Exploring the Effectiveness of Augmented Reality as a Science Visualization Tool for Elementary Students

Cut Rania Kirana[1], Wahyu Sopandi[2], Febrialita Salma Dwinandha Putri[3], Istiqomah[4]

[1,2,3, 4] Basic Education, Education University of Indonesia, Bandung, Indonesia

*cutrania.kirana55@upi.edu, wsopandi@upi.edu, blorasalma394@gmail.com, istiqomah21@upi.edu

Abstract. Education in the era of Smart Society 5.0 faces challenges in integrating advanced technology into various sectors, including science education at the elementary school. This study aims to explore the effectiveness of augmented reality (AR) as a visualization tool in science education and its impact on teaching and learning processes. The study method used was a systematic literature review (SLR) by analyzing ten articles published between 2014 and 2024. The results showed that AR has a significant positive impact on student learning outcomes, including improved understanding of science concepts, interest, and engagement, as well as the development of critical thinking and visualization skills. AR also creates an interactive and immersive learning experience, allowing students to better understand abstract concepts. Although the results are promising, the effectiveness of AR largely depends on the quality of the content, integration in the curriculum, and support from educational institutions. Further study is required to evaluate the long-term impact of AR on learning and knowledge transfer to real-world applications. These findings suggest that AR can be an innovative solution to enhance the science learning experience in elementary schools.

Keywords: augmented reality, science education, visualization tool, students, elementary school.

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INTRODUCTION

Education is an indispensable component of existence. The significance of education is on the rise in the Smart Society 5.0 era, as technology has become an integral component of daily life. Society 5.0 brings changes by integrating artificial intelligence and other advanced technologies into various sectors, including education. This era focuses not only on automation and efficiency but also on the balance between technology and human values.

Education and technology have become increasingly intertwined in the 21st century. This relationship has transformed traditional pedagogical approaches, enabling the development of innovative learning methods that enhance student engagement and understanding. The integration of technology in education not only accesses the wealth of information but also fosters interactive and personalized learning experiences. Technological advancements hold immense promise for transforming education by personalizing learning, enhancing engagement, and improving access to quality content (Badawy et al., 2024). As technology advances, incorporating innovative tools and platforms into the educational landscape has become essential for developing a more efficient, interactive, and relevant learning system. In this transformative era, the education sector encounters several challenges, one of which is the barriers to learning science in elementary schools. Even with the swift advancement of information and communication technology, disparities in learning

approaches and student engagement continue to hinder the attainment of science education objectives.

Science education at the elementary level is essential for laying the foundation for students' understanding of scientific principles and their applications. Science education aims to provide students with a basic understanding of nature and scientific phenomena. Unfortunately, many students have difficulty understanding scientific concepts. Research conducted by Rahmah & Harahap (2024) showed that fifth-grade students experienced difficulties in science learning, with 74% of them achieving low scores. The existing curriculum often focuses more on mastering facts and theories without providing a clear context or practical application, so students cannot relate their knowledge to their daily experiences. One of the primary reasons for this is the limited availability of engaging and interactive teaching resources. A study by Ameliya & Setyawan (2020) revealed that more than half of the students (14 out of 24) struggled to comprehend the content presented, primarily due to a lack of engagement and the implementation of monotonous teaching strategies.

Traditional teaching methods, which often rely on the use of textbooks as the main source of learning, may be less effective in capturing the attention and interest of students, especially elementary school students (Ginting et al., 2023). Textbooks are typically structured in a theoretical and dense format, with few visual or interactive elements that can help early learners process information more deeply. This leads many students to struggle to understand complex scientific concepts. Additionally, the use of textbooks is often teacher-centered, where teachers act as the primary source of knowledge, and students passively receive information (Abid et al., 2022). This approach often does not involve active exploration or experiential learning, which is critical for strengthening children's understanding of science. As a result, many students feel bored or uninterested in science subjects because they do not see the direct relevance between the theories learned in books and everyday life.

Educators face the challenge of crafting innovative methods for delivering course material, allowing students to connect their learning to practical, real-world contexts. One promising approach that has attracted significant attention is augmented reality (AR), a technology that integrates digital content with physical environment to provide an engaging an interactive educational experience. However AR is not the only innovative solution that is available. Other advancements, such as gamification and virtual reality (VR) also show significant potential in transforming education. For instance, gamification leverages game-based elements to increase motivation and engagement (Alshammari, 2020). While VR can help improve students' interest, enthusiasm, and willingness to engage with learning material (Riyana & Setiawan, 2023). In the context of elementary science education, AR has

demonstrated numerous advantages, such as transforming abstract concepts into more concrete and comprehensible forms. Students can enhance their learning outcomes by interacting with and manipulating virtual 3D models, which can help them develop a more profound understanding of the underlying principles and processes (Soo et al., 2019). Moreover, augmented reality can foster collaborative learning, as students can work together to explore and solve problems. This collaborative approach not only improves the learning experience but also assists in the development of critical social and communication skills.

Augmented reality gives an opportunity to enhance student engagement and motivation. This is supported by a study conducted by Sampaio & Almeida (2018) which demonstrates that students exhibit a strong interest in the interaction provided by AR, leading to heightened motivation to complete the tasks assigned by the teacher. Furthermore, the use of AR was associated with increased comprehension, with 73% to 81% of students indicating that they understood the material better after using augmented reality. AR also addresses numerous deficiencies in activities that required an immersive experience that was previously unattainable (Liono et al., 2021). By providing a more immersive and interactive learning environment, augmented reality can capture students' attention and spark their curiosity, which motivates them to take an active role in their educational journey. AR also provides an opportunity for teachers to deliver diverse lessons consistently, preventing monotony and enhancing a rich learning experience. Considering the points discussed, this study seeks to investigate the effectiveness of augmented reality (AR) as a visual tool in science education for elementary school students. This study will also explore how the implementation of AR technology can improve the educational experience, particularly in grasping intricate scientific ideas.

METHODOLOGY

This study employs the systematic literature review (SLR) method. A systematic literature review (SLR) is a methodical approach that facilitates the discovery of relevant data on a specific subject based on established eligibility criteria in order to address the formulated research questions (Fitrianto et al., 2023) This research has multiple stages: creating research questions, conducting a literature search, establishing inclusion and exclusion criteria, selecting relevant literature, and deriving conclusions from the analysis results (Oktaviani et al., 2024)

The procedure for gathering information included an extensive examination of various studies, with the article search refined to ensure a more targeted analysis. The data collection technique in this research was conducted through a literature review. The articles used were

obtained by searching with the Publish or Perish criteria on Google Scholar and several other websites to find journals and scientific articles. Google Scholar provides a broad index of scientific publications, including reputable journals and conference papers, making it easier to access a wide range of information sources. The keywords used in the search were “augmented reality” and “science learning in elementary schools.” The selected articles were published in either Indonesian or English, within the period of 2014 to 2024, to ensure the relevance of the articles. The search resulted in 160 journals matching the keywords.

The next step involved screening the journals to determine inclusion and exclusion criteria. The inclusion criteria included: 1) studies discussing augmented reality, 2) studies examining the application of augmented reality in science learning, and 3) studies demonstrating how AR can enhance science learning for students. Meanwhile, the exclusion criteria included: 1) studies unrelated to AR, and 2) studies that do not address the application of AR in science learning. Once the relevant journals were collected and categorized, the next stage was data analysis. The analysis involved reviewing the content of the selected journals and articles, followed by compiling the results. Through systematic analysis and synthesis of various studies, this research aims to gain a deeper understanding of the potential of augmented reality as an effective tool for improving science learning in elementary schools.

RESULTS AND DISCUSSION

Augmented reality has become known as a significant technology in education, providing innovative pathways to improve the learning experience. Augmented reality is a three-dimensional technology that integrates digital information into real-world environments, enabling users to engage with virtual objects and content effortlessly (Huang et al., 2021). This technology holds the promise of revolutionizing student learning by allowing for a more immersive and interactive engagement with educational content (Elmqaddem, 2019). One of the most significant advantages that augmented reality brings to the field of education is its capacity to improve both visualization and interaction strategies. By integrating virtual elements into the physical world, augmented reality can provide students with a more tangible and engaging learning experience. According to the author's analysis of the relevant literature, there are ten studies that are related to the use of augmented reality as a visual tool for students. These studies are as follows:

Table 1. Literature Review on Augmented Reality in Education

No	Author (Year)	Title of Article	Journal
1	Guntur et al. (2020)	Assessing the Potential of Augmented Reality in Education	Proceedings of the 2020 11th International Conference on E-Education, E-Business, E-Management, and E-Learning
2	Bistaman et al.(2018)	The Use of Augmented Reality Technology for Primary School Education in Perlis, Malaysia	Journal of Physics: Conference Series
3	Raju et al. (2018)	3D-Based Modern Education System Using Augmented Reality	IEEE 6th International Conference on MOOCs, Innovation, and Technology in Education (MITE)
4	Shirley & Malathi (2020)	A Preview of Augmented Reality as a Pioneering Method in Education	IEEE 9th International Conference System Modeling and Advancement in Research Trends (SMART)
5	Rachim et al. (2024)	The Utilization of Augmented Reality as Learning Media on Student Learning Activeness in Modern Education	JRIP: Jurnal Riset dan Inovasi Pembelajaran
6	Fakhrudin & Kuswidyanarko (2020)	The Effectiveness of the Augmented Reality-Based Learning Media Application on Students's Interests and Learning Outcomes of Science Subjects at Elementary Schools	Atlantis Press: Proceedings of the 2nd International Conference Innovation in Education (ICoIE 2020)

No	Author (Year)	Title of Article	Journal
7	Prananta et al. (2024)	Augmented Reality for Interactive, Innovative, and Fun Science Learning: Systematic Literature Review	JPPIPA: Jurnal Penelitian Pendidikan IPA
8	MZ et al. (2022)	Science Augmented Reality Program Media for Elementary Students	JPI: Jurnal Pendidikan Indonesia
9	Safira et al. (2022)	Effectiveness of Augmented Reality (AR) on Elementary School Science Learning Concepts	KLASIKAL: Journal of Education, Language Teaching, and Science
10	Putra et al. (2024)	Exploring Augmented Reality-Based Learning Media Implementation in Solar System Materials	IJORER: International Journal of Recent Education Research
11	Utama et al. (2024)	The Effect of Using AR Technology in Science Learning on Understanding Learning Materials	Jurnal Review Pendidikan dan Pengajaran
12	Setyawan et al. (2019)	Augmented Reality in Science Learning for Elementary Students	Kwangsan: Jurnal Teknologi Pendidikan
13	Anggun et al. (2024)	The Role of Augmented Reality Media to Improve Students' Understanding of Science Learning of Electrical Circuit Material	Adi Karsa: Jurnal Teknologi Komunikasi Pendidikan
14	Hadi et al. (2024)	Analysis of the Application of Augmented Reality Media to Improve the Learning Outcomes	Pendas: Jurnal Ilmiah Pendidikan Dasar

No	Author (Year)	Title of Article	Journal
		of IPAS students in Grade V Elementary School	
15	Sapulette (2023)	The use of Augmented Reality (AR) Learning Media in improving Student Learning Outcomes	Journal on Teaching Education

After reviewing the articles in Table 1, a detailed discussion of each article's findings and implications is summarized and presented in Table 2 below. This table provides an overview of key points and highlights the main contributions drawn from each study, offering insights into how the research aligns with the broader exploration of augmented reality (AR) in education. Table 2 serves as a comparative analysis, allowing for a clearer understanding of the effectiveness, challenges, and applications of AR across various educational contexts, particularly in science learning for elementary students.

Table 2. The Results of Relevant Research on Augmented Reality in Education

No	Author (Year)	Research Result
1	Guntur et al. (2020)	The research in this journal shows that augmented reality (AR) has a significant positive impact on student learning outcomes. AR helps students develop their spatial skills, which are important for various disciplines. The use of AR in learning improves students' problem-solving skills, enabling them to tackle academic challenges more effectively.
2	Bistaman et al. (2018)	The research findings in this journal show that augmented reality (AR) technology has significant potential to enhance the teaching and learning process in primary schools, particularly in Perlis, Malaysia. The use of AR can increase student motivation and engagement, making the learning experience more interactive and engaging compared to traditional teaching methods. AR can be adapted to different learning styles of

No	Author (Year)	Research Result
		students, creating a more inclusive and effective learning environment. AR helps students visualize difficult concepts.
3	Raju et al. (2018)	The research in this journal clearly shows that the use of augmented reality (AR) in 3D-based educational systems can significantly improve student understanding and motivation. With the interactive and immersive approach offered by AR technology, students can more easily understand the subject matter. The research also highlights that AR as an effective educational tool enables the use of reusable 3D models and improves students' visualization skills.
4	Shirley et al. (2020)	The research findings in this journal show that augmented reality (AR) has significant potential to enhance the learning experience at various levels of education, including primary education, and has been shown to be effective in improving students' spatial skills, which are important for various disciplines. The use of AR can stimulate critical thinking in students, helping them become more engaged in the learning process. AR can increase student motivation by making learning more intriguing and interactive. AR was instrumental in adapting online education during the pandemic, demonstrating its ability to support learning in unusual situations.
5	Rachim et al (2024)	The research in this journal has shown that augmented reality (AR) can increase students' motivation and interest in learning, making them more engaged in the process. The use of AR can stimulate critical thinking and improve students' learning performance. AR creates a more interactive and engaging learning experience, helping students to better understand abstract concepts.
6	Fakhrudin, Ali and Arief Kuswidyanarko (2020)	The research results from the journal indicate that the implementation of AR-based learning media significantly improved both student interest and learning outcomes in science subjects among fifth-grade elementary students in Palembang, Indonesia. The experimental group using AR

No	Author (Year)	Research Result
		showed an increase in interest scores from 53.13 to 72.47, while the control group using traditional methods only increased from 55.50 to 62.93. The average post-test score for the experimental group was 84.64, compared to 64.59 for the control group.
7	Prananta et al. (2024)	The research in this journal identifies augmented reality (AR) technology as having enormous potential to enhance the learning experience in science education. AR serves as an effective learning tool that helps students develop critical and abstract thinking skills. The use of AR in science learning makes the learning process more interactive, innovative, and fun, which in turn increases student engagement and understanding of complex concepts.
8	MZ et al. (2022)	The research presented in this journal shows that the Science Augmented Reality Programme (SARP), developed for science learning in elementary schools, has very high validity. The effectiveness of the program was tested through a limited trial with 10 students and a field trial with 28 students, which resulted in 94% and 97% positive feedback in terms of engagement and understanding of the solar system material. The program uses marker-based augmented reality technology to enhance the learning experience, making abstract concepts more tangible and easier to understand.
9	Safira et al. (2022)	The results of this research show that the use of augmented reality (AR) as a learning medium is effective in improving understanding of science concepts. The research was conducted using an experimental method with 39 students from a population of 105 students. There was a significant increase in student learning, with an N-gain of 0.70, which is considered high. The study also showed that AR increased students' motivation and engagement in the learning process, making it a valuable tool for education.
10	Putra et al. (2024)	The results showed that augmented reality (AR) technology significantly increased students' interest and understanding of

No	Author (Year)	Research Result
		complex scientific concepts. AR provides immersive three-dimensional visualization that helps students better understand abstract topics. AR helps to improve students' critical thinking skills, which are important in science learning.
11	Utama et al. (2024)	The research on Augmented Reality (AR) in Natural Sciences education reveals that AR significantly enhances students' understanding of complex concepts through interactive 3D visualizations. It also increases student motivation and engagement, promotes collaborative learning, and improves problem-solving skills.
12	Setyawan et al. (2019)	The research results indicate that the Augmented Reality (AR) learning media, specifically the "Jelajah Angkasa AR" application, is effective and engaging for sixth-grade elementary school students. Developed using the Borg and Gall model, the application focuses on teaching about planets in the solar system through a marker-based AR experience. Validation from experts in design, media, and content confirmed its high quality in terms of content, appearance, and language use. Student responses were overwhelmingly positive, categorizing the application as "very good," suggesting it significantly enhances student motivation and curiosity in learning, both in the classroom and for independent study.
13	Anggun et al. (2024)	The research conducted at SD 09 Peguyangan in Bali, Indonesia, demonstrated that the implementation of Augmented Reality (AR) significantly enhanced students' understanding of electrical circuits. The study found that students' comprehension improved dramatically from 28.1% to 90.6% after engaging with AR through Android devices. AR serves as an effective educational tool, transforming traditional science learning into a more interactive and enjoyable experience, thereby addressing the challenges posed by the abstract nature of science education.

No	Author (Year)	Research Result
14	Hadi et al. (2024)	The research article highlights the effectiveness of Augmented Reality (AR) as a learning medium in enhancing the educational outcomes of fifth-grade elementary school students in science subjects (IPAS). The study finds that AR significantly improves students' understanding of abstract concepts, increases their interest in learning, and enhances their mastery of the material. Various studies cited in the article support these findings, demonstrating that AR can lead to better engagement and academic performance among students. Overall, the research underscores the potential of AR in transforming traditional teaching methods and fostering a more interactive learning environment in elementary education.
15	Sapulette (2023)	The research results from the journal indicate that Augmented Reality (AR) serves as an effective learning medium that significantly enhances student motivation and learning outcomes across various subjects, including physics, mathematics, and cultural studies. The study highlights the positive impact of AR on student engagement and understanding.

Numerous studies have highlighted the potential of augmented reality in education, with its ability to improve learning outcomes, especially in subjects that require high visualization skills, such as science. Out of the 15 studies analyzed in Table 2, all highlight the efficacy of augmented reality (AR) as a learning tool in science education, especially for elementary school students. The detailed findings of the fifteen studies are: (1) improved understanding of science concepts, AR significantly improved students' comprehension of science concepts; (2) increased student interest, the implementation of AR-based learning media has been shown to boost students' interest in science subjects; (3) enhanced critical thinking skills, augmented Reality (AR) promotes the development of enhanced critical thinking skills by encouraging students to explore and experiment within a virtual environment, thereby boosting their problem-solving abilities. By manipulating virtual objects and scenarios, students can engage in scientific inquiry, which is essential for understanding complex concepts; (4) interactive learning experience, the implementation of augmented reality in science education creates a more open and engaging learning atmosphere. This interactivity is crucial for

maintaining students interest and improving their understanding of difficult topics. For instance, instead of just reading about human anatomy, students can visualize and manipulate 3D representations of organs and systems to gain a deeper understanding of their functions and interrelationships; (5) development of spatial skills, the advancement of spatial abilities has been positively influenced by augmented reality, which is crucial for comprehending scientific facts. With better spatial skills, students will be able to visualize and solve problems more effectively, which contributes to good academic performance in science; (6) Motivation and engagement, consistent findings indicate that AR enhances students' motivation and engagement in the learning process. This increased involvement is associated with improved learning results and a more pleasurable educational journey; (7) integration of technology in education, It points out the significance of incorporating contemporary technologies like AR into educational methodologies, particularly within the framework of the changing educational environment shaped by smart society 5.0.

Augmented reality is revolutionizing the way science is taught and understood in education. By integrating digital information into the physical environment, augmented reality fosters an engaging and insightful learning experience that promotes deeper understanding. The technology allows students to interact with complex scientific concepts in a way that is not possible with traditional methods. AR also offers a 'hands-on' learning experience, where students can conduct virtual or simulated experiments without the need for a fully equipped physical laboratory. Several studies have explored the use of augmented reality in various science subjects, including biology, physics, and astronomy. For example, in solar system materials, AR can allow students to explore the planets, see their movements, and learn about their individual characteristics in a much more engaging way than simply reading a textbook. A further instance of augmented reality application was conducted by Mukti (2022) on water cycle content, the evaluation results indicating that this application significantly enhanced students' comprehension of the subject. The average score from reviewers was 33.7, while student input revealed a satisfaction percentage of 99.13%, suggesting that augmented reality can enhance student engagement and comprehension of scientific subjects. This interaction encourages students to be more enthusiastic and curious about science, increasing their engagement and motivation to learn it. This interaction encourages students to be more enthusiastic and curious about science, increasing their engagement and motivation to learn it.

Augmented reality has shown potential in the development of collaborative learning environments. Enabling multiple people to engage with identical virtual elements within a common physical environment, augmented reality enhances collaborative learning experiences and encourages the exchange of knowledge among learners. Studies indicate

that incorporating augmented reality (AR) in collaborative learning settings will improve students' learning outcomes, increases engagement, and build better communication and collaboration skills (Kuanbayeva et al., 2024). In addition to its potential for collaborative learning, augmented reality (AR) can also be leveraged to support personalized learning experiences. By integrating virtual elements adapted to individual student needs and preferences, AR can create relevant and effective learning environments. It allows students to learn at their own pace, explore material that interests them, and receive visual guidance that matches their level of understanding. For instance, in science learning, more visual students can interact with 3D models that depict scientific phenomena in detail, while other students who need simpler explanations can be provided with more basic visualizations. In this way, AR not only increases student engagement but also optimizes the learning process by ensuring that each student receives a learning experience personalized to their individual needs.

The use of augmented reality in education has shown promising results, with numerous studies highlighting its potential to enhance student learning outcomes and engagement. By providing more immersive and interactive learning experiences, augmented reality can help students better visualize and understand complex concepts, particularly in subjects that require strong spatial awareness skills. The integration of AR technology in education not only addresses the challenges of teaching abstract concepts but also prepares students for a future, where digital literacy and technological proficiency are essential. As educators continue to explore and implement AR in their classrooms, the potential for improved educational outcomes and student engagement remains significant, paving the way for innovative teaching practices that can adapt to the needs of diverse learners. However, it is important to note that the effectiveness of augmented reality in education depends on various factors, such as the quality of the AR content, the integration of the technology into the curriculum, and the overall implementation and support within the educational institution. To fully evaluate the effectiveness of augmented reality in education, researchers and educators should consider a range of factors, including student learning outcomes, engagement, motivation, and perceptions of the technology. Additionally, studies should examine the long-term impacts of augmented reality on student learning and the transfer of knowledge to real-world applications.

CONCLUSION

Through the use of augmented reality (AR), this study investigates the potential for AR to serve as an effective visualization tool in the context of scientific teaching for students in elementary schools. Students have the potential to improve their comprehension of difficult scientific subjects through the utilization of augmented reality (AR), which in turn will increase their level of interest and engagement in the classroom. In terms of developing critical thinking

and visualization skills, AR also enhances spatial skills, which are important for understanding scientific phenomena. Although the research shows the great potential of AR in education, the efficiency of AR is highly dependent on the quality of the content, appropriate integration into the curriculum, and support from educational institutions. Therefore, further study is required to evaluate the long-term impact of AR on learning and knowledge transfer to real-world applications. Thus, AR can be an innovative solution to overcome the challenges of science learning in the era of smart society 5.0.

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