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Development of an Augmented Reality-Based Interactive Digital Module for Biology Learning at High School 76 Jakarta

Muhammad Arifin[1*], Zaid Hidayat Rahmatullah[2]
[1,2] Department of Biology Education, Universitas Pendidikan Indonesia, Indonesia.
* Corresponding author : marifin34@gmail.com

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ABSTRACT

This research aims to develop an interactive digital module based on Augmented Reality (AR) for biology learning at High School 76 Jakarta, focusing on enhancing students' conceptual understanding and engagement. The development process adopted the ADDIE model, encompassing the stages of Analysis, Design, Development, Implementation, and Evaluation. The module was designed to complement the biology curriculum for Grade 11, particularly in the topic of human organ systems. AR technology was integrated to provide three-dimensional visualizations of biological structures, allowing students to interact directly with virtual models through smartphones or tablets. Validation was carried out by media experts, content experts, and biology teachers, showing high feasibility scores across functionality, accuracy, and instructional design criteria. The implementation involved 35 students in a limited field trial, and results from questionnaires and learning outcomes indicated a significant increase in student motivation and conceptual mastery. Moreover, students reported that the AR features facilitated deeper understanding and made abstract biological concepts more tangible. This research concludes that AR-based digital modules are effective tools to support innovative and engaging biology learning. Future studies are suggested to expand implementation at different educational levels and explore long-term learning impacts. The integration of AR in biology education offers promising potential in transforming traditional classrooms into immersive, technology-enhanced learning environments.

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INTRODUCTION

The rapid development of digital technologies in the 21st century has transformed the landscape of education and placed increasing pressure on schools to adopt innovative tools that align with the learning styles of digital-native students. In science education, and particularly in biology, traditional instructional approaches often rely heavily on textbooks, static diagrams, and verbal descriptions, which are insufficient for conveying complex and abstract biological concepts. Students frequently struggle to visualize internal structures, understand the spatial relationships of organs, and interpret multidimensional processes merely through two-dimensional materials. These challenges can hinder cognitive processing, lower motivation, and reduce students' overall engagement with the subject. As a result, educators and researchers worldwide are turning to technology-enhanced learning tools to provide more immersive, interactive, and meaningful experiences that improve conceptual understanding and learning outcomes. Among these technological innovations, Augmented Reality (AR) has emerged as one of the most promising tools for transforming traditional teaching approaches.

Augmented Reality is a technology that overlays digital elements such as three-dimensional models, animations, and informational layers onto the real physical environment in real time. Unlike Virtual Reality, which creates a fully artificial world, AR merges virtual objects with real surroundings, allowing learners to interact with digital representations while staying grounded in their physical context. This characteristic makes AR particularly suitable for classroom use, especially in biology, where understanding depends heavily on visualizing organs, systems, and processes that are difficult to observe directly. Studies have demonstrated that AR can improve student motivation, engagement, and conceptual mastery by allowing learners to rotate, zoom, and manipulate three-dimensional biological structures, thereby forming more accurate mental representations. AR also aligns with constructivist learning theory, which emphasizes the importance of active, inquiry-based learning where students are encouraged to discover, explore, and construct knowledge rather than passively receive information. By interacting directly with digital models, students can develop deeper understanding and stronger connections between abstract biological content and real-world applications.

In Indonesia, the integration of digital learning media has increased rapidly, accelerated by educational reforms and the widespread adoption of mobile technologies. However, despite the potential of AR, its implementation in Indonesian high schools remains limited. There is a shortage of locally developed AR-based biology modules that align with the Indonesian national curriculum, and many teachers lack training or access to appropriate resources. Furthermore, most AR research conducted in Indonesia tends to be exploratory and does not involve systematic instructional design, expert validation, or real classroom implementation. These limitations have created a substantial gap between the potential of AR and its actual use in biology education within the country. Human organ systems, one of the most challenging topics in Grade 11 biology, represent an area where such a technology could have the greatest impact. Students often struggle to visualize internal structures that cannot be directly observed, and conventional teaching methods frequently fail to convey the complexity of organ interactions, physiological processes, and anatomical relationships. Despite the clear relevance of AR for these topics, very few studies have focused specifically on developing AR modules for human organ systems in the Indonesian high school context.

A review of previous research reveals several critical gaps that justify the need for the present study. Although AR has been widely explored internationally, there is a lack of localized development of AR-based modules tailored to Indonesian classroom needs, cultural context, and curriculum standards. Most studies involving AR in Indonesia focus on general science topics rather than in-depth biological content such as organ systems. Additionally, earlier studies rarely combine expert validation with classroom-based trials, leaving questions about pedagogical alignment, usability, and real-world feasibility. Another important gap is that existing AR research typically measures only cognitive outcomes, while motivational aspects, usability perceptions, and learning engagement remain underexplored. These factors are essential because AR is not only a cognitive tool but also an affective and behavioral learning stimulus that can significantly shape students' attitudes toward biology. Finally, limited research in Indonesia has used systematic instructional design models, such as the ADDIE framework, to guide the creation of AR modules, which is necessary to ensure scientific accuracy, media quality, usability, and alignment with curriculum objectives.

The present study seeks to address these gaps through several novel contributions. First, this research develops a curriculum-aligned AR-based interactive module specifically designed for Grade 11 biology in Indonesia. The module focuses on the human organ system, addressing a topic that is conceptually challenging and underserved in previous AR research. Second, the study incorporates a comprehensive validation process involving media experts, biology content experts, and high school biology teachers to assess the module's scientific accuracy, usability, instructional design, and overall feasibility. This multi-layered validation approach is rarely conducted in earlier studies but is essential to ensure that the module meets educational standards and practical classroom needs. Third, the study implements the AR module in a real classroom setting at High School 76 Jakarta, involving 35 students in a limited field trial. This approach provides valuable empirical evidence about the module's effectiveness in improving conceptual understanding and enhancing student motivation and engagement. By combining quantitative measures such as pre-tests and post-tests with qualitative data from questionnaires and observations, the study offers a comprehensive evaluation of the AR module's impact.

Furthermore, the study's novelty lies in its simultaneous measurement of cognitive, affective, and usability outcomes, providing a more holistic understanding of AR's role in biology education. This approach expands beyond the traditional focus on knowledge acquisition to include motivational responses, perceived ease of use, and the quality of students' interactive experiences. These dimensions are particularly important because they indicate the sustainability of AR usage in educational settings and its potential influence on students' long-term interest in science. The integration of AR also supports the development of 21st-century competencies, such as digital literacy, critical thinking, problem-solving, and self-regulated learning. By allowing students to explore digital biological structures autonomously and at their own pace, the module encourages reflective thinking and deeper cognitive engagement.

Given these contributions, the purpose of the study is to develop, validate, and implement an AR-based interactive digital module that enhances biology learning in Indonesian high schools. The study aims to investigate the module's effectiveness in improving understanding of human organ systems while also evaluating its impact on student motivation and learning engagement. As a result, this research has significant implications for the future of biology education in Indonesia. It provides a practical model for integrating AR into classroom instruction and offers insights that can guide future curriculum development, teacher training programs, and educational technology investment. In the broader context of digital transformation in education, this study supports the movement toward more interactive, student-centered, and technologically enriched learning environments. The findings are expected to contribute not only to the academic literature on AR in education but also to the practical efforts of schools seeking to modernize their teaching methods and improve student outcomes in science subjects.

RESEARCH METHODOLOGY

This study employed a research and development (R&D) methodology using the ADDIE model as a framework, which includes five key stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was chosen for its systematic approach to instructional design and its adaptability to technology-based learning environments. Each stage was carried out sequentially but iteratively, allowing for refinement based on formative feedback from experts and users. The research focused on the development and testing of an Augmented Reality (AR)-based digital module intended to support the learning of human organ systems in Grade 11 biology at High School 76 Jakarta. The module was developed in the Indonesian language to match the national curriculum standards and student proficiency levels.

In the analysis phase, data were collected through interviews with biology teachers, curriculum analysis, and student questionnaires to determine students' learning needs, challenges in understanding biological structures, and their familiarity with digital technology. The curriculum analysis focused on core competencies (Kompetensi Inti) and basic competencies (Kompetensi Dasar) outlined in the 2013 Indonesian Curriculum for high school biology. The results indicated a strong need for interactive media that could visualize internal organ systems in three dimensions, particularly to address learning difficulties identified in topics such as the circulatory, respiratory, and digestive systems.

During the design and development phases, the content was structured into thematic units aligned with curriculum objectives. Storyboards and wireframes were created to map user interaction with the AR features. The AR module was developed using Unity 3D integrated with Vuforia SDK, allowing marker-based AR visualization triggered through printed textbooks or worksheets. Illustrations, 3D biological models, animations, audio narration, and interactive quizzes were embedded to enhance engagement and support multimodal learning. The module was packaged as an Android-based application to ensure compatibility with students' smartphones, which were the most accessible digital devices among the target users.

The validation process involved three expert groups: media experts, subject matter experts (biology education lecturers), and practicing high school biology teachers. A validation instrument using a Likert scale (ranging from 1 = very poor to 5 = excellent) was used to assess module quality in terms of content accuracy, media design, interactivity, and pedagogical alignment. Feedback from these experts informed several revisions to the AR components, user interface, and instruction flow to improve usability and content clarity. The final version of the module achieved an average feasibility score of 4.6, indicating a high level of acceptability and readiness for classroom use.

The implementation stage consisted of a limited-scale trial conducted with 35 Grade 11 students from High School 76 Jakarta. The implementation was conducted over two 90-minute biology sessions. Students used the module via Android smartphones in small groups. Data were collected through pre- and post-tests to measure conceptual understanding, alongside student response questionnaires to evaluate motivation, usability, and perceived usefulness. Observations were also conducted to document student engagement and interaction with the AR features. Ethical considerations were maintained throughout the process, with informed consent obtained from participants and teachers.

The evaluation stage focused on both formative and summative assessments. Quantitative analysis was conducted using descriptive statistics to assess improvements in student performance and perception. In addition, qualitative feedback from students was analyzed to understand their experiences and suggestions for improvement. Results showed a significant increase in post-test scores and positive student attitudes toward the AR module. The findings suggest that AR-based digital modules can be an effective tool to support biology instruction by making abstract content more accessible and engaging.

RESULTS AND DISCUSSION

The implementation of the augmented reality (AR)-based digital module in a biology learning context yielded significant improvements in student engagement, conceptual understanding, and motivation. The module was tested on a group of 35 Grade 11 students over two instructional sessions. Prior to the intervention, students' average pre-test scores on the human organ system topic were recorded at 57.4 (SD = 8.3). After the use of the AR module, the average post-test score increased to 84.2 (SD = 6.9), indicating a substantial gain in student comprehension.

The paired sample t-test confirmed the statistical significance of the improvement ($t(34) = 12.76$, $p < 0.001$). This suggests that the use of AR-based learning media has a strong effect on cognitive achievement, particularly in topics that involve abstract or microscopic biological structures. These results are consistent with the findings of Akçayır and Akçayır (2017), who found that AR significantly enhances spatial understanding and knowledge retention in science learning environments.

Student response data, gathered through a post-use Likert-scale questionnaire, revealed a high level of satisfaction and positive perception. Approximately 91% of the students rated the module as "very helpful" in visualizing internal organs, while 85% agreed that it made learning more interesting. The qualitative data further showed that students felt more curious and motivated to explore the human organ system due to the module's interactive nature. These findings align with Dunleavy et al. (2009), who highlighted AR's capacity to increase learner motivation and active engagement.

Observational data during the implementation phase supported the quantitative findings. Students demonstrated heightened enthusiasm, cooperative learning behavior, and frequent verbalization of scientific terminology during AR exploration. The ability to rotate, zoom, and examine biological organs from multiple perspectives was particularly appreciated. As Billinghurst and Duenser (2012) stated, AR provides a unique affordance for embodied and experiential learning, which is crucial in science education.

The expert validation process contributed to the development of a highly feasible instructional product. Media experts rated the interactivity and user interface design at 4.7 out of 5. Biology education experts provided a 4.5 average rating for scientific accuracy, while teachers emphasized the module's alignment with curriculum goals and its practicality in a classroom setting. These validation scores exceed the acceptability threshold commonly cited in educational media development (Munir, 2017), confirming the module's readiness for broader use.

In terms of usability, students reported that the module was easy to navigate, with 89% indicating that the instructions and layout were clear. However, minor issues were noted regarding the need for higher-resolution images and smoother AR rendering on lower-end devices. These concerns point to the technological limitations often faced in mobile AR implementation, as noted by Radu (2014), who emphasized the importance of optimizing AR applications for diverse hardware specifications.

The integration of AR with the national curriculum also proved successful. Each feature of the module—ranging from 3D visualization to quizzes—was directly linked to specific indicators in the basic competency framework. This ensured not only content relevance but also learning coherence. According to Cheng and Tsai (2013), alignment with learning objectives is a critical factor in determining the instructional effectiveness of AR tools.

Additionally, the module supported multiple learning styles. Visual learners benefited from 3D models and animations, auditory learners from narrations, and kinesthetic learners from touch-based interactions. This multimodal approach was instrumental in increasing comprehension, especially among students who previously struggled with traditional textbook-based instruction. Research by Ibáñez and Delgado-Kloos (2018) corroborates this, suggesting that AR enhances knowledge acquisition across diverse learner profiles.

The students' reflections emphasized that the module helped them bridge the gap between abstract theory and real-world biology. Several students reported that they could now "visualize how the lungs expand" or "understand blood flow" better than before. These reflections are a testament to the transformative potential of AR in contextualizing biological concepts that are typically hard to grasp without direct observation.

In terms of classroom management, the use of AR modules encouraged collaboration and peer instruction. Students frequently discussed model features with each other, asked questions, and shared insights. This peer learning effect was an unexpected but valuable outcome. As noted by Wojciechowski and

Cellary (2013), AR environments promote meaningful learning through social interaction and co-construction of knowledge.

Despite the clear benefits, some challenges were encountered during implementation. These included occasional connectivity issues, device compatibility problems, and varying levels of digital literacy among students. Teachers had to provide additional support to students unfamiliar with AR apps. This underscores the need for teacher training and infrastructure support to ensure the sustainability of AR-based learning innovations.

The novelty effect of AR must also be considered. While initial engagement was high, future studies should examine whether this engagement persists over time or diminishes once the "wow" factor wears off. Bacca et al. (2014) cautioned that AR effectiveness may wane without continued pedagogical integration and meaningful content updates.

From a pedagogical standpoint, the module also enhanced students' higher-order thinking skills. Several items in the post-test assessed analysis and application abilities. The increase in scores on these items suggests that the interactive nature of AR promoted deeper cognitive processing. This is supported by studies like that of Lin et al. (2016), who found AR environments conducive to critical thinking and problem-solving in science education.

Teachers involved in the implementation expressed positive feedback. They noted improved student participation and reported that lesson delivery was more dynamic. However, they also expressed concern over the preparation time required to incorporate AR tools. These insights affirm the importance of institutional support and training, as highlighted in the work of Yuen et al. (2011).

Another key insight was the enhancement of self-regulated learning. The module allowed students to learn at their own pace, revisit complex concepts, and receive immediate feedback from interactive quizzes. This autonomy supports the development of metacognitive skills, which are critical for lifelong learning. As per Sung et al. (2012), digital learning tools with formative feedback foster independent learning strategies.

From a broader perspective, this study demonstrates the potential of AR-based modules to reduce the abstractness of biological sciences, particularly in regions where laboratory access is limited. It offers an alternative solution for delivering quality biology instruction in under-resourced educational settings, aligning with equity goals in STEM education.

Future development should consider expanding content coverage to include other biology topics and integrating augmented reality with learning management systems for data tracking and personalized instruction. The scalability of the module can be enhanced by providing cross-platform compatibility, including iOS and web-based access.

Overall, the findings of this study indicate that augmented reality-based digital modules are not only technically feasible but also pedagogically effective for enhancing biology learning at the high school level. The blend of interactivity, visualization, and curriculum alignment makes such modules a powerful tool in modern science classrooms.

Continued research is essential to evaluate long-term learning outcomes and to refine the instructional design model for AR integration in Indonesian secondary education. Collaboration between educators, technologists, and curriculum developers will be key to achieving this.

In conclusion, the implementation of an AR-based biology module resulted in meaningful improvements in student learning, engagement, and satisfaction. With proper infrastructure, teacher training, and iterative design, AR has the potential to become a cornerstone of 21st-century science education in Indonesia and beyond.

CONCLUSION

This study concludes that the development of an Augmented Reality (AR)-based interactive digital module significantly enhances students' conceptual understanding in high school biology learning. The integration of three-dimensional visualizations and interactive features effectively supports the comprehension of abstract topics such as the human organ system. The marked improvement in students' post-test scores compared to their pre-test results indicates a substantial cognitive gain. Moreover, students responded positively to the module's usability, interactivity, and visual appeal, reflecting a higher level of learning engagement. These outcomes affirm the instructional value of AR in making complex scientific content more accessible and meaningful for digital-native learners.

In addition to cognitive improvement, the module also fostered behavioral and affective learning outcomes. Students were more motivated, curious, and collaborative during learning sessions involving AR. Teachers acknowledged the module's alignment with the national curriculum and its potential to transform traditional classroom experiences into more interactive and student-centered environments. While minor technical challenges were observed—such as device compatibility and varying levels of digital literacy—the overall feedback from students, teachers, and experts indicated that the module is highly feasible for classroom use and has strong potential for wider implementation.

Therefore, AR-based digital modules hold great promise in transforming science education in secondary schools. To ensure long-term impact and broader accessibility, ongoing teacher training, infrastructure enhancement, and iterative content development are essential. Future iterations should explore expanding the module to other biology topics and integrating it with online learning platforms. This innovation marks an important step toward building an adaptive, engaging, and future-oriented science education ecosystem.

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