

Augmented Reality in Science Education: Improving Learning Outcomes with AI-Powered Media

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Abstract. Natural Science learning in elementary schools often faces challenges due to limited media and the abstract character of the material that is difficult for students to understand. As a result, student learning outcomes in this field tend to be low. This research examines the utilization of Augmented Reality (AR) learning media supported by artificial intelligence (AI) to improve understanding of complex science concepts. AI technology in AR plays a role in adjusting content according to students' abilities, recognizing user responses in real-time, and presenting 3D objects interactively, so that learning becomes more adaptive and personalized. The purpose of this study is to analyze the implementation of artificial intelligence-based *Augmented Reality* learning media in science learning in elementary schools and measure the effect of AI-based AR media on improving student science learning outcomes and identify challenges in using AI-based AR media in the elementary school environment. This research uses a mixed methods approach by combining qualitative and quantitative methods in two elementary schools that have implemented AI-based AR media. Data were collected through interviews and student assessment documentation. The results of the analysis show that the use of AI-based AR learning media significantly improves learning outcomes and student engagement in science learning. In addition, this media also enriches students' learning experience and increases two-way interaction between teachers and students. However, there are constraints such as device limitations, teacher training, and technology infrastructure. This research is expected to contribute to the development of technology-based learning innovations in elementary schools and become a reference in the implementation of effective AI-based AR in science education.

INTRODUCTION

The learning process at the primary school level plays an important role in building students' cognitive and social foundations (Surtikawati et al., 2022). One of the subjects that is often considered difficult is Natural Science, which contains abstract concepts such as the water cycle, photosynthesis, earth structure, and social interactions (Haryanti et al., 2025); (Dwilestari & Dessty, 2022). According to (Laksana, 2016) the presentation of these concepts is still conventional and less contextual, making it difficult for students to understand the material in depth. (Fitriani et al., 2021) also highlighted that the conventional approach with limited media available in science learning is not enough to facilitate meaningful understanding for students.

In the era of digital transformation, the use of technologies such as *Augmented Reality* (AR) in education began to receive widespread attention (Adeyeye, 2024). AR allows students to interact with 3D objects that are integrated into the real world visually, making it easier to understand the material (Indahsari & Sumirat, 2023). The latest innovation is the merging of AR with artificial intelligence (AI). According to (Hernanda & Aji, 2024), AR enhanced with AI technology is able to provide a learning experience that is adaptive and responsive to the individual needs of students. AI enables facial recognition, motion tracking, automatic adjustment of difficulty levels, and immediate feedback based on student performance.

The state of the art of this research lies in the utilization of AI-powered AR in science learning in elementary schools, which has not been explored in depth. Previous studies have mostly discussed AR in general in secondary or higher education (Thahir & Kamaruddin, 2021); (Meilindawati et al., 2023), without involving AI functions in the system. (Danti et al., 2023) shows the positive impact of AR in science learning, but it is still linear and static. Although there have been many studies related to the use of AR in education, most of them focus on the implementation of AR in the context of education at the college level or in other subjects such as math and science at the secondary level. However, few studies focus on the implementation of AR in science subjects at the elementary school level, where the material taught is more abstract and requires a simpler understanding. Existing research has not fully explored how AI-based AR can be applied to clarify concepts that are often considered abstract by students at the elementary level, such as geosphere concepts, photosynthesis, or the water cycle (Suwanto & Desstya, 2024).

The novelty in this research is the use of AR media integrated with AI to provide a more personalized, interactive, and adaptive learning experience for elementary school students. This technology can automatically identify student difficulties and customize content presentation according to each individual's needs. Thus, it not only improves understanding of abstract material, but also fosters interest in learning and two-way interaction in the classroom. The urgency of this research is based on the need for technology-based learning solutions that are relevant to the times and able to answer the challenges of science learning at the primary level. With the limited number of child-friendly AI-based educational software and the lack of teacher training, this research also serves as an initial step in the development of affordable and effective AI-based learning media. This research aims to analyze the implementation of artificial intelligence-based Augmented Reality learning media in science learning in elementary schools and Measure the effect of AI-based AR media on improving student science learning outcomes and identify challenges in using AI-based AR media in the elementary school environment.

METHODS

This research uses a mixed methods approach. This approach was chosen due to the purpose of this study, to analyze the implementation of artificial intelligence-based Augmented Reality learning media in science learning in elementary schools and measure the effect of AI-based AR media on improving students' science learning outcomes as well as identify challenges in the use of AI-based AR media in the elementary school environment. This approach allows researchers to conduct an in-depth analysis of two elementary schools that have implemented AR in their learning, namely Elementary school Gentan 03 in Kebonjeruk, Gentan, Susukan, Semarang Regency, and Iqra' Nogosari integrated Islamic elementary school in Glonggong, Nogosari, Boyolali Regency.

The data collection methods used were interviews and documentation. The interview technique was chosen to explore the direct experiences of teachers and students related to the use of AI-based AR in science learning. Interviews were conducted in a structured manner with questions designed to obtain in-depth information regarding their perceptions and views on the influence of AI-based AR on the learning process and the results achieved. This is in accordance with previous research which states that interviews are an effective method for gaining a deeper understanding of individual perceptions and experiences in an educational context (Ardiansyah et al., 2023). In addition to interviews, documentation was also used as a data collection technique. The documentation in question includes student assessment documents that can provide an overview of student learning achievements before and after the use of AR in learning. This approach is also relevant to research findings by (Susanto et al., 2023) which shows that documentation can be a rich source of data in evaluating changes in student learning outcomes.

The time limitation of the research is the main reason for using these two techniques, as interviews allow researchers to obtain more direct and relevant data in a limited time. Student assessment documentation also serves as supporting data that provides an objective picture of the impact of using AI-based AR on student learning outcomes. Overall, this method is expected to provide a deep insight into the implementation of AI-based AR in science learning in elementary schools and the challenges faced in the process.

RESULTS

Interviews on the Implementation of the Use of AI-Based Augmented Reality Media with Teachers and Students at Two Elementary Schools

The results of interviews conducted with fourth grade teachers at elementary school Gentan 03 can be seen in the following table;

Table1. Results of interviews conducted with fourth grade teachers at elementary school Gentan 03

Initials of Interviewee	Question	Answer Results
Mrs. R	How do you see the use of AI-based Augmented Reality (AR) media in the science learning process in your class?	I think it is very helpful, especially in explaining concepts that are difficult for students to understand, such as the water cycle and the process of photosynthesis. With AI-based AR, they can see directly how these processes occur in an interesting visual form, so they understand the material faster.
Mrs. R	Do you think there is an impact on students' interest in learning after using AI-based AR media in learning?	Based on my view, their interest has increased a lot. The children are more enthusiastic and active in asking questions. Usually they are more focused because the learning experience becomes more interactive. If previously they preferred to play, now they are more interested in learning science.
Mrs. R	What do you think are the challenges in using AI-based AR in learning?	The challenge itself is more of a technical aspect. Sometimes, there are problems with devices such as laptops/handphones that do not always work smoothly due to internet signal constraints. In addition, not all students have the same technical ability in using AI-based AR, so I have to make sure that each student can operate the device properly. Moreover, training for teachers in making AI-based AR media is still minimal so it is not optimal.

Based on the table above, Mrs. R revealed that the use of AI-based Augmented Reality (AR) media in learning science is very helpful, especially in explaining concepts that are difficult for students to understand, such as the water cycle and photosynthesis. With AR, students can see directly how these processes occur in an interesting visual form, so they can more quickly understand the material. Mrs. R also noted an increase in students' interest in learning after the use of AR. The children became more enthusiastic and active in asking questions, as well as more focused in following the learning, due to a more interactive learning experience. Previously, students tended to be more interested in play activities, but now they are more interested in science learning. However, Mrs. R admits that the main challenge faced is technical constraints, such as devices that do not always function smoothly, especially due to internet signal interference. In addition, not all students have the same technical skills in using AR, so Mrs. R needs to ensure that each student can operate the device properly. She also highlighted that training for teachers in making AR media is still minimal, which causes the use of AI-based AR to not be maximized.

The results of an interview conducted with one of the fourth grade students at elementary school Gentan 03 can be seen in the following table;

Table2. The results of an interview conducted with one of the fourth grade students at elementary school Gentan 03

Initials of Interviewee	Question	Answer Results
D	What do you feel when learning using AI-based AR media in science lessons?	I'm really happy, because if we usually only see pictures in books, now we can see moving pictures on the screen. For example, when learning about the sun, I can see how the sun affects life on earth, so it's clearer and more exciting.
D	Do you feel that AI-based AR media helps you learn better?	Yes, I understand better. When I was learning about the water cycle, I was confused, but now after using AI-based AR, I can see the water moving, evaporating, and raining, so it's easier to understand.

Based on the table, it states that students feel very happy when learning using AI-based Augmented Reality (AR) media in science lessons. He revealed that the learning experience became more exciting because, in contrast to only seeing pictures in books, he could now see moving images on the screen. For example, when learning about the sun, she can see directly how the sun affects life on earth, which makes the material clearer and more interesting. She also felt that the AI-based AR media helped her understand the material better. He mentioned that previously he felt confused when learning about the water cycle, but after using AR, he could see the movement of water evaporating and falling as rain, so the concept became much easier to understand.

The results of interviews conducted with fourth grade teachers at Iqra' Nogosari integrated Islamic elementary school can be seen in the following table;

Table3. The results of interviews conducted with fourth grade teachers at Iqra' Nogosari integrated Islamic elementary school

Initials of Interviewee	Question	Answer Results
Mrs. T	How is your experience as a teacher in implementing AI-based Augmented Reality (AR) media in the science learning process?	My experience has been very positive. AR makes the subject matter more vivid. For example, when teaching about the shape and form of objects, students can see in 3D instead of just flat images. This makes it easier for them to understand and more interested in learning
Mrs. T	What feedback do you think you receive from students after using AI-based AR media in learning?	They felt more interested and less bored and by using AI-based AR, the children looked happy. They often expressed greater curiosity and were more active in discussions. Their feedback was very positive, especially in terms of a deeper understanding of the material.
Mrs. T	What obstacles do you think you face in using AI-based AR in learning?	I think the main obstacle is the limited availability of devices. Not all students get access to the same device, so we have to take turns. In addition, the time needed to set up devices that sometimes experience trouble sometimes disrupts the flow of learning.

Based on the interview with Mrs. T, a teacher at Iqra' Nogosari integrated Islamic elementary school, revealed her positive experience in implementing AI-based Augmented Reality (AR) media in science learning. According to her, AR-based makes the subject matter more vivid, such as when teaching about the shape and form of objects, where students can see objects in 3D format, not just flat images. This makes it easier for students to understand the material and increases their interest in learning. Feedback from students is also very positive, they feel more interested and less bored. Students also show greater curiosity and are more active in discussions, which contributes to a deeper understanding of the material. However, Mrs. T also noted that there were obstacles, such as limited devices that caused students to take turns using AI-based AR, as well as the time needed to set up devices that sometimes experienced technical problems, thus disrupting the smooth learning.

The results of an interview conducted with one of the fourth grade students at Iqra' Nogosari integrated Islamic elementary school can be seen in the following table;

Table4. The results of an interview conducted with one of the fourth grade students at Iqra' Nogosari integrated Islamic elementary school

Initials of Interviewee	Question	Answer Results
B	How does it feel to learn using AI-based AR?	It's really fun, so it's like I can see the pictures in the book, but it can move and I can turn it around too.
B	In your opinion, does AI-based AR help you learn more easily?	Yes, because I could see what was being told. That time I saw the animals running around, and then I understood where the animals lived in the trees or on the ground.

Based on the student's table, he feels very happy to learn using AI-based Augmented Reality (AR) media. He said that learning with AI-based AR is very exciting because pictures that are usually only in books can now move and can even be rotated, making the learning experience more interesting. She also feels that AI-based AR helps her learn more easily, as she can see first-hand what is being told. For example, when learning about animals, he can see the animals move, so he better understands where the animals live, whether in trees or on the ground.

T Test Results of Implementation of the Use of AI-Based Augmented Reality Media with Teachers and Students in Two Elementary Schools

The t-test results of elementary school Gentan 03 using the SPSS Program with the Paired Samples T-Test method are as follows;

Table1. T-test results of elementary school Gentan 03

Paired Samples Test									
		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	before implementing AI-based AR - after implementing AI- based AR	- 9,143	6,125	1,637	-12,679	-5,606	- 5,585	13	,000

Based on the results of the T-test, it is known that the significance value is $0.000 < 0.05$ and the value of $t_{hitung} > t_{tabel}$ is $5,585 > 1.7709$. So it can be concluded that H_0 is rejected and H_1 is accepted. So that the implementation of AI-based augmented reality learning media can improve the science learning outcomes of grade IV students at elementary school Gentan 03 and AI-based AR media is effective for improving the science learning outcomes of grade IV students at elementary school Gentan 03

The results of the Iqra' Nogosari integrated Islamic elementary school t-test using the SPSS Program with the Paired Samples T-Test method are as follows;

Table 2. Iqra' Nogosari integrated Islamic elementary school t-test results

Paired Samples Test									
		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	before implementing AI-based AR - after implementing AI- based AR	- 2,524	2,994	,653	-3,886	-1,161	- 3,863	20	,001

Based on the results of the T-test, it is known that the significance value is $0.001 < 0.05$ and the value of $t_{hitung} > t_{tabel}$ is $3.863 > 1.7247$. So it can be concluded that H_0 is rejected and H_1 is accepted. So that the implementation of AI-based augmented reality learning media can improve the science learning

outcomes of grade IV students at Iqra' Nogosari integrated Islamic elementary school and AI-based AR media is effective for improving the science learning outcomes of grade IV students at Iqra' Nogosari integrated Islamic elementary school.

DISCUSSION

AI-based Augmented Reality (AR) technology is increasingly used in education to improve the quality of learning. AI-based AR allows students to interact with subject matter through more real and interesting visualizations (Utama et al., 2024). According to (Puspita et al., 2025) in the context of education in elementary schools, AI-based AR is used to help students understand concepts that are difficult to understand, such as the water cycle or the process of photosynthesis in Natural and Social Sciences lessons. This research will discuss the implementation of AI- based AR media in learning, improving learning outcomes and challenges in its implementation.

Implementation of AI-based Augmented Reality (AR) Media Usage

Based on the results of interviews conducted with teachers and students from two schools, namely elementary school Gentan 03 and Iqra' Nogosari integrated Islamic elementary school, regarding the use of AI-based Augmented Reality (AR) media in the science learning process, it can be concluded that several important things are related to the benefits and experiences of its use. The teacher at elementary school Gentan 03, Mrs. R, gave a positive view on the use of AI-based AR in learning. According to her, AI-based AR is very helpful in explaining concepts that are difficult for students to understand, such as the water cycle and photosynthesis. By using AI-based AR, students can see these processes in a visual form that is easier to understand, which improves their understanding of the material. This is in accordance with research findings by (Aryani et al., 2024), which states that AR is able to present information visually and interactively, which allows students to understand abstract and complex concepts better compared to traditional methods that only rely on text or static images. Mrs. R also noted an increase in students' interest in learning after the use of AI-based AR. The children became more enthusiastic and active in asking questions and more focused in participating in science learning. This is in line with the findings by (Hariyono, 2023) which reveals that the use of AR can increase student engagement and interest in learning. In conventional learning, students often feel bored with the material that is taught monotonously. However, with the use of AI-based AR, the learning experience becomes more interesting and interactive, which can motivate students to participate more actively.

This is also reflected in the experience of teachers at Iqra' Nogosari integrated Islamic elementary school, Mrs. T, stating that the experience of using AI-based AR in learning is very positive. AI-based AR makes the subject matter more vivid, especially in terms of describing objects in three-dimensional (3D) form. For example, when teaching about the shape and form of objects, students can see the object directly, not just a flat image. This makes it easier for students to understand and more interested in learning. Research by (Wahiddiyah et al., 2023) supports this, stating that AR provides a more in-depth learning experience and can increase students' attention and motivation to learn. Mrs. T also noted that feedback from students was very positive. Students become more interested, less bored, and more active in discussions. However, the obstacles faced are the limited devices and the time needed to set up AI-based AR devices.

Students showed a high level of satisfaction with the use of AI-based AR in science learning. This interactive and fun learning experience makes them more motivated to learn. AI-based AR also reduces student boredom that often occurs with conventional learning methods. Students at elementary school Gentan 03 feel very happy and interested in learning using AI-based AR. They feel that AI-based AR media makes material that was previously difficult to understand clearer. For example, when studying the water cycle, students can see the movement of water evaporating, falling as rain, and returning to the sea, which helps them understand the concept more easily.

At Iqra' Nogosari integrated Islamic elementary school, students also experience similar benefits. They feel that learning becomes more exciting and interesting because they can see moving images that previously only existed in textbooks. For example, when learning about animals and their habitats, students can see animals moving and interacting with the environment around them, so they more easily understand where the animal lives. The application of AR also affects the interaction between teachers and students. AI-based AR provides an opportunity for teachers to present materials in a more interesting and interactive way, thus increasing student engagement in learning. Teachers can ask direct questions based on the objects that appear on the AR screen, which encourages students to think critically and actively discuss. This is highly relevant to the research findings by (Hariyono, 2023), which shows that AI-based AR can improve the quality of classroom interaction and encourage more effective discussion-based learning.

Improved Learning Outcomes

The results show that the use of AI-based AR learning media has a positive impact on student learning outcomes. Previously abstract science materials, such as geosphere concepts, the circulatory system, and the water cycle, become easier to understand with the visualizations offered by AR (Zaid et al., 2022). Students can see 3D objects depicting natural phenomena or social processes, which improves their understanding of the material. This is proven by testing the effectiveness of using AI-based AR. This test was conducted using the Paired Samples T-Test method using the SPSS Program to analyze data before and after the implementation of AR on students in both schools. According to (Syafriani et al., 2023) the Paired Samples T-Test method is a statistical method used to compare the average of two related samples taken from the same subject.

At elementary school Gentan 03, the T-test results show a significance value of 0.000 which is smaller than 0.05, and *thitung* of 5.585 which is greater than *ttabel* 1.7709. Thus, H_0 (null hypothesis) is rejected, and H_1 (alternative hypothesis) is accepted. This indicates that the implementation of AI-based AR significantly improves student learning outcomes in science lessons. Based on these results, it can be concluded that the use of AI-based AR media is effective in improving the understanding of science materials at elementary school Gentan 03. In Iqra' Nogosari integrated Islamic elementary school, the T-test results also show a significance value of 0.001, which is smaller than 0.05, with *thitung* 3.863 which is greater than *ttabel* 1.7247. This also shows that the use of AI-based AR has a significant impact on student learning outcomes. Therefore, as in elementary school Gentan 03, it can be concluded that AI-based AR is effective in improving students' science learning outcomes at Iqra' Nogosari integrated Islamic elementary school.

Challenges

Technical challenges in the implementation of AI-based Augmented Reality (AR) in learning are indeed an important issue, although in general, the results are very positive. As mentioned, one of the main obstacles faced by schools is the limited devices that support the use of AI-based AR. This phenomenon is often found in many developing countries, including Indonesia, where access to advanced technology, such as AR devices, is still limited. This inequality of access affects the effectiveness of AR-based learning, as not all students have the necessary devices to optimally access AR-based learning materials. According to (Wibowo, 2023) AR-based learning can increase student engagement, but only if the devices used are sufficient and available to all students. Inequality in device access can create inequity in learning opportunities and reduce the positive impact that can be gained from using AI-based AR. Therefore, one of the proposed solutions is a more equitable provision of devices among students. The provision of these devices is not only limited to tools to access AI-based AR, but also needs to include training so that students and teachers can make the most of this technology.

In addition, other technical issues, such as internet signal interruptions and device operational difficulties, often become obstacles in the implementation of technology, including AI-based AR. This is in line with research findings by (Lutfiah, 2024), which show that the implementation of new technologies

in the classroom is often disrupted by unexpected technical problems, such as difficulties in operating the device and dependence on a stable internet connection. In this case, internet signal interruptions and devices that do not function properly can disrupt the learning process and reduce the effectiveness of using AI-based AR in learning.

To overcome this obstacle, several important steps must be taken. First, it is important for schools to provide adequate devices, as well as ensure the availability and quality of adequate internet connections (Rosyida et al., 2024). Research by (Kuswinardi et al., 2023) also highlights the importance of infrastructure that supports technology in AR-based learning, such as the provision of a strong internet network and hardware that can support AR applications well. In addition, intensive training for teachers and students on how to operate AI-based AR devices is also very important. Teachers need to be given a deep understanding of how to use AR as an effective learning tool, and students need to be taught how to use AR devices smoothly so that the learning process can run optimally.

In addition to technical issues, research by (Nuraeni et al., 2024) also shows that the integration of AR in learning requires careful planning regarding curriculum and teaching. The use of AI-based AR must be designed in such a way that it supports learning objectives and enriches students' learning experience, not just being an interesting tool without a clear purpose. In this case, training for teachers on AI-based AR learning design is also very necessary to ensure that the use of this technology can provide maximum results. Overall, while the application of AI-based AR in learning is promising, its success is highly dependent on managing and solving the technical issues involved. Equitable provision of devices, training for teachers and students, and careful planning of the infrastructure and design of learning with AI-based AR are important steps that need to be taken to overcome these challenges.

CONCLUSION

The use of AI-based Augmented Reality learning media in learning science in elementary schools is proven to improve student learning outcomes by visualizing complex and abstract material. The application of AI-based AR also improves the interaction between teachers and students and provides a more enjoyable and interactive learning experience. However, challenges in terms of technological facilities and teacher training need to be overcome for the full potential of AI-based AR to be utilized. This research makes an important contribution to the development of technology-based learning media at the primary school level and provides insight into the effectiveness of AI-based AR in supporting student learning outcomes.

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