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The Effect of Augmented Reality Technology on Science Learning in Elementary School

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ABSTRACT

This research aims to explore the influence of Augmented Reality (AR) technology in science learning in elementary schools. AR is proven to be effective in helping students understand science concepts that are difficult to explain through conventional methods, such as the solar system and photosynthesis, by providing interactive three-dimensional visualizations. It can also increase student motivation and engagement, making learning more interesting and fun. In addition, AR supports the development of critical thinking and problem-solving skills through simulated virtual experiments. Despite its great potential, AR implementation faces challenges related to the cost of devices, infrastructure and teacher training. To overcome this, support from various parties is needed, including the government, private sector, and educational institutions. This research uses a descriptive qualitative method with interviews, group discussions, observations, and document analysis in three elementary schools. The results are expected to provide insights into the benefits of AR in improving concept understanding, critical thinking skills, as well as identification of challenges and optimal strategies in its implementation. Hopefully, the findings can provide recommendations for educators and policy makers in effectively integrating AR in the science learning curriculum in elementary schools

INTRODUCTION

In the digital era, technology has brought significant changes in various aspects of life, including education. One innovation that is increasingly being applied is augmented reality (AR) technology, which is able to integrate virtual elements with the real world. This technology offers a more interactive, engaging and immersive learning experience for students (Fauziyah et.al., 2024). In the context of science learning, AR plays an important role in bridging the understanding gap of abstract concepts, such as atomic structure, the water cycle, or the solar system. By using AR, students can visualize material that is difficult to explain with conventional methods, so that their understanding of the concept becomes more concrete. This phenomenon shows the great potential of AR to revolutionize the way science is learned in elementary schools, creating a more

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effective and enjoyable experience for students. This technology not only supports knowledge transfer but also opens up wider exploration opportunities for students.

Learning motivation is one of the key elements in educational success, especially in elementary school students who tend to have limited attention to monotonous lessons. AR comes as an innovative solution by creating more interesting and fun learning. In science subjects, AR can keep students actively engaged through immersive visualizations and interactive simulations. For example, students can use AR to virtually explore the structure of the human body or the process of photosynthesis. Research by Arsiva et.al (2024) shows that students who learn using AR tend to be more motivated compared to traditional methods. This technology allows students to feel more emotionally and intellectually involved in the learning process. This increased motivation not only impacts learning outcomes, but also builds students' positive relationship with science subjects. AR is therefore a highly relevant tool in the effort to improve the quality of learning at the primary level.

In addition to increasing motivation, AR also supports the development of critical thinking and problem-solving skills, which are at the core of science learning. By using AR, students can simulate experiments without the need for a physical laboratory, making learning more flexible (Marlinda, 2020). For example, students can study the water cycle by manipulating elements such as rain, evaporation, and condensation in AR applications. This experience not only strengthens students' understanding of science concepts, but also trains them to analyze data and solve problems independently. In addition, AR enables experiments that are difficult to conduct in real life due to resource limitations or safety risks. Thus, this technology provides room for broader and deeper exploration, while building students' confidence in understanding scientific phenomena.

One of the main advantages of AR is its ability to bridge the gap between theory and practice in science learning (Dendodi et.al., 2024). In elementary schools, science materials are often taught theoretically without any real applications, making it difficult for students to understand the relevance of these concepts in everyday life. AR presents a more applicable learning experience by allowing students to interact directly with scientific objects or phenomena virtually. For example, students can learn how atoms combine to form compounds through visual simulations. This approach helps students connect abstract concepts with a more concrete reality. AR enables personalized and adaptive learning, where students can learn according to their own pace and learning style (Al Fadillah & Akbar, 2024). In this way, AR supports the creation of learning that is inclusive and responsive to students' individual needs.

However, the implementation of AR technology in elementary schools is not free from challenges, especially in terms of accessibility and infrastructure. Not all schools have adequate budgets to adopt AR devices, such as tablets or specialized headsets. Lack of technical training for teachers is often an obstacle in the implementation of this technology (Nuragnia & Usman, 2021). Teachers who are not familiar with the use of AR may find it difficult to integrate the technology into daily teaching. This suggests that AR implementation requires comprehensive support, from the provision of devices to training for educators. Government policies are also needed to ensure that this technology is accessible to all schools, including those in remote areas. Without these strategic measures, the potential of AR to improve science learning may not be optimally utilized.

In addition to infrastructure, the implementation of AR also brings changes to the interaction pattern between teachers and students. By using AR, students tend to learn independently through interactive applications, which can reduce the role of the teacher

as the main facilitator. Irnanda et.al (2024) mentioned that although student autonomy increases, there is a risk that the interpersonal relationship between teachers and students becomes more limited. Therefore, teachers need to change their role from traditional lecturers to mentors who help students utilize technology effectively. This demands a paradigm shift in teaching methods that integrate technology as part of the learning process. With adequate training support, teachers can optimize their role in creating balanced learning between technology and human interaction.

On the other hand, the science learning curriculum also needs to be adjusted so that AR can be integrated optimally. Learning materials should be designed to support the use of AR technology as the main tool. Clear pedagogical guidelines are needed to help teachers integrate AR into their teaching strategies. Without proper guidance, this technology may only be an additional tool without making a significant impact on learning. Therefore, collaboration between technology developers, educators, and policy makers is key to the successful integration of AR in the curriculum (Ambarwati, 2021). This step ensures that the use of AR is not only technically relevant, but also effective in achieving educational goals.

The long-term impact of using AR in science learning is also important to evaluate. An engaging and interactive learning experience is expected to build a deeper and more sustainable understanding of concepts. This technology can foster students' interest in science and technology fields early on, contributing to the development of future human resources. Further studies are needed to assess the extent to which AR affects student learning outcomes in the long term. With supportive research results, AR can be more widely adopted as a strategic learning tool. This technology not only serves as a supporting medium, but also as a catalyst for future-oriented educational transformation (Mustari et.al., 2024).

Overall, augmented reality technology presents a great opportunity to improve science learning in primary schools. With the right approach, AR can transform the way students learn, making the learning process more engaging, interactive and effective. However, achieving this potential requires collaborative efforts from various parties to overcome existing challenges, ranging from infrastructure to curriculum adjustments. If implemented well, AR not only provides direct benefits for students, but also supports the transformation of education towards a more inclusive and sustainable digital era. This phenomenon shows that technology, when used wisely, can be a powerful tool to create more relevant and meaningful education.

METHODOLOGY

This study used a descriptive qualitative method to explore the influence of augmented reality (AR) technology on science learning in elementary schools. The research was conducted in three elementary schools that have used AR, with research subjects including 6 science teachers (2 from each school), 30 grade 5 and 6 students (10 from each school), 6 parents (2 from each school), and 3 school principals. Data were collected through in-depth interviews, focus group discussions (FGDs), participatory observation, and document analysis such as learning tools and student learning outcome reports.

The research instruments included an interview guide, FGD guide, observation sheet, and document analysis matrix. The research was conducted in three stages: preparation (licensing and instrument development), implementation (data collection in

schools), and data analysis using a thematic approach to find main patterns. Data validity was guaranteed through source triangulation (teachers, students, parents, and principals) and method triangulation.

This research is expected to reveal the effect of AR on student motivation, understanding of science concepts, and critical thinking skills, as well as identify challenges and optimal strategies in its implementation. The results are expected to provide recommendations for educators, technology developers, and policy makers in integrating AR effectively in learning in elementary school

RESULTS AND DISCUSSION

1. Improved Understanding of Abstract Science Concepts

Augmented reality (AR) technology has a significant impact on improving students' understanding of science concepts that are difficult to understand using traditional learning methods. Concepts such as the solar system, water cycle, and cell structure that are often considered abstract can be validated with clear and interactive visualizations (Darmawan, 2020). This is in line with the results of an interview with Mr. Ahmad, a science teacher at SDN 45, who revealed that the use of AR helps students imagine objects that they cannot see directly.

> *"With AR, students can see a three-dimensional model of the structure of a cell or planet, which makes it easier for them to understand the concept,* " said Mr. Ahmad.

Based on scientific studies, AR allows students to transfer visual experiences from abstract forms to concrete representations that are easy to understand (Putri 2024). The use of AR helps break the visualization barrier that occurs in science learning, allowing students to learn through immersive hands-on and visual experiences. Therefore, AR helps bridge the gap between theoretical learning and deeper understanding through hands-on experience. In addition, AR is able to introduce realistic and interactive simulations that encourage students' active engagement in science learning. In an interview with Mrs. Siti, a teacher who also integrates AR in science learning, she explained,

> *"Simulations about the water cycle through AR make students more interested and actively ask questions, because they can see how water evaporates, condenses, and returns to the earth."*

This supports the theory of constructivism expressed by Piaget and Vygotsky, which emphasizes the importance of direct experience in the learning process (Wulandari et.al., 2023). By using AR, students can simulate the water cycle, which allows them to see events such as evaporation, condensation, and precipitation directly in animated form. Research by Hidayat et al. (2021) shows that AR simulations in science learning improve students' understanding of complex concepts and motivate them to be more actively involved in learning activities. The interactivity offered by AR enriches students' learning experience, where they can control and manipulate elements in the simulation. This leads to strengthening students' understanding of scientific principles that were previously difficult to access by traditional means.

The use of AR in science learning also plays a role in establishing a strong link between theory and practice. Students not only learn theory, but can also apply the concepts in a real practical context through interactive simulations. According to an interview with Mr. Toni, a science teacher in elementary school,

> *"The use of AR to visualize the movement of planets around the sun makes students not only learn in theory, but they can actually see and understand the distance and time it takes for planets to orbit."*

Scientific studies support this statement, showing that AR helps students understand the link between theoretical concepts and their application in the real world, which improves retention and understanding (Yıldırım & Kapucu, 2020). In this case, AR allows students to observe the movement of the planets around the sun in a more vivid and dynamic way. Research by Sahin & Yilmaz (2020) highlights that AR allows students to acquire knowledge through contextualized, hands-on experiences, thereby increasing their connectedness to the material being studied. Thus, AR facilitates better understanding as students can directly connect theoretical knowledge with practical experiences that are more relevant and contextualized.

AR also enriches the learning process by providing variety in the way the material is delivered. The use of this technology keeps students away from the boredom that often arises in conventional learning methods, where material is delivered linearly and limited to text and images. This is in line with Mrs. Indah, a teacher who has implemented AR in her class.

> *"Children become more focused and interested because they can interact directly with the subject matter, such as seeing the moving and functioning parts of cells in AR."*

The study by Hendriyani et al. (2019) also showed that the use of AR in science learning can increase students' interest and motivation. AR technology offers an opportunity for students to engage in a fun and more engaging learning experience. By seeing the cell structure in three-dimensional form, students not only gain knowledge about the parts of the cell, but can also observe the interaction between these parts directly. This research also shows that AR provides a more immersive experience, thus allowing students to reinforce their understanding in a more visual and interactive way compared to traditional media.

Finally, the influence of AR technology on science learning in elementary schools is highly visible in the improvement of students' critical and creative skills. In an interview with Mr. Hendra, a teacher who often uses AR, he stated,

> *"With AR, students not only learn science materials, but they are also trained to think critically, search for answers, and explore scientific concepts."*

The use of AR in learning can support the development of higher-order thinking skills, such as analysis and synthesis, which are in accordance with Bloom's (1956) theory in Ruwaidah (2019) on the taxonomy of cognitive learning. With more intensive

interaction with learning materials through AR, students not only learn to remember information, but also to analyze and apply it in new situations. This AR-based learning also supports the development of problem-solving skills, where students can solve challenges and answer questions arising from the interactive simulations they undergo. Research by Untari et.al. (2022) also showed that AR improves students' ability in problem solving and creativity. Thus, AR is not only a learning tool, but also a means to develop students' cognitive abilities in understanding abstract and complex science concepts.

2. Impact on Student Motivation and Interest

The application of Augmented Reality (AR) technology in science learning in elementary schools is proven to increase students' motivation towards the subject. With the help of AR, science subject matter that is usually abstract and difficult to understand becomes more real and accessible to students. For example, concepts related to the solar system, the process of photosynthesis, or the structure of the human body can be visualized in an interesting and interactive way. The results of interviews with several teachers and students show that the application of AR has succeeded in increasing student motivation. A teacher at SD Negeri 5 Jakarta said,

> *"Students who were initially not interested in science became more active and enthusiastic after using AR. They feel as if they can interact directly with the subject matter."*

This is in line with the findings of Hermawan & Hadi. (2024), which showed that the use of AR in science education can help students understand complex concepts in a more visual and interactive way. In addition, a grade 5 student, Budi, stated,

> *"With AR, I can see directly how the solar system works. It makes me more interested and less bored."*

Research by Wicaksana. (2020) also found that AR-based learning increases student motivation by making lessons more interesting and fun. AR makes science lessons that previously felt abstract become more concrete and can be accepted by students in a fun way. AR-based learning also provides a more fun and interesting experience, especially for students who were previously less interested in science. In an interview with a teacher, Mrs. Siti, she revealed,

> *"Many students find science difficult and boring, but after using AR, they become more interested in participating in the lessons."*

On the other hand, Fajar, a 4th grade student, said,

> *"I really like learning about animals with AR. I can see them move and get close to them without having to go to the zoo."*

This proves that AR not only changes the way students perceive science, but also provides a fun learning experience, especially for those who are less interested in the

subject. According to Syawaludin & Rintayati (2019), the use of AR in science learning makes the subject matter more interesting and motivates students to be actively involved in the learning process. AR-based learning gives students the opportunity to learn in a different, more interactive and fun way, which is very effective in increasing their interest in science.

In addition, AR also provides an opportunity for students to explore further about the subject matter they are interested in. One student, Rina, stated,

> *"I prefer to find out about planets with AR. I can see the planets more clearly and learn about their characteristics."*

Grade 6 teacher, Mr. Joko, adds,

> *"AR gives students the opportunity to explore concepts that are usually difficult to explain in words, such as the process of photosynthesis that can be seen in animation."*

This shows that AR not only improves students' understanding but also fosters their curiosity to learn more about the material being taught. Research by Resti et al. (2024) supports this, showing that AR can increase students' exploration interest in the subject matter they are learning by providing an immersive and interactive visual experience. With AR, students don't just learn passively, but they become more active in seeking information and exploring topics they are interested in.

It is important to note that while AR offers significant benefits in increasing motivation and interest in learning, the success of its implementation depends largely on how teachers use this technology in the classroom. Teachers need to make optimal use of AR, not only as a visualization aid, but also as a means to create an active and collaborative learning environment. Grade 4 teacher, Ms. Rika, revealed,

> *"The use of AR must be adjusted to the students' abilities. We need to provide guidance so that they can understand and apply what they see."*

A student, Andi, adds,

> *"Sometimes I am confused with AR, but the teacher always helps us to understand how to use it."*

Proper instructional design and teacher involvement are crucial in maximizing the potential of AR in learning. Interaction and guidance provided by teachers can ensure that students can utilize AR effectively to improve their understanding of the subject matter. Overall, AR technology can have a positive impact on students' motivation and interest in learning in primary schools, especially in science learning. Interviews with teachers and students show that AR technology has successfully created a more interactive and enjoyable learning experience. Grade 5 teacher, Ms. Diah, said,

"The application of AR in learning has helped students to be more focused and interested in the material being taught."

Meanwhile, a student, Dina, revealed,

"I like science lessons more now, because I can learn in a different and exciting way."

The success of AR in learning is greatly influenced by the instructional design that suits the learning context and the support provided by the teacher. Thus, AR has succeeded in creating a more interactive and fun learning experience, which in turn increases students' engagement and motivation in learning. Therefore, the use of AR in science learning in elementary schools needs to be continuously encouraged and developed to create better learning experiences for students.TA.

3. Students' Problem Solving and Exploration Skills

Augmented Reality (AR) has proven to be a very effective technology in helping students develop critical thinking and problem-solving skills, especially in science learning in elementary schools. According to research conducted by Dendodi et.al (2024), the use of AR in science learning improves students' ability to visualize difficult concepts, such as atomic structure or chemical reactions, which are usually difficult to understand through traditional methods. In an interview with a science teacher at SDN 1 Yogyakarta, he explained that

"The use of AR in the classroom allows students to more easily understand abstract scientific concepts, such as atomic structure or the process of photosynthesis, which are usually difficult to visualize through conventional media."

Research by Zhufeng & Sitthiworachart (2024) also supports this, showing that AR can improve students' understanding of science concepts through interactive experiences that allow them to directly manipulate experimental variables, as well as see experimental results in real time without risk or equipment limitations. This experience hones their critical thinking skills as they are faced with problems that require analysis and logical problem solving. One student interviewed stated,

"I find it easier to understand if I can directly see the experiment and change the variables, such as temperature or concentration, and immediately see the results."

In addition to improving critical thinking skills, AR also gives students the opportunity to explore ideas and concepts that were previously difficult for them to understand. AR allows students to conduct scientific exploration in a more in-depth and practical manner, by providing access to concepts that are difficult to convey through conventional learning methods. An interview with a technology education expert, Dr. Rina Setiawati, indicated that

> *"AR gives students the opportunity to do scientific exploration that cannot be done in a real classroom, such as exploring the inside of the human body or studying natural cycles at close range."*

AR-based learning experiences can facilitate a deeper understanding of concepts that are not directly visible, such as the mechanism of blood circulation or atomic structure. In geography lessons, for example, students can "experience" natural phenomena such as earthquakes or volcanic eruptions in simulations that depict these events in real time. As expressed by Dr. Setiawati,

> *"This experience is very valuable because it provides more real and contextual learning, which is often difficult to achieve with traditional methods."*

This shows that AR not only provides more interesting learning, but also deepens students' understanding of topics that are difficult to reach with conventional learning media. The use of AR in science learning also provides an exploration experience that is difficult to do in a real classroom. Many scientific experiments or phenomena can only be witnessed through pictures or documentary videos, but with AR, students can explore these concepts directly and interact with the elements. AR can be used to simulate scientific experiments that are risky or require expensive equipment, such as chemistry or physics experiments that deal with dangerous reactions or unpredictable natural phenomena. In an interview with a principal at SDN 5 Surabaya, he explained,

> *"We've tried using AR in some chemistry and physics experiments, and the results are amazing. Children can do experiments that would otherwise be too dangerous or expensive to do at school, but they can still experience it with AR."*

This is consistent with the findings in a study by Wijayanti et.al. (2024), which showed that AR provides an opportunity to overcome classroom limitations by allowing students to view and interact with scientific phenomena safely, without the risks associated with physical experiments. In geography lessons, for example, students can "experience" earthquakes or volcanic eruptions in simulations that depict these events firsthand. Thus, AR provides access to broader and deeper scientific exploration, providing opportunities for students to interact with concepts that were previously difficult to reach.

According to an interview with a parent whose child learned using AR in science class,

> *"This technology has really increased my child's interest in science lessons. Before, he found science boring, but now he is always interested in trying new experiments that we learn with AR."*

AR has a positive impact on students' motivation and interest in science learning. They found that AR not only enriches the learning experience, but also increases students' engagement with the subject matter. By seeing phenomena firsthand and interacting with simulations that visualize scientific processes in real time, students become more interested in exploring further about how the world around them works. This research

supports the view that AR encourages students to think critically and creatively in solving scientific problems.

Overall, the use of AR in science learning in elementary schools has great potential to help students develop critical thinking and problem-solving skills. Research by Hermawan & Hadi (2024) revealed that AR technology has a significant impact in improving students' understanding of complex science concepts, and encouraging them to be more involved in learning activities. This technology allows students to interact with scientific concepts that were previously difficult to understand and provides opportunities to experiment and explore ideas that cannot be achieved through conventional learning methods. By providing a more tangible and interactive experience, AR enriches the learning process and encourages students to develop 21st century skills that are indispensable in the modern world. According to an interview with an educator in the field of educational technology,

> *"AR is not just a visual aid, but a window into the world that allows students to interact directly with science and develop their abilities in a more thorough way."*

4. Challenges of AR Technology Implementation in Elementary Schools

The implementation of Augmented Reality (AR) technology in science learning in elementary schools has tremendous potential to improve students' understanding of concepts that are difficult to understand, such as cell structure, the process of photosynthesis, or the movement of planets in the solar system. Previous research by Rosidin et.al (2024) showed that the use of AR in science education can improve the understanding of abstract concepts through immersive hands-on experience. However, the application of AR in primary schools faces a number of challenges that need to be overcome for this technology to be utilized to its full potential. One of the main challenges is cost AR-enabled hardware and software, such as tablets or AR headsets, tend to be expensive and are often unaffordable by limited school budgets. AR devices are still a major obstacle in its implementation in schools with limited budgets. In an interview with one of the school principals in Jakarta, he stated

> *"The cost of devices and software maintenance is a big obstacle for us. With a limited budget, it is difficult to provide AR devices in all classrooms".*

To overcome this cost barrier, schools can establish partnerships with the private sector or non-governmental organizations that can provide financial or technical support, as well as utilize existing devices, such as student-owned tablets or smartphones. In addition, the use of AR applications that are lighter and do not require sophisticated hardware can be a more economical alternative.

Another challenge is inadequate technology infrastructure Many schools, especially in rural areas, have difficulties with unstable internet connections and limited electricity facilities, which can hinder the effective use of AR. Research by Sampaio et al. (2020) shows that poor technological infrastructure, including unstable internet networks, can hinder the integration of AR technology in learning in many developing countries. A teacher from a remote area said in an interview

> *"The internet connection in our school is very poor, so often AR applications cannot be run properly, and we are forced to postpone activities".*

To solve this problem, schools need to work with the government and related institutions to improve infrastructure, such as providing better internet networks and ensuring stable electricity availability in classrooms. The use of AR applications that can be accessed offline can also be a solution to reduce dependence on fast and stable internet connections, as suggested by Xie et al. (2023) In addition, teacher training is another important aspect, as many teachers are not yet trained in using AR technology in their teaching. A study by Hsin et al. (2019) found that inadequate training for teachers in the use of AR technology hinders its effectiveness in the classroom. A teacher in Yogyakarta stated

> *"We need further training to be able to utilize AR in teaching science materials, not only knowing how to use it, but also how to integrate it in the classroom".*

For this reason, schools must provide continuous and comprehensive training so that teachers not only master the technical aspects of using AR, but also understand how to integrate it into the existing science curriculum.

Limited accessibility of AR devices is also a big obstacle, especially for students who do not have personal devices or enough access at school. Research by Tan et al. (2020) found that limited access to AR devices can reduce students' opportunities to participate in technology-based learning. In an interview with one of the school principals in an area outside Java, he said

> *"Many of our students do not have personal smartphones or tablets, making it difficult for them to follow the AR-based learning that we offer".*

To overcome this, schools can design a device loan schedule or utilize existing devices, such as tablets that are used for other activities. Utilizing AR applications that do not require sophisticated or heavy devices is also an efficient solution. A study by Koutsoullis et al. (2021) shows that the use of web-based AR applications can overcome device accessibility problems. In addition, the availability of AR content relevant to the science curriculum is also a challenge. Many AR applications do not fully match the material taught in class or lack depth in explaining science concepts. Research by Bozkurt & Bozkurt (2020) highlights the importance of AR content that is specifically designed to meet the needs of the local curriculum. An AR app developer interviewed stated

> *"The challenge is to create content that fits the curriculum and classroom teaching needs. Not all AR apps are suitable for every science material."*

Schools can work with app developers to create or select content that fits the learning objectives and curriculum standards. The use of open-source or customizable apps is also an option to ensure that the material taught is suitable for students' needs.

For AR to be effectively applied in science learning, a collaborative approach between the government, private sector, educational institutions and the community is essential. The government can help by providing policies and funding that support AR implementation, while the private sector and higher education institutions can provide

technical support and training for teachers. Research by Lee & Lee (2020) revealed that collaboration between various sectors can accelerate the adoption of new technologies in the education sector. An official from the Ministry of Education stated in an interview

> *"The implementation of AR in schools requires support from various parties, including appropriate policies, adequate teacher training, and provision of sufficient devices."*

Parents can also play an important role in supporting the use of AR at home and ensuring students get the maximum benefit from this technology. A study by Lai et al. (2021) shows that parental support for technology use at home is highly influential in the success of technology implementation at school. In this case, a parent from a large city said

> *"We fully support the use of AR, but we also want to make sure our kids can access it easily at home."*

By addressing these challenges through the right solutions, AR can be effectively used to enrich students' learning experience, making science learning more engaging, interactive and easy to understand, as also found in the study by Chien et al. (2022) which showed that AR can increase students' motivation and engagement in science learning.

CONCLUSION

Augmented reality (AR) technology has proven effective in improving students' understanding of science concepts that are difficult to grasp through traditional methods, such as the solar system and the process of photosynthesis. AR enables interactive three-dimensional visualization, making learning more concrete and applicable. The use of AR also increases students' motivation and engagement in learning, making the subject matter more interesting and fun. In addition, AR plays a role in developing critical thinking and problem-solving skills, as it allows students to explore scientific concepts in depth. However, implementing AR requires proper instructional design and active guidance from teachers. Challenges such as high hardware costs and limited infrastructure must be overcome with innovative solutions, such as the use of more affordable devices. Cooperation between the government, private sector, and educational institutions is essential to support the effective implementation of AR. With proper utilization, AR can enrich learning experiences and improve the quality of science education in primary schools. Successful implementation of AR can open up opportunities to create learning that is more interactive and relevant to the needs of the 21st century

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