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ORIGINAL RESEARCH

Learning module for electricity and magnetism with augmented reality to enhance students' conceptual understanding

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Abstract
This research aims to produce a learning module for Electricity and Magnetism with mobile augmented reality to Enhance Students' Conceptual Understanding. This research is a type of research design. The development model used is 4D Model (Define, Design, Develop, Disseminate), which consists of five development phases, namely analysis, design, development, implementation, and evaluation. The results of this study are learning modules that have been installed with QR-code and ModulAR apps that run on the Assmblr Edu Application. The developed materials received highly favorable ratings from experts, with content experts assigning an average score of 87% and media experts providing an average score of 86%. Teacher and student feedback indicated an average satisfaction rate of 88% and 87%, respectively. Then, the module and ModulAR apps were implemented at SMKN 1 Cikarang Pusat, which involved 36 students. The use of learning modules with mobile augmented reality based on the Inkuiri approach is also effective in enhancing students' Conceptual Understanding. It can be seen from the average n-gain score of 0.59, included in the moderate category. Furthermore, this research provides valuable insights into the potential of AR for enhancing physics education and offers practical recommendations for future research endeavors in this area.

Keywords: Augmented reality · conceptual understanding · electricity and magnetism · Learning module

INTRODUCTION

Implementing interactive learning modules will enhance student motivation and participation by offering a dynamic and stimulating learning environment. Leveraging digital devices as instructional tools will empower learners to develop the requisite skills for the Fourth Industrial Revolution, including critical thinking, problem-solving, creativity, innovation, collaboration, and communication (Gaol & Suprihatin, 2020; Wayan Widana, 2020).

Understanding serves as the cornerstone of personal growth, providing a solid foundation for individuals to enhance their abilities and expand their knowledge. When applying different approaches to generate ideas, a deep comprehension of concepts allows for more effective problem-solving, creativity, and innovation. By grasping fundamental principles, individuals can adapt to new challenges, refine their critical thinking skills, and develop unique perspectives. This intellectual foundation not only fosters continuous learning but also empowers individuals to navigate complex situations with confidence and efficiency, ultimately leading to meaningful self-improvement and the ability to generate innovative ideas (Husna et al., 2021; Nurjannah & Kusnandi, 2021; Tang & Hew, 2022). By mastering fundamental principles, individuals can adapt to new challenges, refine their critical thinking skills, and

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develop unique perspectives. This intellectual foundation not only fosters continuous learning but also empowers individuals to navigate complex situations with confidence and efficiency, ultimately leading to meaningful self-improvement and the ability to generate innovative ideas.

Comprehension is a prerequisite for higher-order cognitive abilities such as application, analysis, synthesis, and evaluation in the learning process (Sahara dkk., 2020). A concept is a general idea or abstraction representing a category or class (Khatin-Zadeh & Farsani, 2022). Concepts are mental representations of categories of objects, events, or ideas that share common characteristics (Darling-Hammond et al., 2020; Fabricius, 2023).

In the context of this study, comprehension plays a crucial role in facilitating students' ability to grasp complex theories in electricity and magnetism. By integrating Augmented Reality (AR) into learning modules, students are provided with a more interactive and immersive experience that enhances conceptual understanding. A learning module serves as a self-contained instructional resource, offering learners the necessary materials, activities, and assessments to master specific competencies (Shelviana et al., 2020; Sopacua et al., 2020). Instructional modules should be designed not only to equip learners with subject-specific knowledge but also to develop the critical thinking and problem-solving skills necessary for academic and professional success. Augmented Reality (AR), a technology that overlays digital content in the real world, offers a powerful tool for enhancing learning outcomes. By providing learners with a more immersive and interactive experience, AR can foster a more profound understanding and promote active engagement with the subject matter (Liu et al., 2020; Akçayır & Akçayır, 2017).

The development of augmented reality-based learning represents a significant innovation in educational technology, offering new possibilities for enhancing student engagement and understanding. Augmented Reality (AR), as defined by (Azuma, 1997), is a technology that superimposes computer-generated images on a user's view of the real world. This technology has the potential to revolutionize education by providing immersive and interactive learning experiences. Research conducted by (Liu et al., 2019), (Faridi et al., 2021), and (Ewais & Troyer, 2019) suggests that AR can enhance students' critical thinking skills, improve learning outcomes, and make education more engaging and effective, especially in local contexts.

Assemblr Edu is a versatile augmented reality (AR) platform tailored for educational applications. By utilizing AR technology, Assemblr Edu facilitates the creation of interactive AR content, including images, videos, and animations (Damayanti & Putra, 2024; Majid et al., 2023). The platform's user-friendly interface and accessible features empower educators, students, and creators at all levels to produce engaging AR experiences (Syarifnur & Pratiwi, 2024). Assemblr World, the broader platform, offers a range of AR and VR solutions, from the professional-grade Assemblr Studio to the business-oriented Assemblr for Business. With its customizable tools and scalable solutions, Assemblr World caters to various industries, including education, tourism, and retail.

These studies collectively demonstrate the versatility of Augmented Reality (AR) in enhancing various aspects of the learning process. From improving student engagement and understanding in chemistry (Tuta et al., 2022) and geometry (Prasetiawati et al., 2023) to fostering positive learning attitudes in physics (Fidan & Tuncel, 2019), these studies highlight the potential of AR to transform the educational landscape. The development of an AR-based science book by (Yulianti et al., 2023) further emphasizes the potential of AR to create engaging

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and interactive learning experiences across different subjects. Research by (Baabdullah et al., 2022) demonstrated that AR-based learning applications significantly enhanced university students' learning experiences, particularly in terms of interactivity, affective benefits, and cognitive gains. Similarly, This study investigated the impact of AR-based Physics Independent Learning (MPIL) on the development of 21st-century skills (Wibowo, 2023).

Similarly, this study aimed to develop and evaluate an AR-based learning module for electricity and magnetism to improve students' conceptual understanding of key topics in electromagnetism. A multiple-choice test was administered to assess their knowledge of basic atomic concepts, electrical materials, electrical quantities, circuit configurations, magnetic fields, and electromagnetic induction. Based on the results, which revealed significant weaknesses in students' understanding of series, parallel, and combination circuits, magnetic force, magnetic induction, and electromagnetic induction, this Learning Module for Electricity and Magnetism narrowed its scope to these specific topics.

METHODS

The study adopted a Research and Development (R&D) design, aiming to develop an innovative and effective learning module tailored to enhance students' understanding of electricity and magnetism. The research followed a structured instructional design framework, ensuring that the module was systematically developed, tested, and refined based on empirical evidence and educational best practices. To achieve this, the study employed the ADDIE model a widely recognized instructional design methodology that facilitates a systematic and iterative approach in the development of educational tools.

The ADDIE model consists of five key stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage played a crucial role in shaping the learning module, ensuring that it effectively meets students' learning needs. In the Analysis phase, extensive needs assessments, curriculum evaluations, and student learning diagnostics were conducted to identify key conceptual challenges and gaps in students' prior knowledge. This phase was critical in defining the scope and instructional goals of the module.

The Design phase involved structuring the learning content, creating an instructional blueprint, and determining the best technological integration strategies, including the use of augmented reality (AR) to facilitate interactive learning. The Development phase focused on the actual creation of the learning module, including content production, multimedia design, and programming of AR-based interactive elements. The Implementation phase involved pilot testing the module in real classroom settings, gathering teacher and student feedback, and making necessary revisions. Finally, the Evaluation phase assessed the effectiveness of the module through quantitative and qualitative analyses, including pretest-posttest comparisons, student engagement metrics, and user experience surveys.

Analyze

The first step in building an augmented reality (AR)-based learning module is to conduct a detailed study of the learners' needs (Ramadhani & Rosy, 2023). Researchers use extensive curriculum analysis and data collection approaches such as surveys and interviews to detect the gap between expected learning objectives and learners' actual achievements. This study provides the framework for developing unique and meaningful learning objectives.

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Figure 1. ADDIE's Model

In this study, data collection was conducted through questionnaires, structured interviews, and diagnostic tests involving both students and teachers. The diagnostic test assessed students' baseline understanding of key topics, while the questionnaires and interviews provided qualitative insights into learning difficulties, instructional preferences, and technological adaptability.

Design

The insights from the analysis phase are expanded upon during the design phase (Handrianto et al., 2021). The design phase builds upon the findings from the analysis stage by outlining the overall instructional structure, learning resources, and AR integration strategies. This phase focused on developing a well-structured learning sequence, ensuring that the AR module, instructional materials, and learning activities align with the learning objectives. A detailed storyboard was developed to outline the flow of content delivery and user interactions within the AR environment. The storyboard defined the narrative, interactive elements, and learning pathways, ensuring a smooth and engaging user experience. The design process came next, intending to identify the visual and content features of the AR medium. The learning method was then established, defining the exact activities and strategies to be used.

Development

The development phase transforms the design into a fully functional Augmented Reality (AR) learning module aimed at enhancing students' understanding of electricity and magnetism. This phase involves selecting appropriate AR authoring tools, such as Unity 3D and Vuforia, to create an interactive and immersive learning experience (Aydin et al., 2023). The AR module integrates 3D models of electrical circuits, magnetic field visualizations, and electromagnetic induction simulations, allowing students to explore abstract concepts in a more tangible way.

The content of the AR module is developed based on validated educational materials to ensure accuracy and relevance to the curriculum. Interactive animations are designed to illustrate dynamic processes, such as the movement of charged particles and the formation of magnetic fields. Additionally, gesture-based interactions enable students to manipulate virtual components, fostering active engagement and deeper conceptual understanding. To ensure the module's effectiveness, experts in AR technology and physics education evaluate the design

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for usability, content accuracy, and engagement level. A formative evaluation is conducted by involving students in initial trials, gathering feedback on usability and learning impact. This iterative process allows for continuous refinement before broader implementation. By combining advanced AR technology with pedagogical principles, this learning module provides an innovative approach to teaching electricity and magnetism, making complex scientific concepts more accessible and engaging for students.

Implementation

The implementation phase involves the practical application of the developed product in a real-world setting (Nita et al., 2022). This phase allows for a comprehensive evaluation of the product's effectiveness and provides an opportunity to make refinements based on user feedback.

The created AR module is then used in a real-world learning setting. Before full-scale implementation, a small-scale trial is done to obtain feedback and make any necessary changes. Once polished, the module is ready for general use. To measure the effectiveness of the developed learning module, this study employed a pretest-posttest design. The pretest was administered before students engaged with the module to assess their baseline understanding of electricity and magnetism. Following the implementation of the learning module, a posttest was conducted to evaluate improvements in student learning outcomes.

The scores presented in Table 3 were obtained from these assessments, where the pretest score (44.2) reflects students' initial knowledge, and the posttest score (77.2) indicates their performance after learning with the module. The effectiveness of the intervention was further analyzed using the normalized gain (n-Gain) formula introduced by Hake (1998), which is calculated as present in Equation 1.

$$\langle g \rangle = \frac{\text{Posttest Score - Pretest Score}}{\text{100 - Pretest Score}} \tag{1}$$

Evaluation

The final stage of the development process is evaluation. Researchers examine the success of the AR module in attaining its intended learning outcomes using various data collection tools, including exams, surveys, and observations. A detailed study of the data enables researchers to evaluate the module's strengths and faults and make recommendations for future improvements (Jonnalagadda et al., 2022).

The primary objective of formative evaluation is to identify areas for improvement in the development process. By assessing the alignment of each stage with the predetermined specifications and gathering feedback from experts and learners, formative evaluation ensures that the final product effectively meets the learning objectives and addresses the identified needs.

Then, descriptive analysis was conducted based on expert validation using a Likert scale and the scores from each item were then converted into percentages using the equation 2.

$$\%score = \frac{\text{Score Obtained}}{\text{Max Score}} \times 100\% \tag{2}$$

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Score from Equation 2 was categorized into rating scales according to (Whatoni & Sutrisno, 2022) category is presented in Table 1.

Table 1. Categoris Scale likerts

Score	Category
81 – 100 %	Very Good (SB)
61 – 80 %	Good (B)
41 – 60 %	Moderate(C)
21 – 40 %	Less Poor (K)
≥ 20%	Poor (SK)

Subsequently, to determine the improvement in students' learning outcomes before and after instruction, the normalized gain score $\langle g \rangle$ was calculated using Equation 1. The interpretation of the normalized gain score was based on Hake's criteria as cited by (Hakim et al., 2021) in Table 2.

Table 2. N-gain Score Interpretation

N-Gain Score	Interpretation
$0 < g < 0.30$	Low
$0.30 \leq g < 0.70$	Moderate
$0.70 \leq g \leq 1.00$	High

RESULT AND DISCUSSION

Result

Recognizing the importance of expert input, the design of the teaching module and AR materials underwent a thorough review process following their initial development. Feedback from subject matter experts and educational technology specialists was carefully analyzed and incorporated into the design, leading to significant improvements in the overall quality and effectiveness of the learning materials.

This resulted in an innovative module designed to enhance students' understanding of fundamental electricity and magnetism concepts. A key feature of this module is the integration of QR codes within each animation, allowing students to seamlessly access relevant AR content using the Assmblr Edu app on their mobile devices. This approach fosters independent learning by empowering students to explore and engage with the material at their own pace.

The augmented reality (AR)-based learning module for electricity and magnetism was specifically designed to enhance students' conceptual understanding through an interactive and immersive experience. The module was developed using Assemblr Edu, an AR platform that enables students to visualize complex electrical and magnetic concepts in a more tangible and engaging manner. The context of this AR implementation focuses on enhancing students' spatial understanding and conceptual grasp of fundamental topics such as Kirchhoff's laws, electrical circuits, magnetic fields, and electromagnetic induction. By incorporating 3D models, interactive simulations, and guided exercises, the module allows students to manipulate circuit components, observe real-time electromagnetic interactions, and simulate different circuit configurations, which are traditionally challenging to comprehend through static textbook explanations.

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Figure 1. Learning Module

The content of the AR module includes interactive simulations, virtual experiments, and 3D visualizations aligned with the curriculum standards for electricity and magnetism. Each section of the module is carefully structured, beginning with theoretical explanations, followed by AR-based demonstrations, and culminating in hands-on exercises where students apply their knowledge in simulated real-world scenarios. The AR component is seamlessly integrated into the learning process, ensuring that students actively engage with the material rather than passively consuming information.

In terms of learning application, the module follows a student-centered approach, encouraging active exploration and inquiry-based learning. Students are guided through structured activities that require them to interact with AR elements, make predictions, test hypotheses, and analyze results. For instance, when studying magnetic field interactions, students can observe real-time visualizations of field lines around current-carrying conductors, enabling them to understand abstract concepts more concretely. Similarly, when exploring circuit configurations, they can manipulate virtual circuit elements to see how voltage and current behave in series and parallel circuits.

The effectiveness of this AR-enhanced learning module was rigorously evaluated through a combination of student feedback, expert reviews, and quantitative performance assessments. The results indicate a significant improvement in students' conceptual understanding and engagement levels. The module received high ratings from subject matter experts (86%), media specialists (87%), teachers (88%), and students (87%), underscoring its impact as an effective instructional tool. Moreover, students who initially struggled with understanding circuit behaviors and electromagnetic principles exhibited a notable increase in learning retention and problem-solving abilities after engaging with the AR-enhanced materials.

In summary, this AR-based module represents a transformative approach to teaching electricity and magnetism, bridging the gap between abstract theories and tangible understanding. By integrating technology-driven learning experiences, the module not only enhances engagement but also fosters critical thinking, problem-solving skills, and deeper conceptual mastery among students. Future improvements may include the integration of

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adaptive learning pathways and AI-driven feedback mechanisms to further personalize the learning experience and optimize knowledge retention.

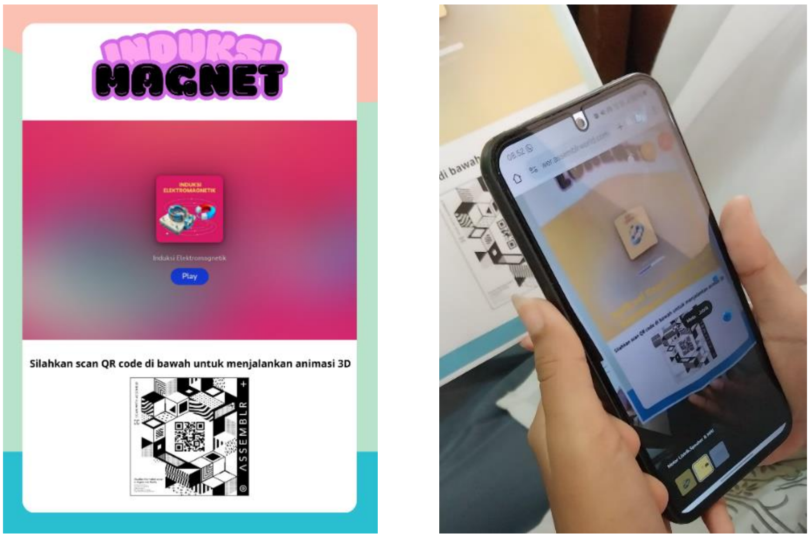

Figure 2. AR Simulation and QR Code

A three-week experimental study involving 36 participants was conducted to investigate the effectiveness of [mention the intervention, e.g., the AR-based learning module]. The results of the data analysis demonstrated a significant improvement in student performance. Notably, the post-test mean score exhibited a substantial increase of 33.1% compared to the pre-test scores. This significant improvement is further corroborated by the calculated N-gain score of 0.59, which falls within the moderate category, indicating a moderate level of learning gain achieved by the participants.

Table 3. Score pretest-posttest

No	Test	Score
1	*Pretest*	44.2
2	*Posttest*	77.2
3	*n-Gain*	0.59

To develop this instructional module, Canva was utilized to structure the content, create visually appealing designs, and integrate relevant images, graphs, and videos. Upon completion of the module design, AR media for various electrical and magnetic components were developed using Assemblr Edu. These AR media were then animated to demonstrate various concepts such as magnetic fields, electromagnetic induction, and electrical circuits. The interactive AR media were subsequently integrated into the instructional module via QR codes. By scanning the QR codes using a mobile device, students could directly visualize and interact with the 3D models.

Based on the descriptions, the developed electricity instructional module, which integrates augmented reality, has proven to be an effective tool in enhancing physics learning quality. Through the collaboration between the Electricity and Magnetism module and the inquiry-based approach, students not only acquire new knowledge but also cultivate curiosity and enhance their learning motivation.

Discussion

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The findings of this study highlight the significant impact of augmented reality (AR)-based learning modules on students' conceptual understanding of electricity and magnetism. The integration of AR technology within instructional modules enhances student engagement, facilitates interactive learning, and promotes a deeper understanding of abstract scientific concepts. The study's results revealed that the AR-based learning module received positive evaluations from experts, teachers, and students, with an overall approval rating exceeding 85%. Furthermore, the implementation of the module resulted in a notable improvement in students' academic performance, as evidenced by the increase in post-test scores by 33.1% and an N-gain score of 0.59, categorizing the learning gain as moderate.

These findings align with previous research indicating that AR-supported learning fosters student engagement and comprehension in STEM education (Akçayır & Akçayır, 2017; Liu et al., 2021). The ability of AR to visualize complex phenomena, such as electromagnetic induction and circuit configurations, provides students with an immersive and interactive learning experience that traditional instructional methods often lack. Additionally, the inclusion of QR codes within the module, allowing students to access AR simulations via the Assemblr Edu application, empowers learners with greater autonomy in exploring course materials at their own pace.

Despite these promising outcomes, some challenges were observed during the study. Initial difficulties in using the Assemblr Edu app and scanning QR codes, as well as issues related to internet connectivity and device compatibility, impacted the learning experience for some students. These technical barriers highlight the need for adequate training and infrastructure support to maximize the effectiveness of AR-based learning tools.

Overall, the study underscores the potential of AR-based learning modules in enhancing physics education. By bridging the gap between theoretical concepts and practical applications, AR technology provides an innovative and effective approach to science education. Future research should explore the scalability of AR-based learning across different subjects and investigate its long-term impact on student learning outcomes.

CONNCLUSION

This study demonstrates the successful development and implementation of an innovative augmented reality (AR)-based learning module for electricity and magnetism. The rigorous development process, which included expert feedback and iterative refinement, resulted in a high-quality module that effectively integrates engaging AR elements, such as 3D animations and interactive visualizations accessed through QR codes.

The evaluation results were highly positive, with experts and students expressing intense satisfaction with the module's design and effectiveness. Furthermore, implementing the module significantly improved student learning outcomes, as evidenced by a substantial increase in post-test scores and a moderate N-gain score. These findings suggest that integrating AR technologies can effectively enhance student engagement, motivation, and conceptual understanding in physics education.

This study provides valuable insights into AR's potential as a powerful pedagogical tool. Further research is warranted to explore the long-term impact of AR-based learning, investigate the optimal implementation strategies for different learning contexts, and assess AR's effectiveness across a wider range of subjects.

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The module's direct application revealed a number of limitations, particularly related to technological infrastructure. A substantial number of students experienced difficulties scanning QR codes due to subpar smartphone capabilities. Additionally, the intermittent internet connection within the learning environment disrupted the smooth delivery of augmented reality content, impacting the overall learning experience.

While the developed electricity and magnetism teaching module offers innovative features such as AR animations and QR codes, it also has certain limitations. The primary constraint is the limited scope of the content, as it does not comprehensively cover all essential aspects of electricity and magnetism. Moreover, the testing process was confined to a single classroom, making it difficult to accurately measure the module's effectiveness in significantly enhancing student understanding due to the absence of a control group. Additionally, the developers' experience in creating AR animations may have influenced the quality and interactivity of the visuals. Despite these limitations, the module still contributes significantly to improving physics education. Further development must address these shortcomings and create a more comprehensive and practical teaching module.

AUTHOR CONTRIBUTIONS

The first author responsible for collecting both quantitative and qualitative data through surveys and interviews. They will analyze the data using statistical software and write the section of the research paper pertaining to quantitative findings. The second author collaborated with Author 1 on the design of experiments to test the research hypothesis, assist in data collection, and contribute to the writing of the section on qualitative findings. The third author assisting in integrating research findings, constructing a coherent argument, and drafting the discussion section that examines the implications of the research.

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