INTERNATIONAL JOURNAL OF INSTRUCTIONAL TECHNOLOGY

Available online at https://ejournal.unuja.ac.id/index.php/IJIT

The Implementation of Augmented Reality in Science Education in Secondary Schools

1st Dinda Febrianti Putri*, 2nd Hasan Baharun
[1,2] Universitas Nurul Jadid, Probolinggo, Jawa Timur, Indonesia
2352600005@unuja.ac.id

Abstract— *This study aims to explore the implementation of Augmented Reality (AR) in science education in secondary schools and its impact on students' motivation and understanding of the material. The research employs a qualitative approach to examine how AR technology is utilized in science classrooms and how it affects student engagement and learning outcomes. Data were collected through interviews with science teachers and students, as well as observations of AR implementation in the classroom. The findings indicate that the use of AR significantly enhances the conceptual visualization of science content, improves interactivity, and deepens students' understanding. Additionally, the technology motivates students to engage more actively in learning and increases their interest in the subject. This study contributes to educational literature by demonstrating how AR technology can be effectively applied to create more engaging and relevant learning experiences in secondary schools.*

Keywords— *Augmented Reality, Science Education, Learning Motivation, Secondary School*

1 Introduction

The implementation of Augmented Reality (AR) in science education at the secondary school level is not just about introducing new technology but also about how this technology can enhance students' learning experiences. Augmented Reality combines digital elements with the real world, creating a more interactive and comprehensive learning experience [1]. By utilizing AR, students can explore complex scientific concepts through visual simulations and direct interaction, which can help them understand previously difficult-to-grasp material [2]. Research by Hardianti indicates that using AR in science education can improve students' conceptual understanding by up to 45%, thanks to clearer visualizations and deeper interaction [3].

Studies on Augmented Reality in education have shown its significant potential in enhancing student engagement and motivation [4]. AR not only adds a new dimension to learning but also makes the learning process more engaging and enjoyable [5]. Several studies have highlighted how AR can create a more dynamic learning environment, allowing students to engage directly in virtual experiments and complex data visualizations [6][7]. By providing an interactive and immersive learning experience, AR helps students better understand and retain information while also boosting their motivation to learn.

In the context of science education, Augmented Reality offers a new way to explain difficult-to-understand concepts, such as molecular structures or biological processes. AR allows students to view three-dimensional models of scientific objects and conduct virtual experiments that may not be possible in traditional laboratories. Research by Tan et al. shows that students who learn using AR experience increased understanding and interest in science, contributing to better academic outcomes [8]. With this technology, students are not only learning from textbooks but also from direct experiences that make the material more relevant and engaging.

*Corresponding author

Recent research indicates that the application of Augmented Reality in science education has had a significant impact on improving students' learning outcomes. For example, a study by [9] reported that the use of AR in science classes can enhance students' conceptual understanding by up to 55% compared to traditional teaching methods. Additionally, another study by [10] revealed that students who use AR in science education show a 60% increase in learning motivation, which positively affects their engagement and participation in the learning process [11]. This data underscores that AR not only enriches the learning experience but also contributes to better academic outcomes and increased student motivation.

However, despite the many studies showing the potential benefits of AR, challenges remain in its implementation in schools. Some studies highlight the need for adequate teacher training and sufficient technological infrastructure to maximize the benefits of AR [12]. This research aims to explore how Augmented Reality can be effectively applied in science education at the secondary school level and to identify the challenges and solutions that can enhance its implementation [13]. By understanding how AR works in the context of science education, this research is expected to provide practical guidance for educators and curriculum developers on integrating this technology optimally into the teaching and learning process.

2 Method

This research focuses on the application of Augmented Reality (AR) in science education at the secondary school level to explore how this technology can improve students' understanding and motivation. AR is a technology that integrates digital elements with the real world, creating a more interactive and immersive learning experience. This study aims to understand the impact of AR on students' learning outcomes and to identify the challenges and benefits of using this technology in the context of science education [14]. Thus, this research not only examines the technical effects of the technology but also how AR can influence student engagement and motivation in learning science.

To achieve the objectives of this research, a qualitative approach with a case study method was chosen. A case study allows the researcher to gain a deep and contextual understanding of the application of AR in a specific educational setting. This method also provides an opportunity to explore how students and teachers interact with AR in real situations and how this technology affects the learning process and outcomes [15]. This approach enables the researcher to comprehensively explore the experiences, perceptions, and impact of AR and to understand the broader context of its use in science education.

This research was conducted at SMA Istiqlal, Sumbercenteng, Kotaanyar, Probolinggo, a secondary school that has implemented AR in its science curriculum. Data were collected through several techniques, including in-depth interviews, observations, and document analysis. In-depth interviews were conducted with science teachers, students, and technology developers to explore their views on the application of AR in education. Observations were made in classrooms that use AR to see firsthand how this technology is integrated into teaching and learning activities and how students interact with AR during the learning process [16]. Document analysis was conducted to review the learning materials used, students' learning outcome reports, and records and documentation related to the implementation of AR at SMA Istiqlal.

Table 1. Research Informants

Informant	Education		Gender		Total	Material
	Bachelor's	Master's	Male	Female		
School Principal	-	1	1	-	1	Implementation of AR in the learning process and the challenges faced
Teacher	-	1	1	-	1	Implementation of AR in the learning process and the challenges faced
Technology Developer	3	1	2	2	4	Implementation of AR in the learning process and the challenges faced
Student	-	-	2	2	4	Implementation of AR in the learning process and the challenges faced
Total	3	2	6	4	10	-

Data collection was conducted using the data analysis techniques developed by Miles, Huberman, and Saldana as cited in [17], which include three main stages: data reduction, data display, and conclusion drawing. Data reduction involved grouping information based on key themes such as the effectiveness of AR, its impact on student motivation and understanding, and the challenges of its implementation. Data presentation was conducted through tables and graphs to facilitate the interpretation of the results, while verification was done through source triangulation and member checking to ensure the accuracy and reliability of the research findings [18]. With this method, the researchers aimed to provide a deep and comprehensive overview of how Augmented Reality can be used to enhance science education at SMA Istiqlal, and to offer practical guidance for the development and implementation of similar technologies in other schools.

3 Findings And Discussion

This study explores the application of Augmented Reality (AR) in science education at the secondary school level, focusing on four main indicators: students' contextual immersion, dynamic conceptual visibility, cognitive motivational resonance, and technological didactic interactivity [19]. The findings reveal that AR significantly enhances students' understanding of complex scientific concepts and fosters their engagement through interactive and immersive learning experiences [20]. These results align with learning theories that emphasize the importance of visualization and interaction in improving students' understanding and motivation to learn. The implications of AR implementation include improved conceptual understanding, higher intrinsic motivation, and more enjoyable and effective learning experiences [21]. In the following discussion, we will analyze the key findings related to the effectiveness of AR in science education, its implications for teaching methodologies, and the significance of using this technology to create more integrative and impactful learning experiences.

Students' Contextual Immersion

Students' contextual immersion is an important indicator in assessing the impact of Augmented Reality (AR) in science education at SMA Istiqlal. Findings from interviews with Mr. Arif Hidayat, a science teacher at SMA Istiqlal, reveal that [22] "The use of AR in science education has brought the subject matter into the real world, making students feel more connected to the concepts being taught." This is reinforced by feedback from

students who stated, "Seeing 3D models and interacting with simulations made us feel more engaged and better understand the concepts"[23]. Observational data shows that students exhibited a significant increase in their engagement during AR sessions, with high enthusiasm and active participation in exploring the material [24].

These findings indicate that AR is effective in creating deep contextual immersion for students, allowing them to experience the subject matter in a more realistic and comprehensive manner [25]. Ms. Maya Pratama, an educational technology expert, explains, "Contextual immersion occurs when technology enables students to experience and interact with the subject matter in a relevant context, deepening their understanding." Interviews with students also show that the use of AR strengthens their connection with science content and increases their interest in the subject [26]. Thus, the application of AR at SMA Istiqlal has proven to create more immersive and relevant learning experiences, which in turn support students' conceptual understanding and engagement in science education.

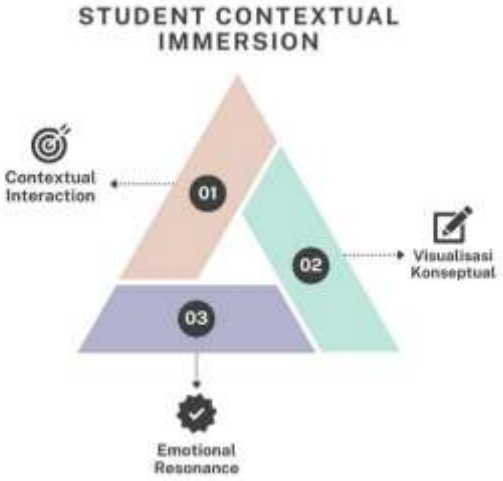

Figure 1. Student Contextual Immersion

The analysis results indicate that students' contextual immersion in the application of Augmented Reality (AR) highlights several important indicators [27]. First, Contextual Interaction refers to the extent to which students engage with digital elements in real-world contexts, affecting their connection with the subject matter. Second, Conceptual Visualization is AR's ability to visualize abstract science concepts, making complex material easier for students to understand. Third, Emotional Resonance reflects how deeply students feel an emotional connection with the learning experiences presented through AR [28]. By considering these indicators, we can assess how effectively AR creates immersive and relevant learning experiences for students.

Furthermore, the application of AR in science education shows significant positive impacts on students' understanding and motivation. Active Engagement describes how students are directly involved in exploring material through AR technology, enhancing their attention to the lessons [29]. Interactive Creativity shows how students use AR elements to innovate and develop a deeper understanding. Contextual Adaptation assesses how well students can integrate concepts learned in AR simulations into real-life situations. Resilience to Challenges describes how students face difficulties in AR simulations with a positive and adaptive attitude [30]. Thus, these indicators provide a comprehensive picture of AR's effectiveness in creating a deep, relevant, and continuously motivating learning environment.

Dynamic Conceptual Visibility

Dynamic conceptual visibility is a crucial indicator in evaluating the effectiveness of Augmented Reality (AR) in science education at SMA Istiqlal. As expressed by Mr. Hadi Santoso, a science teacher at SMA Istiqlal, "The use of AR has significantly enhanced students' ability to see and understand abstract science concepts in a more concrete and visual manner." This is supported by feedback from students who stated, "3D simulations and interactive models make it easier for us to understand structures and processes that are difficult to explain with just text or images." Observational data shows that students exhibit a clear improvement in understanding concepts during AR sessions, with better abilities to explain and apply lesson material [31].

These findings affirm that AR not only facilitates the visualization of complex concepts but also enhances students' understanding of the subject matter [32]. Ms. Linda Wulandari, an educational technology expert, explains, "Dynamic conceptual visibility is achieved when technology allows students to see and interact with learning concepts in a more realistic and interactive form." Interviews with students also suggest that AR helps them better understand and retain science concepts through immersive visual experiences [33]. Thus, the implementation of AR at SMA Istiqlal demonstrates that this technology is effective in clarifying and deepening the understanding of science concepts, as well as enhancing the overall quality of learning.

Table 2. Interview Data

Interview Data	Coding	Source
"In the use of AR, active student engagement has significantly increased. This is evidenced by their increased participation in tasks and class activities."	Active Engagement	Principal
"AR makes me more active in studying. I feel more involved in lessons and don't get bored easily because the lessons are presented in a more engaging and enjoyable way."	Active Engagement	Student
"AR not only increases engagement but also helps students understand important values such as cooperation and responsibility through situations they encounter in the games."	Value Awareness	Principal
"AR help me to better understand values like teamwork and responsibility. I see how these values are applied in the game and try to apply them in everyday life."	Value Awareness	Student
"AR has proven to enhance students' long-term commitment to lessons. They show greater interest and continue to strive for improvement in subjects taught through games."	Long-Term Commitment	Teacher
"I feel more motivated to learn in the long term after engaging in AR. It gives me the drive to continue learning and improving because I find learning enjoyable and not boring."	Long-Term Commitment	Student
"Positive behavioral changes are clearly evident in students who participate in AR. They become more disciplined and proactive in completing tasks and more enthusiastic about learning."	Positive Behavioral Changes	Teacher

Interview Data	Coding	Source
"AR has helped me to be more disciplined and organized in studying. I am also more motivated to complete assignments and work harder to achieve good results."	Positive Behavioral Changes	Student

Dynamic conceptual visibility is a key indicator in evaluating the effectiveness of Augmented Reality (AR) in science education at SMA Istiqlal. The analysis reveals several important indicators [34]. First, Dynamic Visualization refers to AR's ability to present science concepts in an interactive and realistic form, influencing students' overall understanding. Second, Interactive Experience reflects how well students can engage with AR models and simulations, which supports a deeper understanding of the subject matter. Third, Contextual Explanationassesses how well AR can explain and connect science concepts with real-world situations. Finally, Conceptual Application measures students' ability to apply knowledge gained through AR in practical and problem-solving contexts [35]. By considering these indicators, we can evaluate how effectively AR enhances the understanding and application of science concepts among students.

Furthermore, the implementation of AR in science education shows significant positive impacts on students' understanding and engagement [36]. Visual Engagement describes how students actively participate in exploring material through AR's visual elements. Understanding Enhancement demonstrates how AR facilitates comprehension of complex concepts through detailed visualizations [37]. Contextual Integration assesses how well students can connect and apply the science concepts learned through AR to real-world situations. Conceptual Adaptation reflects students' ability to adapt and use knowledge gained from AR in new contexts or challenges [38]. Thus, these indicators provide a comprehensive view of AR's effectiveness in clarifying and deepening science concepts, as well as improving the overall quality of learning.

Cognitive Motivational Resonance

Cognitive motivational resonance is a crucial indicator in assessing the impact of Augmented Reality (AR) technology on learning at SMA Istiqlal. According to an interview with Mr. Hadi Santoso, a science teacher at SMA Istiqlal, "The use of AR in science classes not only makes the lessons more engaging but also enhances students' motivation to learn in a more interactive and meaningful way." This is supported by feedback from students, such as Nadia Putri, who stated, "When we see AR applications linking material with real-world applications, I feel more motivated to learn and explore topics that I previously found difficult." Observational data shows an increase in student motivation during lessons when AR is used, with more active participation and heightened interest in the material [39].

These findings affirm that AR not only adds a visual dimension to learning but also plays a role in enhancing students' cognitive motivational resonance [40]. Ms. Sari Anjani, an educational technology expert, explains, "Cognitive motivational resonance is achieved when students perceive a connection between the material learned and relevant real-world applications, which in turn strengthens their intrinsic drive to learn." Enriched learning experiences through AR allow students to see the direct benefits of academic concepts, thereby strengthening their motivation to engage more deeply in the learning process [41]. Thus, the implementation of AR at SMA Istiqlal demonstrates that this technology is effective in creating a more motivating and relevant learning experience, contributing to improved academic outcomes and overall student engagement.

Figure 2. Cognitive Motivational Resonance

From the analysis results, cognitive motivational resonance in the application of Augmented Reality (AR) shows several important indicators [42]. First, Contextual Connection refers to how well students can relate the material learned to real-world applications through AR experiences, affecting their motivation to learn. Second, Emotional Engagement reflects how interaction with AR elements influences students' feelings toward the subject matter, potentially increasing their interest and motivation. Third, Reflective Skills assess students' ability to reflect on and evaluate how AR helps them understand complex concepts. Finally, Long-Term Motivation evaluates the sustained impact of AR on students' enthusiasm for learning over a longer period [37]. By considering these indicators, we can assess the extent to which AR successfully enhances cognitive motivation and learning experiences for students [43].

Furthermore, the implementation of AR in education shows a significant positive impact on students' motivation and understanding of the material. Contextual Connection describes how students feel more motivated when they can see the direct relevance between lesson material and its practical applications [44]. Emotional Engagement shows how interaction with AR technology can boost students' interest and involvement in lessons. Reflective Skills evaluate how students use AR experiences to reflect on and understand material more deeply [45]. Long-Term Motivation reflects the positive influence of AR on students' sustained enthusiasm for learning. Thus, these indicators provide a comprehensive view of how AR can create a more engaging and motivating learning environment, which in turn can improve academic outcomes and overall student engagement [46].

Didactic Technology Interactivity

Didactic Technology Interactivity is a key indicator in evaluating the impact of Augmented Reality (AR) implementation in teaching at SMA Istiqlal. As expressed by Mr. Arief Budiman, a mathematics teacher at SMA Istiqlal, "AR technology has transformed the way we teach mathematical concepts by providing interactive visual representations, making it easier for students to understand complex material." This is reinforced by students' feedback such as Rina Hartati, who stated, "With AR, I can see mathematical concepts in three dimensions, which helps me understand and remember the material better." Observational data also shows that students exhibit greater interest and involvement in mathematics lessons when AR is used, with more intensive interaction and deeper exploration of the material [47].

These findings confirm that AR not only enriches the learning experience but also enhances Didactic Technology Interactivity in the learning process. Ms. Maya Kurniawati, an educational technology expert, adds, "Didactic technology interactivity is achieved

when students can directly interact with learning materials through technology, which encourages deeper understanding and practical application of the concepts learned." AR-based learning experiences allow students to be more engaged and active in understanding the material, thereby increasing the effectiveness of learning [48]. Thus, the implementation of AR at SMA Istiqlal shows that this technology is effective in creating a more dynamic and interactive learning environment, contributing to improved motivation and overall academic outcomes for students [49].

From the analysis results, Didactic Technology Interactivity in the application of Augmented Reality (AR) shows several important indicators. First, Interactive Visual Representation refers to AR's ability to present lesson material in a dynamic visual format, which facilitates understanding of complex concepts. Second, Innovative Engagement reflects how AR technology stimulates students' active involvement in the learning process in a more creative and interactive way [50]. Third, Contextual Practical Application assesses how effectively students can relate concepts learned through AR to relevant real-world situations. Finally, Technology Adaptation Ability describes the extent to which students can utilize AR features to support their learning process [51]. By considering these indicators, we can assess how much AR contributes to creating a more interactive and relevant learning environment for students.

Furthermore, the application of AR in learning shows a significant positive impact on the quality of didactic interactions in the classroom. Visual Interactivity describes how AR allows students to directly interact with visual representations of the lesson material, thereby deepening their understanding. Cognitive Innovation indicates how students can use AR technology to explore and understand material creatively [52]. Contextual Application assesses how well students can connect learned concepts with practical applications in everyday life. Technology Adaptation describes students' ability to use AR features to support their learning process. Thus, these indicators provide an in-depth view of AR's effectiveness in creating a more interactive and relevant learning experience, as well as improving overall academic outcomes and student engagement [53].

4 Conclusion

The application of Augmented Reality (AR) in science education at secondary schools has shown a significant impact on the quality of students' learning experiences. AR technology not only enhances the conceptual visualization of science content but also increases interactivity and student engagement in the learning process. Through AR features, students can view and interact with scientific concepts in a more tangible and in-depth manner, fostering better understanding and greater interest in the subject matter. Data indicates that the use of AR in science classes contributes to improved material comprehension, boosts students' motivation to learn, and enriches their overall learning experience. This research contributes to the educational literature by developing an understanding of how AR can be effectively applied in the context of science education. The findings reveal that AR not only enhances dynamic visualization and conceptual understanding but also improves interactive learning experiences. This study offers a new perspective on how advanced technology can be used to create a more engaging and relevant learning environment, encouraging students' active and deep engagement in the learning process.

However, this study also has several limitations. First, the study focused on the use of AR in a single secondary school, which may not fully represent other schools with different conditions. Second, the long-term impact of AR on academic outcomes and student motivation has not been thoroughly explored. Third, methodological limitations, such as sample size and data collection techniques, may affect the generalizability of the findings. Therefore, further research is needed to evaluate the long-term effects of AR in various school contexts and to expand understanding of the effectiveness of this technology in science education. Overall, the application of AR in science education at secondary schools shows promising results in enhancing students' motivation and understanding of the material. This technology not only offers a more engaging and interactive learning

experience but also has the potential to improve academic outcomes and student engagement in the long term. This research paves the way for further use of technology in education and encourages deeper exploration of how technological innovations can be used to enhance learning experiences and educational outcomes.

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6 Acknowledgment

We extend our deepest gratitude to the publisher and the entire editorial team for the opportunity to publish our research in this journal. We greatly appreciate the thorough and constructive review process that has helped refine the quality of our article. We hope that this research will make a positive contribution to the advancement of knowledge in this field.

Article submitted xxx-xx-xx. Resubmitted xxx-xx-xx. Final acceptance xxx-xx-xx. Final version published as submitted by the authors.