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The Effectiveness of Augmented Reality-Based Learning Media on Elementary School Students' Visual-Spatial Abilities

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Abstract: Science learning in elementary schools still faces obstacles, particularly because students struggle to understand the state of matter and its changes. This struggle arises since the concept is abstract and requires strong visual-spatial abilities. To address this, the present study aims to determine the effectiveness of augmented reality-based learning media in improving students' visual-spatial abilities, especially in science. The research method employed was a quasi-experimental design with a pretest-posttest control group. Seventy fourth-grade students participated, divided into two control groups and one experimental group. To measure outcomes, the research instrument consisted of a visual-spatial ability test developed based on five main indicators. For analysis, data were examined using a t-test to assess differences in learning outcomes between groups, and an N-Gain test was used to measure the improvement. Results revealed a significant difference between the two groups, as indicated by the t-test with a significance value of 0.002 < 0.05. Additionally, the N-Gain test demonstrated that the experimental group achieved an average N-Gain of 64.63%, categorizing it as fairly effective; in contrast, the control group obtained only 46.10%, placing it in the less effective category. Therefore, using augmented reality significantly enhances students' visual-spatial abilities in the context of states of matter and their transformations. These findings imply that augmented reality can serve as an alternative, relevant, and innovative learning medium to support science learning in elementary schools.

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INTRODUCTION

Elementary school education plays a crucial role in shaping students' knowledge, particularly in the study of Natural and Social Sciences (IPAS), which require abstract thinking skills. Many students struggle to understand visualization-based materials, as the learning media used are primarily textbooks and conventional methods. One example of material that frequently presents difficulties is the topic of states of matter and their changes, such as the processes of evaporation, condensation, crystallization, and sublimation, which cannot always be directly observed in everyday life. Elementary school students often encounter misconceptions about scientific concepts, necessitating the use of appropriate learning strategies (Ellison, 2025). Furthermore, low visual representational abilities contribute to the difficulty of learning science at the elementary school level (Hidayat & Rahmi, 2025). Therefore, it is crucial to provide learning media that connect abstract concepts with everyday phenomena, enabling students to understand the phenomena that occur in everyday life rather than simply memorizing them (Mansour et al., 2025)

Abstract science subjects, such as the state of matter and its changes, will be easily understood by students if they have good visual-spatial skills. Visual-spatial skills are one of the cognitive aspects essential for understanding scientific concepts, natural structures, states of matter, and their changes, as well as relationships between spaces. This ability helps students visualize objects that cannot be directly observed, thereby improving the relationship between concepts and everyday experiences. According to Faridah and Muzakki (2024), good visual-spatial skills have a significant impact on student academic achievement, especially in science and mathematics. Furthermore, a teaching style that aligns with multiple intelligences, including visual-spatial, plays a crucial role in supporting the development of students' critical thinking and problem-solving skills (Kiyugan & Accad, 2025). Therefore, education in elementary school is a strategic phase for developing students' visual-spatial competencies, which contribute to an increased understanding of science concepts (Annetta et al., 2024).

Visual-spatial skills play a crucial role in understanding science concepts, particularly those related to the states of matter and their transformations, which require spatial imagination and visualization of state changes. Visual-spatial skills encompass abilities such as spatial perception, spatial relations, spatial orientation, spatial rotation, and spatial visualization, which have been demonstrated to correlate with student success in understanding mathematics and science (Supli & Yan, 2024). This condition makes it difficult for students to connect theoretical knowledge with the realities they experience in everyday life. In line with Wilson's (2020) findings, traditional learning media often fail to facilitate effective visual representations, necessitating a technology-based approach to improve student motivation and understanding of science concepts. Other research also confirms that low achievement in science learning is partly due to the limited media that can visualize abstract materials (Koç & Kanadlı, 2025). Therefore, research indicates that the implementation of augmented reality-based mobile applications can provide interactive and contextual learning media, thereby facilitating students' understanding of abstract science concepts (Fatmawati et al., 2025).

The development of digital technology is highly beneficial in overcoming the limitations of conventional learning in schools, particularly in elementary schools. The use of technology in the learning process not only increases the effectiveness of material delivery but also enriches students' learning experiences. One technology that can help students understand the material of the state of matter and its changes is augmented reality, which allows combining virtual objects with the real world in real-time. According to Piedade & Batista (2025), this augmented reality-based media can provide a more interactive and enjoyable learning experience for students. In addition, augmented reality has been proven to increase student engagement due to its advantage in visualization capabilities, which are presented in a more engaging manner than static images or ordinary videos (Schmidt & Stumpe, 2025). Augmented reality can also bridge abstract scientific concepts into real-world learning experiences, thereby enhancing students' understanding of science (Chen et al., 2025). Thus, augmented reality can be an innovative solution to address the challenges of science learning at the elementary school level.

The use of augmented reality media has a positive impact on science learning, leading to improved learning outcomes and enhanced visual-spatial abilities. According to Tiep & Huong (2025), the integration of augmented reality in elementary school science education can enhance students' spatial skills and improve their academic performance. Another study reveals that the application of augmented reality technology in elementary school learning contexts can facilitate students' understanding of complex three-dimensional concepts that are challenging to visualize through conventional media (Kazanidis & Andreadou, 2025). Research by Hermawan & Hadi (2024) shows that the integration of augmented reality in learning can help students understand three-dimensional and abstract concepts that are difficult to grasp through traditional methods, as this technology combines virtual objects with the real world in an interactive manner. In addition, augmented reality has also been shown to foster students' curiosity and improve students' attitudes towards science learning, which ultimately can have a positive impact on students' academic achievement. Based on this research evidence, it can be confirmed that augmented reality has a significant contribution in improving the quality of science learning, especially in students' visual-spatial dimensions.

In Indonesia, several studies have also demonstrated the positive potential of augmented reality in science learning in elementary schools. For example, research by Nursyaidah (2025) developed augmented reality media for science learning that can increase student engagement and clarify the understanding of abstract science concepts through interactive visualization. Another study, conducted by Fathuloh (2025), demonstrated that the application of augmented reality-based learning media is practical in enhancing the visual-spatial abilities of elementary school students, as it displays learning objects in three dimensions and in a contextual setting, making them easier to understand. Deritawati (2025) demonstrated that augmented reality applications are practical in enhancing learning outcomes and motivation among elementary school students in science subjects, as they provide interactive and contextual learning experiences. Research by Elford (2022) found that the use of augmented reality in science learning can reduce students' cognitive load and increase their positive attitudes towards science through interactive and contextual visual experiences. Based on these findings, it can provide evidence that the integration of augmented reality in science learning in elementary schools has great potential to increase the effectiveness of learning as well as the relevance of the material to students' daily lives.

Although numerous studies have demonstrated the benefits of augmented reality, most focus on STEM subjects or on secondary and higher education levels. Research examining its impact on elementary students' visual-spatial abilities in science learning remains limited. This study addresses this gap by investigating how augmented reality-based learning media influence elementary school students' visual-spatial abilities. Previous systematic reviews have shown that modern technologies, including augmented reality, enhance motivation and learning outcomes by providing interactive and contextual learning experiences (Hosseini et al., 2025). However, there has been little in-depth discussion of visual-spatial abilities in the elementary school context. Visual-spatial abilities are a crucial factor in understanding abstract science concepts, and research has shown that the use of augmented reality can bridge the cognitive gap between students with varying levels of spatial abilities (Abuhashish & Ismail, 2025).

Based on the background and problems mentioned above, this study aims to analyze the effect of using augmented reality media on students' visual-spatial abilities in science learning, with a focus on the material of states of matter and their changes, in elementary schools. This study aims to provide empirical evidence on the effectiveness of augmented reality as an innovative medium that supports cognitive skills essential for early development. In addition, the results of this study are expected to contribute to the development of the literature on technology integration through the application of augmented reality in elementary education, as well as support teachers in designing more engaging, interactive, and collaborative learning experiences (Rahman et al., 2025). Therefore, this study aims to fill this gap, providing practical contributions in designing science learning media based on augmented reality that are more effective and appropriate for the needs of elementary school students in Indonesia (Najib & Suprihatiningrum, 2025).

METHOD

This study used a quasi-experimental method with a pretest-posttest control group design. This design was chosen because it allows researchers to compare learning outcomes between groups treated with augmented reality media and control groups that were not treated or used only conventional methods. According to Sugiyono (2019), quasi-experimental designs are widely used in educational research because researchers cannot always fully randomize subjects. Quasi-experiments are an appropriate approach when researchers cannot fully randomize subjects but still want to observe causal relationships (Gunawan, 2025). According to Gopalan et al, (2020), quasi-experimental designs are widely used in educational research because they can provide more valid estimates of treatment effects than pre-experimental designs.

Data collection was conducted through pretest and posttest questions. The research design consisted of two groups: an experimental group that participated in learning while receiving augmented reality media treatment and a control group that participated in conventional learning without augmented reality media treatment. Each group was given a pretest before the treatment and a posttest after the learning treatment. The research subjects were 70 fourth-grade elementary school students. The control class consisted of 35 students, and the experimental class consisted of 35 students. The sample selection was conducted using a purposive sampling technique, taking into account the similarities and characteristics of the students. The participants were 70 fourth-grade students from two elementary schools in Wonogiri, Indonesia, selected using purposive sampling. The schools were chosen because they met the criteria for implementing augmented reality-based learning media and the teachers demonstrated a strong willingness to collaborate in the learning process. Preliminary observations also indicated that the students' visual-spatial abilities were relatively low, making the schools appropriate settings for this study.

This quasi-experimental study aimed to determine the effect of augmented reality-based learning media on students' visual-spatial abilities. The research instrument consisted of a visual-spatial ability test developed based on five indicators: spatial perception, spatial rotation, spatial visualization, spatial relations, and spatial orientation. The instrument's content validity was evaluated through expert judgment involving a media expert, a material expert, and a visual-spatial expert to ensure content relevance and clarity. Empirical validation was then conducted using item–total correlation analysis (*r*-test), and only items that met the validity threshold were retained. Reliability testing using Cronbach's Alpha yielded a coefficient of 0.826, indicating high internal consistency. Therefore, the instrument was considered both valid and reliable for measuring students' visual-spatial abilities. The instrument was developed through a systematic process consisting of the following steps: (1) Formulate a conceptual definition of the visual-spatial abilities to be measured, (2) Establish an operational definition of visual-spatial abilities as a concrete measurement basis, (3) Develop test indicators based on the operational definition, (4) Develop multiple-choice test items that represent each indicator of visual-spatial abilities, and (5) Provide answer keys for all questions. The research design is shown in Table 1 below:

Table 1 Research Design

Group	Pretest	Treatment	Posttest
Control	01	-	03
Eksperiment	02	X	04

Information:
01 = Pretest for control class
02 = Pretest for experimental class
X = Treatment with augmented reality-based learning media
03 = Posttest for control class
04 = Posttest for experimental class

In this study, the control class was administered a pretest (01) prior to the learning activities, with the aim of assessing the students' initial cognitive abilities, and a posttest (03) after the activities were completed. Meanwhile, the experimental class was given a pretest (02) before receiving treatment in the form of learning and the use of augmented reality media (X), then given a posttest (04) after the learning was completed. This design allows for comparative analysis both internally (pretest-posttest for each group) and between groups (control-experiment) to assess the effect of using augmented reality media. The use of the control class and the experimental class aims to determine whether there is an increase in students' visual-spatial abilities in the class that received no media treatment and the class that received media treatment. The research data were then analyzed to determine the differences in the increase in these abilities, using the t-test and the N-Gain test for data analysis.

Table 2 Research Stages

No	Research Stage	Activity Description
1	Preliminary Analysis	Conducting a literature review, identifying and formulating the problem.
2	Research Design Planning	Preparation of a quasi-experimental design with a pretest-posttest control group model.
3	Determination Of Research Subjects	The research subjects were determined through purposive sampling techniques among fourth grade elementary school students.
4	Implementation Of the Pretest Ability Test	Students were given a pretest before being given treatment.
5	Providing Treatment (Intervention)	The experimental group received learning using augmented reality media, while the control group received learning using conventional methods.
6	Implementation Of the Posttest Ability Test	Students were given a posttest after being given treatment.
7	Data Collection and Data Processing Stage	Data was obtained from test results (pretest-posttest), then the data was processed quantitatively.
8	Research Data Analysis	The data were analyzed using statistical tests (t-test and N-Gain test) and the results were interpreted.

The series of research stages outlined in this study adheres to the basic principles of quasi-experimental research using a pretest-posttest control group design. These stages begin with a preliminary analysis conducted by reviewing the literature, identifying the problem, and formulating an appropriate focus. This is followed by the development of a quasi-experimental research design to compare the results of the control and experimental groups. The sample was selected using a purposive sampling technique, specifically targeting fourth-grade students from a school that met the research criteria.

A pretest was administered before the lesson, and a posttest at the end of the lesson. The purpose of this study was to determine the initial and final abilities of students in the control and experimental classes. This was done to determine whether there were significant differences after the introduction of augmented reality media. This provided a strong basis for measuring the effects of the intervention. The data obtained from the pretest and posttest were then processed quantitatively to generate information. This was then analyzed using statistical tests such as the t-test and N-Gain. These data were then interpreted to draw conclusions regarding the effects of the intervention. Thus, this series of stages can form a logical, measurable, and precise research flow within the methodological framework required in this quasi-experimental research.

RESULTS AND DISCUSSIONS

The use of interactive learning media based on augmented reality has proven effective in improving students' visual-spatial abilities by utilizing a visualization approach to abstract material that requires concrete media, particularly in science lessons on states of matter and their changes. This media combines augmented reality capabilities to directly display three-dimensional objects, allowing students to practice imagining, rotating, and connecting the processes of state change. This type of visualization significantly assists students in developing visual-spatial skills, as they not only see static images but also explore the shape and orientation of objects from various perspectives.

Through the use of augmented reality, students can directly understand how states change, thereby helping them grasp the material better and increasing their motivation to learn. The topic of states of matter and their changes was chosen as the context because it often presents difficulties due to limited imagination in visualizing the phenomenon of state change. Furthermore, this material was chosen because it has a high level of relevance to students' daily lives. With the support of augmented reality, students can directly observe how state change occurs when matter melts, evaporates, or sublimates, allowing them to practice more accurate spatial visualization. To assess the effectiveness of augmented reality, students first completed a visual-spatial pretest, then, after the treatment, they were given a visual-spatial posttest of comparable difficulty. These results are expected to demonstrate the extent to which augmented reality can contribute to improving students' visual-spatial abilities while strengthening their understanding of the state of matter and its changes.

Figure 1. First view of augmented reality media (left) and main menu view of augmented reality media (right)

Students access the augmented reality application in the AR menu, which then displays material on changes in the state of matter with three-dimensional visualizations. This subsection presents learning content aligned with the learning outcomes of the Natural Sciences (IPAS) in a more engaging and interactive format. The material is designed to match real-life events, such as melting ice, evaporating water, or sublimating camphor, allowing students to more easily relate the concepts to everyday experiences. This principle aligns with the notion that students learn more effectively when the material they study is relevant to their lives. After receiving treatment through augmented reality media, students are then asked to complete a posttest in the form of visual-spatial ability questions related to five indicators: spatial perception, spatial rotation, spatial visualization, spatial relations, and spatial orientation. This test consists of 15 multiple-choice questions designed to measure the extent to which the use of augmented reality media can help students understand the material on the state of matter and its changes more concretely.

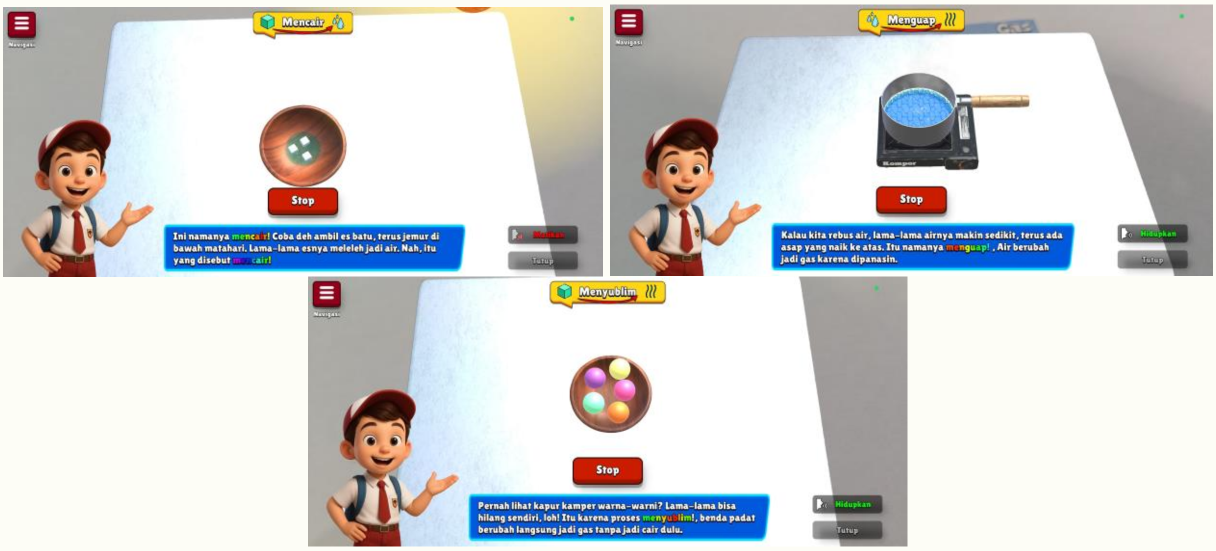

Figure 2. Example of display of changes in state of matter in the AR menu (melting, evaporation, sublimation)

The pretest and posttest data for the control class, which received no treatment, and the experimental class, which received treatment using augmented reality media, were measured using t-tests and N-Gain scores. The test results used an independent sample t-test on the posttest scores of both groups. This test aimed to determine whether there were significant differences between the control class, which used conventional methods, and the experimental class, which used augmented reality media.

Table 3. Posttest T-Test Results

Group	N	Mean	Std. Dev	t	Sig. (2-tailed)
Control	35	71.71	14.018	-3.195	.002
Eksperiment	35	81.54	11.605	-3.195	.002

Based on Table 3, the significance value (sig. 2-tailed) is 0.002 < 0.05, indicating a significant difference between the control and experimental groups. This means that the increase in posttest scores of students in the experimental group was not only higher descriptively but also statistically significant. Thus, learning with augmented reality has a significantly greater impact on students' visual-spatial abilities compared to traditional learning methods. The average score for the experimental group was 81.54, significantly higher than the average score of 71.71 for the control group. This difference suggests that the integration of augmented reality not only helps students understand the abstract concepts of matter, states of matter, and their transformations, but also enhances their visual-spatial abilities, which are essential for learning science. These results are consistent with those of Elford (2022), who found that the use of augmented reality can reduce students' cognitive load and increase positive attitudes toward science learning.

The N-Gain score was calculated to determine the extent of improvement in students' visual-spatial abilities after participating in the learning. The N-Gain score was chosen because it not only shows the difference in scores between the pretest and posttest, but also allows for the assessment of learning effectiveness compared to the maximum possible score that students can achieve; thus, this analysis can describe more objective improvements (Hake, 1998).

Table 4. N-Gain Score Test Results

Group	N	Mean N-Gain (%)	Std. Deviation	Category
Control	35	46.10	18.94	Less Effective
Eksperiment	35	64.63	18.10	Quite Effective

The N-Gain test results above indicate that the average N-Gain score for the experimental class was 64.63, which is categorized as quite effective. In contrast, the control class's score was 46.10, categorized as less effective. These results demonstrate that augmented reality-based learning can significantly improve students' visual-spatial abilities compared to conventional learning methods. The moderately effective improvement in the experimental class indicates that, while augmented reality learning resulted in better grades, there was also a significant difference in students' understanding of spatial concepts, as measured by five indicators (spatial perception, spatial rotation, spatial visualization, spatial relations, and spatial orientation).

The improvement in the experimental class was driven by augmented reality's ability to display three-dimensional visualizations, allowing students to see and imagine abstract phenomena concretely. Meanwhile, the control class relied solely on verbal explanations from the teacher and static images in textbooks. This finding aligns with research by Huang (2025) that demonstrated that the application of augmented reality-based media in science learning can enhance students' visual representation through the presentation of interactive and contextual learning experiences.

The analysis results indicate that this study demonstrates the potential of augmented reality-based learning to improve elementary school students' visual-spatial abilities. This improvement is clearly evident from the comparison of t-test results and N-Gain scores between the control and experimental groups. Students learning using augmented reality gained direct visualization experience of the processes of changes in state of matter, such as sublimation, crystallization, or condensation, which were previously difficult for them to visualize through verbal explanations alone. With 3D object visualizations that students could observe in real time, it was easier for them to construct accurate mental representations.

The effectiveness of augmented reality in improving visual-spatial abilities can be understood through cognitive psychology theories. Augmented reality engages dual coding processes by combining verbal and visual representations, facilitates mental rotation and spatial visualization through 3D object manipulation, and lowers cognitive load by providing concrete visual contexts for abstract concepts. These mechanisms help students construct stronger mental representations of spatial relationships, leading to improved visual-spatial performance.

These results support Juwairiah's (2025) view that augmented reality can strengthen spatial skills while improving students' academic achievement in science. Furthermore, the success of augmented reality in bridging the cognitive gap between students with varying levels of visual-spatial ability aligns with findings (Abuhashish & Ismail, 2025), which demonstrate that augmented reality can address cognitive differences and improve students' conceptual understanding in science learning. Augmented reality enables students with low spatial abilities to grasp abstract concepts, as the visualizations displayed are interactive and easy to comprehend.

Thus, the successful use of augmented reality in improving students' visual-spatial abilities also has practical implications. Teachers can utilize augmented reality as an alternative learning medium to support science learning, particularly on abstract topics such as states of matter and their changes. This aligns with Rahman (2025), who emphasized the importance of innovation and student motivation for learning. In other words, the use of augmented reality impacts not only cognitive aspects but also affective aspects and learning motivation.

Although the research results demonstrate the effectiveness of using augmented reality in improving students' visual-spatial abilities, this study has several limitations. The learning media used are still limited to Android-based system applications. This can be a challenge if students do not have an Android smartphone or are using a device with a different operating system, such as iOS. This can limit accessibility. Furthermore, the use of smartphones in elementary schools still requires special attention because each school's policy regarding allowing students to bring or use these devices varies. This situation makes the use of this media in the classroom not always optimal, as it depends on the availability of devices owned by students. Therefore, further research is needed to consider developing media that is compatible with various platforms and to more systematically assess the integrity of digital device use in schools.

Overall, the results of this study suggest that augmented reality is a worthy consideration as an innovative learning medium in elementary schools. The significant improvement in the experimental group compared to the control group demonstrates that the use of augmented reality media can be a solution to students' difficulties in understanding abstract concepts in science learning. Therefore, this study supports the use of augmented reality-based press as an effective, relevant, and contextual learning strategy to improve the quality of science education in elementary schools.

CONCLUSIONS

Based on the research findings, it can be concluded that the use of augmented reality-based learning media significantly improved elementary school students' visual-spatial abilities in the topic of states of matter and their changes. This is demonstrated by the t-test results, which showed a significant difference between the experimental and control groups. The N-Gain analysis also revealed that the improvement in the experimental class fell into the moderately effective category, whereas the control class was categorized as less effective. These findings provide empirical evidence that the use of augmented reality can provide a more interactive, contextual, and meaningful learning experience, thus helping students develop more accurate spatial abilities for abstract phenomena such as sublimation, condensation, and crystallization.

Furthermore, the research results also show that the use of augmented reality has a positive impact not only on cognitive aspects, such as visual-spatial abilities, but also on affective aspects, including increased student motivation and engagement during the learning process. From an educational practice perspective, these findings imply that teachers can integrate augmented reality as a complementary learning tool to make science instruction more concrete and engaging. Schools may incorporate augmented reality-based activities into classroom projects or digital literacy programs within the Kurikulum Merdeka framework to strengthen students' conceptual understanding. Additionally, teacher training programs should introduce the pedagogical use of augmented reality to equip educators with strategies for designing interactive lessons aligned with students' cognitive needs.

However, this study still has limitations. The augmented reality media used can only be accessed through Android-based devices, thus limiting accessibility for students using other operating systems. Furthermore, smartphone use in elementary schools remains dependent on school policy, necessitating specific arrangements to prevent disruptions to learning activities. Therefore, further research is expected to develop augmented reality media that are compatible with various platforms and examine strategic implications consistent with elementary school policies in Indonesia. Future research could also explore the long-term effects of augmented reality-based learning on students' problem-solving and reasoning skills, compare augmented reality with other emerging technologies such as virtual or mixed reality, or investigate how individual factors such as gender and prior spatial ability influence augmented reality learning outcomes.

Thus, this study can provide theoretical contributions to strengthen the literature on the effectiveness of augmented reality in improving students' visual-spatial abilities, as well as practical contributions for teachers in designing more interactive science lessons tailored to the needs of elementary school students.

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