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Integrating Augmented Reality into Blended Learning for Improved Magnetism Conceptual Understanding

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Abstract

In pursuing innovative educational strategies, this study investigates the integration of Augmented Reality (AR) with blended learning to enhance students' conceptual understanding of magnetism. Utilizing AR as a significant educational tool provides an immersive experience that aids in comprehending complex concepts. At the same time, blended learning combines traditional classroom methods with online resources for a more effective approach. This research employs an experimental design with a pretest-posttest control group involving 60 students from the Islamic University of Raden Intan Lampung enrolled in a physics course on magnetism. The experimental group experienced AR-enhanced blended learning, while the control group received traditional blended learning without AR. Quantitative data analysis included descriptive statistics and the N-Gain test to measure the intervention's effectiveness, with ANOVA used to examine differences in conceptual understanding between the groups. Qualitative data was gathered through semi-structured interviews and analyzed thematically to identify common themes and patterns. The results indicate a significant improvement in the experimental group's understanding of magnetism compared to the control group, highlighting AR's effectiveness in enhancing interactivity and engagement, facilitating the visualization of abstract concepts, and reinforcing the linkage between theory and practical application. These findings offer educators and curriculum developers valuable insights, laying a foundation for future interdisciplinary educational research.

Keywords: *Augmented Reality; Blended Learning; Conceptual Understanding; Magnetism*

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INTRODUCTION

Augmented Reality (AR) integration in educational contexts has evolved remarkably, gaining significant attention in recent years, particularly in science education. AR has matured into a critical educational technology alongside other immersive technologies, offering immersive experiences that facilitate a deeper understanding of complex concepts [1]. This evolution is notable as AR has progressed from simple overlay techniques to sophisticated interactive simulations, dramatically altering student-content interaction [2]. Its adaptability to various learning styles and real-time feedback capability has notably enhanced its effectiveness in educational settings [3], while its role in promoting active learning, as highlighted by Hajirasouli and Banihashemi [4], encourages meaningful exploration of subject matter. Consequently, AR's impact on retention and understanding of scientific concepts, including magnetism, has become a focal point of modern educational research [5].

This progression in the application and sophistication of AR in education provides an ideal segue into the discussion of blended learning [6], [7], a method that synergizes the strengths of both online and traditional classroom formats and complements AR's dynamic capabilities [8]. This integration represents a confluence of two cutting-edge educational strategies, enhancing the other's effectiveness. While AR offers immersive and interactive experiences, blended learning provides a structured yet flexible framework that accommodates diverse learning preferences and paces. These approaches present a holistic model for contemporary education [9], particularly in science [10], where combining theoretical knowledge and practical application is paramount.

Blended learning has emerged as a potent educational approach, adapting to the evolving educational landscape [11]. Research by Ballouk et al. [12] underscores its adaptability in addressing diverse learning needs. However, implementing this approach, especially in science education, is not without challenges, including ensuring consistent access to technology and adapting to various learning paces. Despite these challenges, Bowden [13] observed that the potential for enhanced engagement and achievement outweighs such obstacles. The personalized nature of blended learning, particularly valuable in subjects like physics, is crucial for accommodating different approaches to understanding challenging concepts [14], [15]. Additionally, integrating practical and theoretical learning in these environments aids conceptual understanding and fosters critical thinking [16]–[18].

The concept of magnetism underscores the necessity of innovative educational methods due to its inherently abstract nature, posing significant challenges in traditional educational setups. As Fidan & Tuncel [19] pointed out, combining advanced tools such as AR and blended learning methodologies becomes indispensable to conveying its principles. Abdusselam & Karal [20] and Nakamura & Mizuno [5] advocate for these modern teaching aids, with AR providing interactive and visually engaging ways to unravel the complexities of magnetic fields, as Gholap & Li [21] observe. In tandem, Míguez-Álvarez et al. [22] propose that blended learning facilitates hands-on experiments and real-world applications, rendering abstract magnetism concepts more concrete and relatable. This synergistic application of AR and blended learning enhances understanding and stimulates a more curious exploration of magnetism.

AR's potential in teaching complex subjects like magnetism has been a significant focus in educational research. Studies show that AR provides interactive experiences, rendering abstract concepts more tangible and understandable [23]–[25]. Furthermore, AR's ability to visualize invisible forces like magnetic fields enhances conceptual understanding [26]. This interactive nature allows learners to manipulate variables in real time, deepening their grasp of magnetic principles. AR thus bridges the gap between theory and practice, maintaining student interest in physics [26], [27].

The combination of AR and blended learning creates an innovative model, leveraging the interactive nature of AR with the flexibility of blended learning [9], [28], [29]. This synergy enables comprehensive educational experiences crucial for subjects like physics [27], [30]. Blended learning's versatility allows for a seamless transition between theory and practical application, catering to varied learning paces and styles [31]. Moreover, this approach significantly boosts student motivation and engagement [8], representing a substantial advancement in the application of technology in education.

Understanding students' grasp of physics is vital for evaluating educational interventions [32]. Studies indicate that engagement and motivation are essential to conceptual understanding in physics [23]. Engaging teaching methods, especially those incorporating technology and interactive media, have increased interest and participation [33], while timely feedback and assessment enhance comprehension [34]. The link between engagement and success in science is clear, underscoring the need for engaging methodologies.

Despite the recognized potential of AR and blended learning in enhancing educational experiences, their combined effect on understanding magnetism remains under-explored. Magnetism's unique challenges necessitate tailored educational strategies [20]. While promising, the potential of AR for visualization and blended learning for flexible environments lacks empirical validation in the context of teaching magnetism [35]. Understanding how these technologies can be effectively integrated is crucial [36]–[38]. This study aims to fill this research gap by exploring the effects of AR-based blended learning on students' conceptual understanding of magnetism.

Current research highlights the individual benefits of AR and blended learning, but there is a significant gap in studies investigating their combined application in teaching complex physics concepts like magnetism. This study addresses this gap by integrating AR with blended learning to enhance conceptual understanding of magnetism, providing empirical evidence on the efficacy of this approach. It explores the effects of AR-based blended learning on students' understanding of magnetism and their responses to using AR in learning. The findings are expected to contribute to educational technology and physics education, offering valuable insights for educators and curriculum developers and laying a foundation for future interdisciplinary research in teaching complex scientific concepts.

METHOD

This study employed a mixed-method approach with an explanatory sequential design to evaluate the impact of Augmented Reality (AR) technology combined with blended learning on students' understanding of magnetism. Initially, quantitative data were collected, followed by qualitative data to deepen insights from the quantitative analysis. The research design included a randomized pretest-posttest control group setup, with one group experiencing AR-based blended learning (experimental group) and the other undergoing traditional blended learning without AR (control group), as depicted in Figure 1.

The study involved 60 participants, divided equally between the experimental group (E1) and the control group (C1), each comprising 30 students, representing 50% of the total sample. The participants, aged between 18 and 22, were enrolled in a physics course on magnetism. The experimental group engaged in a blended learning environment utilizing AR mobile software (cg-physicsAR), while the control group followed a traditional blended learning approach without AR technology. Gender distribution in the experimental group was 11 males and 19 females, whereas the control group consisted of 9 males and 21 females. This setup allowed for a comparative analysis of the effects of AR-based learning versus traditional methods on students' conceptual understanding of magnetism.

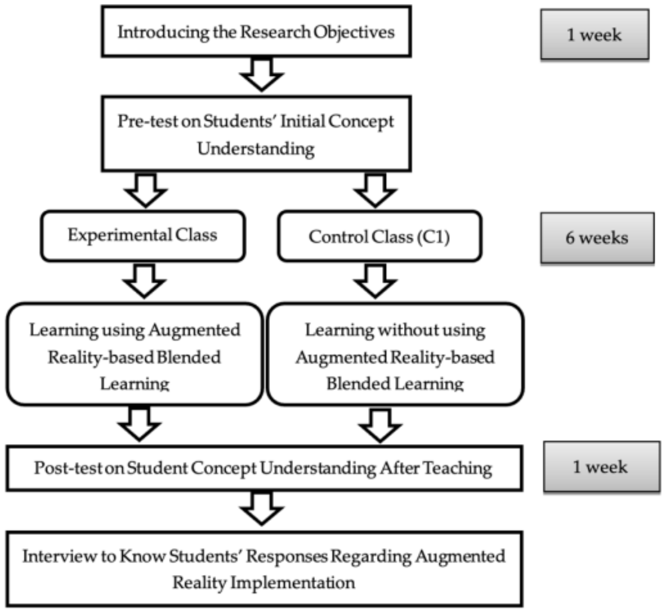

Figure 1. Experimental Design

The study followed a structured weekly plan for the experimental and control groups, with the experimental group using AR technology and the control group following traditional methods. In Week 1, the experimental group used AR to visualize magnetic poles and field lines, followed by an online quiz, while the control group had a lecture and quiz on the same topics. Week 2 involved AR exploration of Earth's magnetic field and online resources for the experimental group, compared to classroom discussions and online resources for the control group. Week 3 had the experimental group simulating magnetic fields with AR, while the control group used physical tools for demonstrations. In Week 4, the experimental group conducted AR-based magnetic force experiments, and the control group had a lecture on magnetic forces and problem-solving activities. Week 5 focused on AR exploration of electric motors and video tutorials for the experimental group, with the control group assembling electric motors and watching videos. Finally, in Week 6, the experimental group used AR to visualize charged particle motion and completed online exercises, while the control group attended a lecture supported by diagrams and online exercises. This setup enabled a detailed comparison of learning outcomes between the AR-enhanced and traditional methods.

Data collection techniques included a physics conceptual understanding test consisting of 64 multiple-choice questions, which evaluated students' grasp of magnetism. Reliability analysis using the Rasch model confirmed the test's robustness with a Cronbach's Alpha value of 0.93. The research used semi-structured interviews to gather students' perspectives on using Augmented Reality (AR) in physics lectures, explicitly focusing on magnetism within a blended learning framework. These interviews aimed to understand the impact of AR on students' learning experiences and conceptual comprehension. The interview process involved explaining the interview's purpose, briefing participants on the methodology, and encouraging students to provide reasons for their responses to gain deeper insights into their experiences with AR. The interviews, each lasting about 30 minutes, included seven questions designed to explore how AR enhances cognitive skills in understanding magnetism. The questions focused on interpreting information, conceptual and theoretical modeling, classification of concepts, summarizing abstract ideas, drawing conceptual conclusions, comparative analysis, and explaining cause-and-effect relationships in magnetism.

Additionally, the application of AR technology in presenting visualizations on mobile devices is exemplified in Figure 2, illustrating the integration of this technology in the learning process.

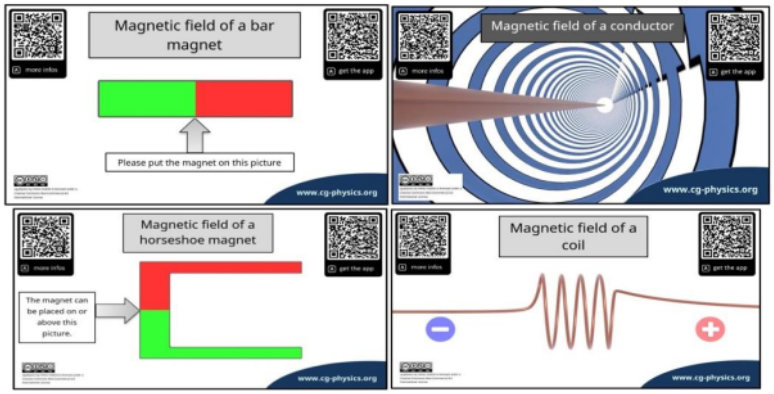

Figure 2. Presentation of Augmented Reality Tool Visualization

The study began with an initial evaluation by a Basic Physics lecturer, who identified challenges in teaching magnetism due to its abstract nature. To address these challenges, the research implemented mobile augmented reality (AR) technology compatible with platforms like iPhone and Android, bringing magnetism principles to life through 2D and 3D visualizations. In the experimental group (E1), AR was integrated into face-to-face sessions to explore and visualize magnetism concepts, supported by online quizzes and resources. Over time, students engaged with more complex topics using AR, supplemented by video tutorials and exercises. In contrast, the control group (C1) followed a traditional blended learning approach without AR, relying on conventional lectures and physical demonstrations, though both groups covered the same topics and accessed online quizzes and resources. The AR application in the experimental group transformed teaching by visualizing magnetic fields and facilitating interactive sessions, allowing for an evaluation of AR's efficacy in enhancing the learning experience compared to traditional methods. Figure 3 illustrates the practical application of AR in studying magnetism, highlighting its potential to enhance both in-person and remote learning.

Figure 3. Students in the Classroom Using AR in the Learning Process

Data Analysis

The data analysis in this research rigorously evaluated the impact of Augmented Reality (AR) in a blended learning environment on students' conceptual understanding of magnetism. The quantitative component involved a detailed analysis of concept understanding tests administered to experimental and control groups before and after the intervention—descriptive statistics summarized data, including mean, standard deviation, minimum, and maximum scores. The N-Gain test measured the effectiveness of the intervention, providing a normalized measure of improvement. The primary statistical method was Analysis of Variance (ANOVA), used to examine differences in conceptual understanding between the experimental group utilizing AR and the control group without AR. ANOVA results determined whether the differences in learning outcomes were statistically significant.

The qualitative data were derived from semi-structured interviews with students in the experimental group to gather in-depth insights into their experiences with AR technology. Interview responses were transcribed and thematically analyzed to identify common themes and patterns. This analysis provided a richer context to the quantitative findings, helping understand the qualitative aspects of student engagement with AR technology. The final data analysis stage involved synthesizing quantitative and qualitative findings, enabling a comprehensive understanding of AR technology's impact on students' physics learning.

RESULTS AND DISCUSSION

This section presents and discusses the study's findings, which aimed to evaluate the effectiveness of Augmented Reality (AR)-based blended learning in enhancing students' conceptual understanding of magnetism. The analysis includes both quantitative and qualitative data, providing a comprehensive view of the impact of AR on learning outcomes.

Quantitative Analysis

The quantitative analysis aimed to evaluate the effectiveness of AR-based blended learning in enhancing students' conceptual understanding of magnetism. This was assessed through pre-test and post-test concept understanding tests conducted with the experimental and control groups. The analysis of test scores revealed distinct patterns in the learning outcomes of both groups. The pre-test results indicated a similar understanding of magnetism concepts across the experimental and control groups. However, the post-test results exhibited notable differences, suggesting a variation in the impact of the teaching methods.

The Analysis of Variance (ANOVA) was conducted to evaluate the differences in conceptual understanding of magnetism between the experimental and control groups. Table 1 presents a comprehensive summary of the ANOVA results.

Table 1. Summary of the ANOVA Results

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-value	p-value
Between Groups	37.61	1	37.61	16.15	0.03
Within Groups	135.06	58	2.33	-	-
Total	172.67	59	-	-	-

The ANOVA test's significant F-value of 16.15 (p = 0.03) indicates that AR-based blended learning significantly improves students' conceptual understanding of magnetism. This statistical significance highlights the potential of AR to transform abstract concepts into more accessible and engaging learning experiences.

The study examines the impact of Augmented Reality (AR)-based blended learning on students' conceptual understanding of magnetism. As summarized in Table 5, the quantitative data highlights a significant difference in learning outcomes between the experimental and control groups, evidenced by an F-value of 16.15 and a p-value of 0.03. This statistically significant result indicates that students exposed to AR-based blended learning achieved a higher understanding level than those who experienced traditional teaching methods.

This enhancement in learning can be attributed to AR technology's immersive and interactive nature, which engages students by providing novel and visually rich experiences [39]. AR enables the representation of complex, abstract concepts such as magnetic fields and forces in a more tangible and accessible manner. This is particularly beneficial in physics education, where students often struggle with visualizing and comprehending such abstract phenomena [40].

The superiority of the experimental group's performance, as demonstrated by the significantly higher post-test scores, suggests that AR not only aids in the initial understanding of these concepts [41] but also reinforces and solidifies this knowledge over time [42]. The ability of AR to transform theoretical knowledge into lifelike visualizations appears to bridge the gap between abstract theories and their practical implications, making learning more effective and enjoyable [43].

Table 2 further illustrates the effectiveness of AR-enhanced blended learning in the experimental group, evident from the significant increase in mean scores from 54.43 to 79.43, a marked contrast to the control group's more modest rise from 48.66 to 65.11. The reduction in standard deviations across both groups indicates a more uniform understanding, with the experimental group showing a notable consistency in learning outcomes. The substantial N-Gain value of 0.549 for the experimental group, compared to 0.320 for the control group, further underscores the augmented impact of AR technology in improving conceptual understanding. The increased minimum and maximum scores in the experimental group reflect the broad spectrum of student performance improvement, emphasizing the AR intervention's comprehensive effectiveness in enhancing students' grasp of magnetism.

Table 2. The Statistics Descriptive Data of Pre-test and Post-test of Conceptual Understanding

Group	Mean Score	Standard Deviation	Minimum Score	Maximum Score	N-Gain
Experimental (Pre-Test)	54.43	1.82	45	60	0.549
Experimental (Post-Test)	79.43	0.99	75	85	
Control (Pre-Test)	48.66	1.49	40	55	0.320
Control (Post-Test)	65.11	1.01	60	70	

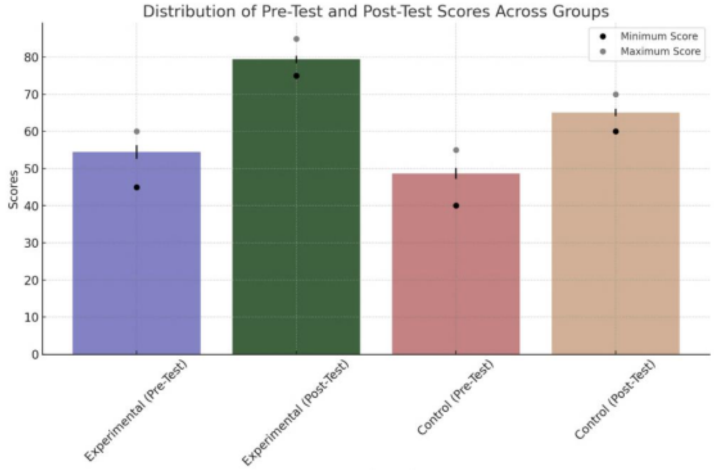

Figure 4. Distribution of pre-test and post-test scores across both the experimental and control groups

Figure 4 visually reinforces these findings by illustrating the pre-test and post-test scores distribution across both groups. The figure clearly shows the superior performance of the experimental group, reflecting the positive impact of AR on their learning process.

As Table 2 illustrates, the experimental group's mean scores increased from 54.43 to 79.43, compared to the control group's rise from 48.66 to 65.11. The reduced standard deviation in the experimental group indicates a more consistent level of understanding across students, suggesting that AR helps level the learning field, making it easier for all students to grasp complex concepts. The N-Gain values further support this, with the experimental group achieving a substantial improvement of 0.549 compared to the control group's 0.320, reinforcing the argument that AR significantly enhances conceptual understanding.

These findings align with previous research, showing that AR can effectively support learning by making abstract concepts more concrete. Studies by Alamsyah et al. [40], Singh et al. [43], and others have consistently found that AR's visual and interactive elements improve students' ability to internalize and apply theoretical knowledge. The consistency of these findings across different studies underscores AR's potential as a transformative tool in education, particularly in subjects that require a robust conceptual understanding.

In summary, the quantitative data demonstrates that AR-based blended learning significantly enhances students' conceptual comprehension of magnetism. This improvement can be directly linked to the ability of AR to make learning more engaging, interactive, and accessible, thereby addressing some of the traditional challenges associated with teaching abstract scientific concepts.

Qualitative Analysis

While the quantitative results demonstrate a clear statistical advantage for the experimental group, the qualitative data from student interviews provide deeper insights into how and why AR technology enhances learning. The thematic analysis of the interview results reveals several key themes that underscore the pedagogical benefits of AR technology in enhancing the learning experience of physics students, particularly in the complex domain of magnetism. The students were given some simple questions that can be seen in Table 7.

Table 3. Interview Transcript

Class	Question	Response Code	Keywords of Student Responses	Theme
E	QE1	SE1	Understand magnetic field properties, solve magnet problem	Enhanced Conceptual Understanding
		SE2	Predict charged particle trajectory	
		SE3	Direction of magnetic force	
	QE2	SE1	Magnetic field in coiled wire, practical applications	Real-world Application and Relevance
		SE2	Impact on animal navigation, air transport	
		SE3	Magnetic fields in MRI (Magnetic Resonance Imaging) devices.	
	QE3	SE1	The magnetic field causes an electric current	Scientific Reasoning and Analytical Skills
		SE2	Centripetal force in magnetic field	
		SE3	Magnetic lines of force around a bar magnet	
	QE4	SE1	Understanding abstract magnetic fields	Visualization of Abstract Concepts
		SE2	Magnetic field around the infinite wire	
		SE3	Biot-Savart law and magnetic fields	
	QE5	SE1	Magnetic force on current conductor	Scientific Reasoning and Analytical Skills
		SE2	Magnetic field lines in solenoids	
		SE3	Geographic vs. magnetic poles	
	QE6	SE1	Compare magnetic field equations	Scientific Reasoning and Analytical Skills
		SE2	Total magnetic force on the wire	
		SE3	Compare magnetic fields on straight vs. parallel wires	
	QE7	SE1	Explain solenoid formation	Scientific Reasoning and Analytical Skills
		SE2	Charged particles and magnetic fields	
		SE3	Magnetic force on current-carrying wire	

The study also used qualitative data from semi-structured interviews to explore how students responded to AR when learning magnetism. These interviews provided rich insights into the students' experiences and perceptions of AR technology in their learning process, complementing the quantitative findings.

The responses revealed overwhelmingly positive feedback regarding the use of AR, particularly in enhancing engagement and interactivity in the learning environment. Students consistently noted that AR made learning more engaging and interactive, facilitating a deeper connection between theoretical concepts and real-world applications. For example, they highlighted how AR helped them visualize and understand the practical implications of magnetic fields in everyday technologies like electric motors and MRI machines. This ability to link abstract scientific concepts with tangible real-world applications suggests that AR can significantly enhance the relevance and context of learning, making complex ideas more accessible and exciting.

Furthermore, students reported that AR improved their scientific reasoning and analytical skills. They described how AR-enabled them to theorize and deduce the effects of varying magnetic field strengths on charged particles and explain cause-and-effect relationships within magnetic scenarios. This shift from rote learning to a more analytical approach underscores AR's potential to foster critical thinking and deeper cognitive engagement. Students could better understand and apply the underlying principles more effectively in problem-solving contexts by visualizing magnetic interactions in a dynamic, interactive format.

The thematic analysis of the interview responses uncovered several key themes, including enhanced conceptual understanding, real-world application and relevance, improved scientific reasoning and analytical skills, visualization of abstract concepts, and increased engagement and interactivity. These themes illustrate the multifaceted benefits of AR in the educational context, particularly in subjects involving complex and abstract concepts.

For instance, the theme of **Enhanced Conceptual Understanding** directly correlates with the students' improved ability to grasp fundamental principles of magnetism, as noted in the interviews. Students repeatedly emphasized how AR's visual and interactive nature solidified their understanding of magnetic fields and forces, aligning with improved test scores' quantitative findings. This enhancement is crucial in science education, where abstract concepts can be challenging to internalize through traditional methods.

The **Real-world Application and Relevance** theme emerged as students expressed that AR helped them see the practical side of their learning. The ability to relate classroom knowledge to everyday applications made the content more exciting and meaningful, leading to more excellent retention and application of knowledge. This finding is significant for educators aiming to make science more relatable and engaging for students.

Scientific Reasoning and Analytical Skills were another prominent theme, with students indicating that AR stimulated higher-order thinking. Through interactive simulations, they could experiment with variables and observe outcomes, which deepened their understanding of cause-and-effect relationships in magnetism. This aligns with educational theories advocating active learning approaches to develop critical thinking skills.

The **Visualization of Abstract Concepts** was repeatedly mentioned as a key advantage of AR. Students appreciated how AR demystified complex ideas by providing precise, visual representations that were easier to understand than traditional static images or verbal explanations. This capability is particularly beneficial in physics, where many abstract concepts are difficult to visualize.

Finally, **Engagement and Interactivity** were central to the students' positive experiences with AR. They found that the interactive nature of AR kept them more focused and involved in the learning process. This increased engagement is likely to contribute to better learning outcomes, as students are more likely to stay motivated and retain information when actively involved in the learning process.

The findings from this study have significant implications for educational practice, particularly in science education. Integrating AR into blended learning environments offers a more engaging and practical learning experience, enhancing students' conceptual understanding and motivation. Educators and curriculum developers should consider incorporating AR technology to support diverse learning styles and foster a deeper, more interactive engagement with the subject matter.

In line with these findings, previous studies also emphasize that Augmented Reality (AR) is acknowledged as an instrumental medium in supporting learning and constitutes a critical factor in enhancing student engagement and zeal in educational activities [44]. Chou et al. [45] suggest that integrating these technological aids significantly enhances students' conceptual understanding throughout the learning process. Turan et al. [47] have articulated that AR significantly influences student interest, potentially augmenting motivation and attentiveness in the learning trajectory. Prior studies indicate that integrating 3D object content within AR environments can positively influence student motivation, interaction, and engagement in educational processes [46]. Wen [48] posits that AR technology facilitates immersive learning experiences, transcending conventional spatial and temporal boundaries. Unlike traditional e-learning by its mobility, AR-based learning offers the advantage of accessibility and flexibility, enabling learners to engage with educational material via mobile technology at any location and time [49].

Subsequent research has illuminated the impactful role of AR in the learning sphere, as evidenced by studies conducted by Liu et al. [35], Hsu and Liu [28], Cai et al. [50], and Nakamura and Mizuno [5]. Abdusselam and Karal [20] discovered that AR-based methodologies significantly enhance the classroom learning environment. This study, involving an experimental group and two control groups, demonstrated that interactive AR simulations, especially in the context of magnetism, can profoundly aid students in grasping complex concepts such as magnetic field lines and direction. Furthermore, the use of AR in educational settings has been found to cultivate a more relaxed yet focused learning atmosphere, corroborating the findings of Farid et al. [46], who reported positive influences of AR on learning outcomes and the development of critical thinking skills in students. Specifically, the application of AR in the visualization of physics concepts like magnetic fields, current flow, and electric potential has been shown to enhance students' cognitive skills, thereby improving their academic performance. AR technology, thus, is heralded for its potential to render classroom environments more effective and efficient, particularly in online learning systems.

Complementing these findings, Cai et al. [50] observed a substantial impact of AR technology in physics education, particularly in bolstering student self-confidence and comprehension of physics concepts. In this study, the comparison between the AR and Flash groups revealed a notable advantage in favor of AR in enhancing conceptual understanding and self-assurance among students. Additionally, Dutta et al. [44] affirmed that AR's application in mobile-based online learning significantly captures student attention and fosters motivation. They argued that the realistic physical visualizations offered by AR are more efficacious in the learning process compared to traditional image presentations in textbooks, suggesting that AR's interactive and immersive visualizations can enrich learning experiences by improving interaction, cognitive processes, and overall enjoyment in learning.

The implications of these findings are far-reaching. As AR technology becomes more accessible, it has the potential to revolutionize education by making learning more immersive, interactive, and effective. Future research should continue to explore the various ways AR can be integrated into different educational contexts and its long-term impact on student learning and retention.

Despite these positive findings, several limitations must be acknowledged, including the relatively small sample size and its limitation to a single institution, which may affect the generalizability of the results. Additionally, the short duration of the study, spanning only a few weeks, might not capture long-term retention and understanding, and the reliance on self-reported student data could introduce bias. Future research should address these limitations by including a larger, more diverse sample to enhance generalizability and by conducting longitudinal studies to examine the long-term effects of AR-based blended learning on conceptual understanding and retention. Furthermore, incorporating objective measures of student engagement and learning outcomes, such as standardized tests and observational data, is recommended to complement self-reported data. Exploring the impact of AR on other scientific concepts and in different educational contexts could also provide broader insights into its effectiveness and applicability.

CONCLUSION

This study investigated the impact of integrating Augmented Reality (AR) with blended learning on students' understanding of magnetism at the Raden Intan State Islamic University of Lampung, employing a mixed-method approach to compare an experimental group using AR-based blended learning with a control group experiencing traditional blended learning. The quantitative findings, derived from pre-test and post-test evaluations, showed a significant improvement in the experimental group's conceptual understanding of magnetism, with statistical analysis, particularly ANOVA, revealing a marked increase in mean scores and a substantial N-Gain value, indicating that AR significantly enhances students' grasp of complex concepts. Qualitative insights from semi-structured interviews further supported these findings, with students reporting that AR improved their conceptual understanding, particularly in visualizing magnetic fields and their real-world applications, fostering a deeper connection between theory and practice, enhancing engagement, and creating a more interactive and memorable learning experience.

AUTHOR CONTRIBUTIONS

Ardian Asyhari: Supervise, validate, review, edit, and finalize manuscripts. Ajo Dian Yusandika: conceptualization, methodology, analysis, and manuscript drafting. Sergii Sharov: Provide expertise in ICT integration, contribute to methodology refinement, and assist in manuscript editing and review.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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