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Analysis of the Utilization of Augmented Reality (AR) Technology in Interactive Science Learning in Schools

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ABSTRACT

This study aims to analyze the use of Augmented Reality (AR) technology to support interactive science learning in schools. The research method used is a qualitative approach with a case study design, involving direct classroom observation, in-depth interviews with teachers and students, and documentation of learning activities. The results show that the use of AR can increase students' interest in learning and understanding of abstract concepts in science. AR also encourages more interactive and participatory learning. The role of teachers shifts to that of facilitators who need to master technological tools and design innovative learning strategies. However, the implementation of AR in schools still faces obstacles such as limited infrastructure and educators' digital competencies. These findings provide important insights into the potential and challenges of AR integration in education, and serve as a basis for policy development and teacher training to encourage digital transformation in science learning.

Keywords: Augmented Reality, Science Learning, Interactivity, Digital Education

INTRODUCTION

The need for innovation in science learning is very important considering that science is a subject that not only demands deep conceptual understanding, but also develops critical, analytical and logical thinking skills in students (Hasnawiyah & Maslena, 2024). Understanding abstract concepts in science, such as biological processes, the laws of physics, or chemical reactions, is often difficult if only presented through conventional methods. Therefore, an innovative, interactive, and contextual learning approach is needed so that students can actively construct knowledge and relate scientific concepts to real-life phenomena. Innovation also plays a role in creating more engaging and challenging learning experiences, thereby increasing student motivation, curiosity, and engagement in the learning process (Dendodi et al., 2024).

Traditional learning tends to be theoretical, teacher-centered, and has minimal interaction, so it is often less able to attract students' attention and interest in participating in the learning process (Amirova, 2025). This method generally emphasizes one-way delivery of material through lectures or textbooks without actively engaging students in exploration and problem-solving. As a result, students become passive, quickly become bored, and struggle to grasp complex concepts, especially in subjects like science that require visualization and contextual understanding. The long-term unattractiveness of this method can lead to decreased learning motivation, low class participation, and reduced critical and creative thinking skills. Therefore, a transformation of learning towards a more innovative, participatory, and technology-based approach is needed to create a more enjoyable, meaningful, and effective learning environment.

The development of digital technology has brought significant changes in the world of education, encouraging the birth of various innovations that have changed the way teachers teach and students learn.(Sinaga & Firmansyah, 2024)One technology that shows great potential in the learning process is Augmented Reality (AR), which can combine the real world with virtual elements in an interactive and immersive way. This technology allows digital objects such as 3D images, animations, or additional information to be displayed in a real-world environment through devices such as smartphones or tablets, thus creating a more lively and engaging learning experience (Salsabila & Putra, 2024). In the context of science education, AR can help visualize abstract concepts, such as atomic structure, human organ systems, or the processes of material transformation, which were previously difficult to understand through text or two-dimensional images alone. Thus, AR not only enriches learning media but also increases student engagement, strengthens conceptual understanding, and stimulates curiosity and creativity in learning (Einsthendi et al., 2024).

Augmented Reality (AR) allows the visualization of abstract concepts in science learning to be more concrete, real, and easier for students to understand (Hariyono, 2023). With this technology, material that could previously only be explained verbally or through two-dimensional images, such as molecular structure, the circulatory system, or the laws of physics, can be presented in three-dimensional form that can be viewed and manipulated interactively. The resulting learning experience becomes more immersive, as students can seemingly "enter" the material and explore it directly. This not only helps improve conceptual understanding but also stimulates students' interest, motivation, and active involvement in the learning process (Mahmudi et al., 2025).

The potential of Augmented Reality (AR) in enhancing interactive learning is enormous, especially in creating more engaging, dynamic and motivating learning experiences (Aminudin et al., 2024). By combining visual, audio, and digital interactive elements into a real-world environment, AR is able to capture students' attention more effectively than conventional methods. This

technology encourages active student engagement because they are not only recipients of information but can also interact directly with learning objects in three dimensions. This interactivity can significantly increase learning motivation, strengthen concentration, and encourage active participation during the learning process. Furthermore, the use of AR can also support various student learning styles, including visual, kinesthetic, and auditory, thus providing a more inclusive and personalized approach to education (Papanastasiou et al., 2019).

The use of Augmented Reality (AR) in learning has the advantage of strengthening students' understanding through the presentation of material in the form of simulations and direct learning experiences that are close to the real world (Chien et al., 2019). With AR, students can see and interact with abstract or complex objects visually and kinesthetically, making it easier to internalize concepts (Rahmawati & Indrawan, 2025). For example, in science learning, AR allows students to simulate chemical reactions, explore human anatomy, or observe the movement of planets interactively, without the need for a physical laboratory. This approach not only makes learning more enjoyable but also helps deepen understanding because students experience the learning process themselves through exploration and direct engagement. Thus, AR contributes significantly to increasing the effectiveness of learning through contextual, concrete, and meaningful experiences.

School readiness in implementing Augmented Reality (AR) technology is one of the key factors in the successful integration of this technology in learning (Ewais et al., 2025). Although AR has great potential in improving the quality of education, the reality is that not all schools are adequately prepared, both in terms of infrastructure and human resources (HR) (Egaji et al., 2022). In terms of infrastructure, challenges include limited supporting devices such as smartphones, tablets, or stable internet connections, as well as the lack of space or facilities that support the optimal use of digital technology in the classroom. Meanwhile, from a human resources perspective, many teachers still lack sufficient technical knowledge and skills to operate and integrate AR into the learning process. The lack of training, mentoring, and technical support also poses a barrier. Therefore, systematic and sustainable efforts are needed from schools, the government, and other education stakeholders to build an ecosystem that supports the adoption of AR technology, including strengthening teacher capacity, providing adequate facilities and infrastructure, and developing a curriculum that is responsive to technological advances.

Mapping the use of Augmented Reality (AR) technology, which has been implemented in several schools, is needed as a strategic step to determine its effectiveness, challenges, and potential for development in educational settings. This mapping is crucial for identifying best practices, infrastructure readiness levels, teacher competencies, and student responses to the use of AR in the learning process (Alalwan et al., 2020). With comprehensive data, stakeholders can design policies, training, and develop AR-based learning systems that are more targeted and tailored to the needs of each educational unit. Furthermore,

the mapping results can also serve as a basis for developing standards for implementing AR technology in schools, encouraging collaboration between schools in sharing resources, and ensuring that the use of this technology is not merely sporadic but part of a sustainable and inclusive learning transformation (Fatimah et al., 2024).

The research gap in studies on the use of Augmented Reality (AR) technology in education lies in the dominance of quantitative approaches that focus more on aspects of effectiveness, such as improving student grades or learning outcomes. Qualitative studies that delve deeper into the direct experiences of users, particularly teacher and student perceptions of AR use in learning contexts, are still very limited. Furthermore, there are not many studies that specifically discuss the dynamics of AR implementation in the classroom, including interactions, adaptation of teaching methods, and curriculum integration. Another gap is the lack of studies examining the challenges of AR implementation in various types of schools with varying social and economic backgrounds and levels of technological readiness. Therefore, further research is needed that can provide a contextual and holistic picture of the reality of AR use in the education system.

The novelty of this research lies in the presentation of an in-depth qualitative analysis of the actual use of Augmented Reality (AR) technology in science learning in the school environment, with an emphasis on interactivity and user experience, rather than solely on quantitative learning outcomes. This research makes a unique contribution by directly exploring the perceptions, responses, and involvement of teachers and students in the AR-based learning process, as well as providing contextual insights into various factors that support and hinder the implementation of this technology, including infrastructure readiness, educator competency, and classroom dynamics. This approach is expected to enrich the literature that has so far been dominated by quantitative studies and open up space for the development of AR implementation strategies that are more effective and in line with real needs in the field.

The purpose of this study is to analyze how Augmented Reality (AR) technology is utilized in interactive science learning in schools, with a focus on in-depth understanding of the process of integrating AR into teaching and learning activities. This study also aims to explore teacher and student perceptions regarding the effectiveness, benefits, and challenges faced in using AR in the classroom. In addition, this study is expected to produce relevant strategic recommendations to support the development and implementation of AR technology more optimally in the context of primary and secondary education, taking into account real-world conditions.

METHODOLOGY

The research approach used in this study is a qualitative approach that aims to understand in depth the experiences, perceptions, and interactions between teachers and students regarding the use of Augmented Reality (AR)

technology in science learning, with a focus on social and educational phenomena that occur naturally in the school environment. The type of research applied is a case study, namely by investigating the use of AR in one or several schools that have implemented this technology, although a phenomenological approach is also an alternative if the main focus is directed at exploring the subjective experiences of teachers and students (Putra et al., 2024). This research was conducted in several secondary or elementary schools, with research subjects including science teachers, students involved in AR-based learning, and principals or curriculum developers when necessary. Data collection techniques included direct observation of the AR-based science learning process, in-depth interviews with various parties to explore their views and challenges, and documentation such as learning media, syllabi, lesson plans, and student learning outcomes. Instruments used included open-ended or semi-structured interview guides, classroom observation sheets, field notes and audio/video recordings with permission. The data obtained were analyzed through a data reduction process, data presentation in the form of thematic narratives, and conclusions drawn based on emerging patterns or themes. To ensure data validity, source triangulation, member checking to validate results with participants, and an audit trail to ensure transparency of the analysis process were used.

RESULTS AND DISCUSSION

The research results show that the use of Augmented Reality (AR) technology in science learning can significantly increase student interest and enthusiasm. Students appear highly engaged when interacting with materials visualized through AR, such as the solar system, the structure of the human body, and chemical reactions, which were previously difficult to understand abstractly. These interactive and concrete visualizations not only make learning more engaging but also strengthen the understanding of scientific concepts in depth. Teachers and students both stated that the learning experience with AR facilitates mastery of the material and helps students more easily remember the information presented. In addition, the use of AR also increases active student participation in class through questions, discussions, and exploration in project-based activities and simulations.

However, this study also found a shift in the role of teachers in the learning process, shifting from mere information providers to interactive learning facilitators. This requires teachers to possess technological skills and the ability to design learning activities integrated with AR. On the other hand, several obstacles to AR implementation exist, primarily related to limited infrastructure and resources. Not all schools have adequate devices such as smartphones or tablets compatible with AR applications, and some teachers still experience difficulties operating the technology due to a lack of training and technical support. These findings underscore the need for systemic support to optimize AR's potential in education equitably.

Table 1. Summary of Research Findings on the Use of AR in Science Learning

Observed Aspects	Key Findings	Narrative Quotes/Participant Perceptions
Student Interest and Enthusiasm	Students are very enthusiastic and more engaged when using AR.	"Learning is fun, like playing a game but you can understand the lesson." – Student A
Concept Understanding	AR visualization makes it easier to understand abstract concepts	"Children understand the respiratory system more quickly." – Teacher B
The Role of Teachers	Teachers transform into facilitators in learning	"I mostly guide and provide challenges, not lectures." – Teacher C
Infrastructure and Technology Constraints	Limited equipment and lack of teacher training are obstacles.	"In our school, not all students have phones that support AR." – Teacher D
Student Interactivity and Engagement	AR improves student participation and communication in class	"Usually they are quiet, now they are discussing with each other and competing to try the application." – Teacher E

The research findings table illustrates five key aspects of the use of Augmented Reality (AR) technology in science learning in schools: increased student interest, conceptual understanding, teacher role, interactivity, and technical challenges. The use of AR has been shown to increase learning enthusiasm due to the more concrete and visually appealing visualization of material, making it easier for students to understand abstract concepts in science such as the respiratory system or atomic structure. Teachers also experienced a shift in their role from instructors to facilitators, which requires technological competence and pedagogical creativity. However, limited devices and a lack of teacher training are significant barriers to implementation. Increased participation and communication between students were also observed during AR-based learning processes. These findings align with a number of previous studies, such as those by Akçayır and Akçayır (2017) who noted that AR improves motivation and learning outcomes but faces technical challenges, and a study by Ibáñez and Delgado-Kloos (2018) which confirmed AR's potential in supporting STEM learning. Other studies by Billinghurst et al. (2015) and Kamarainen et al. (2013) also supports that AR is capable of creating a more immersive and collaborative learning experience, making it a relevant

medium in the digital transformation of science education.

Relevance of Findings to Constructivism Theory

The findings in this study show strong relevance to constructivism theory, which emphasizes that knowledge is actively constructed by students through meaningful learning experiences, not simply received passively from teachers (Saleem et al., 2021). In the context of Augmented Reality (AR)-based learning, students are directly involved in the exploration process, manipulating virtual objects, and observing concretely visualized scientific phenomena. These activities create an immersive and contextual learning experience, enabling students to connect new knowledge with prior understanding more effectively. Furthermore, the use of AR also encourages collaboration, discussion, and reflection, which are essential elements of a constructivist approach. Thus, AR not only strengthens the process of internalizing concepts but also creates an active, participatory learning environment and facilitates the construction of deeper knowledge, in accordance with the main principles of constructivist theory (Juwairiah et al., 2025).

Augmented Reality (AR) creates a learning environment that supports active exploration and reflection, where students not only receive information, but are also directly involved in the process of discovering, observing, and understanding concepts independently (Yusuf, 2024). Through three-dimensional visualization and digital interaction, students can explore scientific objects or phenomena in a more realistic and contextual way, such as examining the detailed structure of body organs or simulating complex scientific processes. This experience fosters curiosity and allows students to build knowledge through hands-on experience. Furthermore, AR also opens up space for students to reflect on what they learn, both individually and through group discussions, thereby strengthening understanding and developing critical thinking skills. Thus, AR plays a crucial role in shaping the learning process to be not only informative, but also transformative and meaningful.

AR as an Innovation in Science Learning

Augmented Reality (AR) technology has proven to be an innovative learning medium in science education, because it is able to present material in an informative, educational and interesting way (Resti et al., 2024). AR provides a different learning experience compared to conventional methods by combining interactive visual elements and digital reality that enrich the learning process (Hermawan & Hadi, 2024). In the context of science learning, which often includes abstract and complex concepts, AR is able to present concrete and contextual visualizations, making it easier for students to understand the material more deeply. Furthermore, the interactive and immersive characteristics of AR can increase student motivation, engagement,

and curiosity, making the learning process not only a cognitive activity, but also a fun and meaningful experience. Therefore, AR has great potential to be an innovative solution in science learning that is adaptive to technological developments and the learning needs of today's digital generation.

The use of Augmented Reality (AR) technology in science learning is also in line with achieving 21st century learning goals, which emphasize the development of critical thinking, collaboration, communication, and problem-solving skills (Demircioglu et al., 2023). Through interactive, simulation-based learning experiences, AR encourages students to analyze information, evaluate situations, and draw conclusions independently—core competencies in critical thinking. Furthermore, AR applications are often combined with project-based activities or group discussions, directly strengthening collaborative and communication skills among students. When faced with scientific challenges or scenarios in a virtual environment, students are also trained to find solutions and make decisions, thus developing their problem-solving skills. Thus, AR serves not only as a visual aid but also as a medium for transforming learning that supports students' readiness to face the demands and dynamics of the 21st century.

School Readiness as a Determining Factor for Success

School readiness is a determining factor in the success of implementing Augmented Reality (AR) technology in the learning environment. The success of AR integration is not only determined by the availability of the technology itself, but also depends heavily on the readiness of infrastructure such as hardware (smartphones, tablets, and internet connections), as well as the availability of AR applications relevant to the curriculum. Furthermore, teacher competence in operating and integrating AR into teaching and learning activities is a crucial element, considering that teachers act as facilitators who must be able to design meaningful and interactive learning. School policy support also plays a crucial role, both in the form of budget provision, ongoing training for teachers, and the development of internal regulations that encourage technology-based learning innovation. Without comprehensive readiness, the use of AR is feared to be only a temporary trend that does not have a significant impact on the quality of learning (Hidayat et al., 2025).

To ensure the effective and sustainable implementation of Augmented Reality (AR) technology in learning, consistent training and technical assistance are needed for teachers and educators. This training aims not only to improve technical skills in operating AR devices and applications, but also to equip teachers with a pedagogical understanding of how to integrate this technology appropriately into the teaching and learning process. Ongoing technical assistance is also necessary to provide teachers with support when facing technical challenges in the field, while also encouraging innovation and adaptation to constantly changing technological developments. With structured training and assistance, teachers will be more confident in using AR, able to

design creative and interactive learning, and become agents of change in the digital education transformation in schools (Hutasoit, 2025).

Long-Term Potential in Digital Transformation of Education

The use of Augmented Reality (AR) has significant long-term potential to drive digital transformation in education, particularly in terms of curriculum digitization and the development of learning media. With AR's ability to present interactive, dynamic, and contextual content, this technology can be the foundation for designing curricula that are more adaptive to the needs of the 21st century. AR enables the integration of learning materials with immersive visual experiences, thus opening up opportunities to create digital learning resources that are more engaging, personalized, and tailored to students' learning styles. In the long term, the use of AR can shift the learning paradigm from one-way and passive to an active, collaborative, and exploration-based learning experience. Furthermore, AR also encourages cross-disciplinary collaboration between educators, technology developers, and policymakers to design a more innovative, inclusive, and future-oriented education system (Fadhluzzakiyy et al., 2025).

Augmented Reality (AR) has great potential to become an effective pedagogical transformation tool if developed systematically and inclusively. Systematic development includes integrated planning of curriculum, technology, and learning methods, so that AR is not merely a complement but is truly integrated into meaningful teaching strategies. Furthermore, an inclusive approach ensures that all parties, including teachers, students, and schools with varying levels of technology access, can benefit from this innovation. This includes providing equitable training, developing content relevant to local contexts, and policies that support equitable technology adoption. With this approach, AR can transform the learning process to be more interactive, adaptive, and student-centered, while bridging the gap in education quality between regions or social groups (Taufiqurrahman, 2022).

CONCLUSION

The use of Augmented Reality (AR) technology has been proven to increase student interest and enthusiasm in science learning through engaging, interactive, and contextual visualizations. This technology significantly helps students understand abstract concepts more concretely, thereby contributing to improved comprehension of the material. In the process, the role of teachers has also undergone a transformation from information providers to learning facilitators, who are required to master technology and be creative in designing AR-based learning activities. However, AR implementation still faces several challenges, such as limited devices and infrastructure, and low digital competency among some teachers, which need to be addressed through support from educational

institutions and ongoing training programs. Overall, AR has great potential to transform science learning into a more interactive and meaningful one, provided it is accompanied by appropriate curriculum integration and comprehensive policy support.

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