integration of AR to improve the quality of science learning at the primary level.

2. Methodology

This study uses the Systematic Literature Review (SLR) method to identify, evaluate, and synthesize research results related to the implementation of Augmented Reality (AR) in science learning in elementary schools. This approach allows for a deeper understanding of the effectiveness as well as the challenges faced in implementing AR in an educational context. This study analyzes two main variables, namely the application of AR technology in science learning in elementary schools as the independent variable, and the effectiveness and challenges of AR application as the dependent variable.

The data sources used consist of primary data and secondary data. Primary data was obtained through interviews and direct observation to explore in-depth information about teachers' and students' experiences in using AR during the learning process. This technique was used to identify key themes, patterns, and inferences from actual practices occurring in the field. Meanwhile, secondary data was collected through literature studies related to the use of AR in science learning in elementary schools. This approach helps to summarize and synthesize existing information, in order to provide a comprehensive understanding of the topic under study.

The data collected was analyzed using two techniques: content analysis, which focused on reviewing relevant articles to identify common patterns and themes related to the use of AR in science learning, and thematic analysis, which was used to group findings based on the main themes that emerged in the literature. This approach provides greater insight into the effectiveness and challenges of AR implementation in primary school settings.

A number of previous studies were used as key references in support of this study. Studies conducted by Karang et al. (2024) and Riyanti et al. (2024) showed that AR can improve students' understanding of abstract concepts in science. Setyawan et al. (2019) and Winarni and Purwandari (2023) highlighted the increase in student motivation and participation through interactive and fun AR media. On the other hand, research by Fearn and Hook (2023), Rosmaria and Mairisiska (2024), and Suryaning et al. (2022) highlighted key challenges such as infrastructure limitations, teacher readiness, and technology integration in the curriculum. The study from Dilmen and Atalay (2021) also strengthens the argument regarding the importance of systemic support in the implementation of AR-based learning technology in elementary schools.

3. Results and Discussion

The results of the literature review show three major themes in the implementation of AR: increasing understanding of abstract concepts, increasing student motivation and engagement, and infrastructure and human resource challenges including:

a. Benefits of Augmented Reality Implementation in Science Learning in elementary school One of the benefits found is the increase in students'

understanding of abstract scientific concepts, this AR technology helps students to see interactive three-dimensional visualizations of scientific phenomena or objects such as the solar system, the water cycle to the photosynthesis process. This helps students to understand the material more easily (Purnama et al., 2024; Rosmaria & Mairisiska, 2024; Riyanti et al., 2024; Karang et al., 2024; Widianto et al., 2021). This is also supported by the research findings of Saputri and Susilowati (2022) which states that AR significantly helps improve student understanding compared to conventional methods that are difficult to visualize (Ryni & Sukarmin, 2025). These findings are consistent with the study by Febriyanti and Andriani (2025), which reported measurable improvements in elementary students' achievement after integrating AR-based interactive multimedia into science instruction.

b. Increased Student Motivation and Engagement. Besides helping to improve student understanding, based on research by Setyawan et al. (2019), Riyanti et al. (2024), Rosmaria and Mairisiska (2024), Dilmen & Atalay (2021) the use of AR in the learning process also states that the use of AR in the classroom makes students more excited and motivated to learn because it offers a fun and interactive learning experience. The active involvement of students during the learning process is proven to be able to foster curiosity and enthusiasm for learning in students. According to Winarni and Purwandari (2023) the use of AR coupled with STEAM-based blended learning significantly increases student learning motivation because they have the opportunity to explore independently through interactive learning media. Supporting this argument, Sudarno et al. (2025) emphasized that AR integration within inquiry-based learning environments fosters active participation and strengthens students' intrinsic motivation during science learning activities.

c. Challenges of AR Implementation in Science Learning at Elementary School. This literature review also found a number of challenges in using AR technology in elementary schools. Among them are the limitations of technological infrastructure such as the availability of hardware such as tablets or smartphones and inadequate internet connections (Fearn & Hook, 2023; Winarni & Purwandari, 2023; Adebagbo et al., 2024; Familoni & Onyebuchi, 2024). In addition, a significant challenge is the readiness and competence of teachers to incorporate AR into the learning process. According to Winarni and Purwandari (2023), Fearn and Hook (2023), Adebagbo et al. (2024), and Wahyuanto et al. (2024) teachers who lack special training related to the use of AR in learning usually have low self-confidence so that it can hinder the effectiveness of using AR in the classroom. In addition, problems related to costs that are quite expensive to procure AR technology and develop applications that are used for interactive learning and in accordance with the curriculum so that in some schools the implementation of AR in schools as a learning resource is uneven (Familoni & Onyebuchi, 2024; Rosmaria & Mairisiska, 2024).

d. Strategies for Optimizing AR Implementation in Primary Schools.
The challenge to optimize the use of AR in elementary schools is quite high, but when calculating the magnitude of the benefits offered by this advanced technology several studies have provided several strategic recommendations to help improve the effectiveness of AR implementation in the school environment such as, providing adequate devices and stable internet connectivity (Widianto et al., 2021; Rosmaria & Mairisiska, 2024). Then, for teachers who still lack confidence, intensive ongoing training can be provided regarding the effective use of AR technology. The training is expected to not only focus on technical but also on pedagogical aspects so that teachers are able to use AR in learning maximally (Setyawan et al., 2019; Winarni & Purwandari, 2023; Adebagbo et al., 2024). Finally, the development of AR content that is in accordance with the curriculum and is user friendly to maintain the purpose of using it which is not only interesting but also effective in the learning process (Riyanti et al., 2024; Saputri & Susilowati, 2022). Syahrir et al. (2025) emphasized the importance of curriculum-aligned AR modules to ensure pedagogical relevance and usability in primary education. It is hoped that by applying the strategies that have been given by previous researchers AR technology can be optimized so that the existing challenges can be resolved or minimized so that the use of AR can improve the quality of the teaching and learning process in schools, especially science learning in elementary schools optimally (Arici et al., 2021; Mardiwati et al., 2024).

Based on the results of the research that has been presented, the implementation of AR in the science learning process can offer solutions to conventional challenges in the learning process, especially in conveying abstract processes visually, the benefits obtained such as increased understanding of concepts and active participation from students are directly proportional to the theory of constructivism which states that students learn more effectively when they are active and involved (Riyanti et al., 2024; Saputri & Susilowati, 2022) indirectly this also states that the effective use of AR not only has the potential to improve learning outcomes in the short term but can strengthen motivation and interest in learning science continuously.

Another finding is that the benefits of AR technology can only be effective and optimal if supported by adequate technological infrastructure and teacher resource readiness. The research results of Adebagbo et al. (2024) and Fearn and Hook (2023) stated strongly regarding intensive training and support for teachers to be more confident and have good competence in using AR technology in the learning process. Based on the analysis of these studies, a more holistic approach to implementation is needed, which includes increased funding for technology infrastructure at the primary school level, continuous teacher training, and cooperation between technology developers and educational institutions to create AR applications that meet the needs of the curriculum and the characteristics of students in primary schools.

As a complement to the description, this article presents a synthesis of the results of the review of various previous studies in the form of a table, which summarizes the objectives, methods, main findings, and implications and novelty of each study reviewed. This table is compiled to provide a more systematic and comprehensive picture of the contribution of each study to the understanding of the effectiveness and challenges of implementing AR in science learning in elementary schools, while strengthening the basis for the recommendations proposed in this article. The synthesis can be seen more clearly in Table 1, which presents a comparative summary of the various studies analyzed in this study.

Table 1. Results of Literature Review

No	Author & Year	Research Objective	Method	Key Findings	Implications	Novelty
1	Karang et al. (2024)	Examining the impact of AR in science learning on elementary school students' understanding	Quantitative experiments	AR significantly improves understanding of science concepts compared to conventional methods.	AR can be used as a visualization tool for conceptual learning.	Testing the influence of AR on understanding specific science material
2	Setyawan et al. (2019)	Developing and testing the effectiveness of AR media in elementary school science education	R&D	AR effectively attracts students' interest in learning and increases engagement.	Teacher training is needed to optimize the use of AR.	Focus on developing AR media that has been tested directly on elementary school students.
3	Riyanti et al. (2024)	Analyzing the effectiveness of using AR in science learning in elementary schools	Systematic Literature Review	AR has a positive impact on student understanding, motivation, and interaction.	There is a need for technology-based curriculum development with AR integration.	Compilation and synthesis of AR literature in science learning in elementary schools
4	Dilmen & Atalay (2021)	Analyzing the effect of AR application on students' 21st century skills and basic skills	Quasi-eksperimen	AR enhances students' creativity, problem solving, and collaboration	AR supports the development of future skills in science learning	Focus on 21st century skills that are rarely evaluated in the AR context
5	Fearn & Hook (2023)	Exploring barriers and opportunities for the use of AR in elementary school science education	Qualitative (service design)	Barriers: infrastructure & training; Opportunities: immersive learning experiences	AR implementation requires policy support and technological infrastructure in schools.	Using a service design approach in the context of science education
6	Rosmaria & Mairisiska (2024)	Examining the effect of AR technology on science learning outcomes of elementary school students	Experiment	Significant improvement in student learning outcomes and understanding	AR can be used as the main media in experience-based learning	Recent empirical studies showing the impact of AR on learning outcomes
7	Winarni & Purwandari (2023)	Integrating AR with STEAM approach through blended learning	Experiment	AR+STEAM enhances creativity and understanding of interdisciplinary concepts	The combination of AR and STEAM opens up opportunities for integrated learning innovation.	A unique integration of AR, STEAM, and blended learning in an elementary school context
8	Suryaning et al. (2022)	Develop AR program media for elementary school students	R&D (ADDIE)	Interactive AR media is interesting and effective in	AR media must be developed based on	Development of ADDIE-based AR media for specific

	on science material	helping to understand science material.	curriculum and student needs.	elementary school science content

Literature Review Results

Based on the results of the table synthesis, it can be seen that most studies focus on the effectiveness of AR in improving understanding of scientific concepts and student learning outcomes. Some studies also highlighted the increase in student motivation and engagement, as well as the integration of AR with STEAM-based curriculum approaches. However, aspects such as the development of critical thinking skills or 21st century abilities are still relatively rarely studied in depth. To provide a clearer visual picture of the distribution of these foci, this article also includes an analytical chart showing the proportion of each research theme. This visualization reinforces the argument that while AR has great potential, there is still ample room for further research targeting other important aspects of the learning process in primary schools. The distribution of the focus of the study can be seen in Figure 1, which presents a visualization of the proportion of the main themes in research related to the use of AR in primary school science learning.

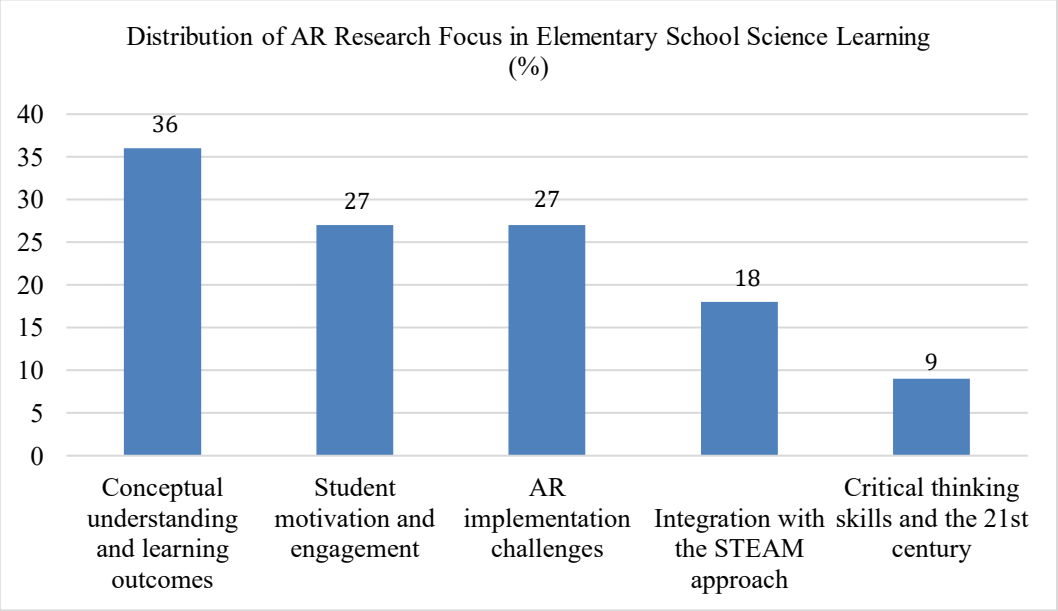

Figure 1. Distribution of AR Research Focus in Elementary School Science Learning

The graph above presents the percentage distribution of the focus of research studies on the application of Augmented Reality (AR) in science learning in elementary schools. It can be seen that the largest portion, about 36%, comes from studies that focus on improving students' concept understanding and learning outcomes. Furthermore, 27% of studies focused on aspects of learner motivation and engagement, and another 27% discussed AR implementation challenges such as infrastructure limitations and teacher readiness. On the other hand, the integration of AR with curriculum approaches or learning models such as STEAM was only reflected in 18% of the studies, and the least, 9%, addressed the

development of critical thinking skills and 21st century capabilities. This finding suggests that although AR has been extensively researched in the cognitive context, there is still a great opportunity to expand the research focus towards other competencies that are essential in modern learning.

4. Conclusion

Overall, the use of Augmented Reality (AR) technology in the learning process of Natural Sciences (IPA) in elementary schools shows high potential to improve understanding of abstract scientific concepts, increase student motivation and activeness in the learning process. Based on the literature review that has been found, AR is proven to be effective for enhancing students' learning experience through interactive and three-dimensional visualizations that help students understand difficult material. On the other hand, there are many challenges that must still be faced to optimize the use of AR in the learning process such as limited infrastructure, high costs and teacher readiness to use this technology.

This study also paid attention to the importance of developing technological infrastructure in elementary schools supported by continuous training so that teachers can use AR optimally, for further research it is recommended to conduct research related to the long-term implementation of AR as well as the development of AR media that are more relevant to the needs of students. For future studies, it is recommended that more in-depth investigations be conducted on the application of AR in education for a long period of time, as well as creating AR that is more in line with the curriculum and the needs of students. This research should also further investigate ways to overcome technical and cost constraints in the use of AR at the basic education level.

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