Journal of General Education and Humanities
Vol. 5, No. 2, April 2026, pp. 3135 – 3147, https://doi.org/10.58421/gehu.v5i2.1451
ISSN 2963-7147

An Interactive Augmented Reality-Based Learning Model for IPAS Oriented Toward Scientific Literacy

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Article Info

Article history:

Received 2026-04-20
Revised 2026-04-28
Accepted 2026-05-19

Keywords:

Augmented Reality
Cognitive Improvement
Hybrid Learning
Integrated Science Learning
Scientific Literacy

ABSTRACT

This study investigates the development and implementation of an interactive Augmented Reality (AR)-based learning model for Integrated Science and Social Studies (IPAS) oriented toward scientific literacy. The background highlights the challenges in students' understanding of abstract concepts and the low scientific literacy levels resulting from the dominance of conventional, low-visualization learning methods. The objective of this study is to develop and evaluate an AR-based learning model that facilitates conceptual understanding and supports scientific literacy in junior high school students. A Research and Development (R&D) approach is employed using a modified Waterfall model comprising analysis, design, implementation, and testing stages. The study also applies an experimental procedure with three learning treatments: printed book-based learning, independent AR-based learning, and a combined approach integrating both methods. Data are collected through documentation of pre-test and post-test results and analyzed using descriptive statistical techniques. The findings reveal that the combined learning approach produces the most significant improvement in students' learning outcomes, with the average score increasing from 50.1 in the pre-test to 80.4 in the post-test. The results indicate that integrating AR into a structured learning model enhances students' understanding of abstract concepts and supports the development of scientific literacy. The study concludes that the proposed AR-based learning model provides a more interactive, concrete, and meaningful learning experience and can serve as an effective instructional strategy in IPAS learning at the junior high school level.

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1. INTRODUCTION

Education in the digital era demands continuous innovation, not only in instructional media but also in learning models that can effectively enhance students' understanding of abstract concepts and their learning motivation. The shift toward a student-centered learning paradigm positions students as active participants in constructing knowledge, making learning motivation a critical factor influencing engagement and academic success [1]. Active student involvement has been shown to improve learning outcomes, knowledge retention, and higher-order thinking skills in modern educational contexts [2].

At the junior high school level, Integrated Science and Social Studies (IPAS) includes many abstract and complex concepts, such as human organ systems, cellular structures, and social phenomena, which are difficult to visualize. However, current teaching practices are still largely dominated by conventional approaches that rely on textbooks and two-dimensional media. This condition often leads students to rely on rote memorization rather than developing deep conceptual understanding. As a result, students' conceptual understanding and learning motivation remain relatively low. Research indicates that limited visualization in science learning significantly contributes to students' difficulties in understanding abstract and dynamic concepts [3].

From a theoretical perspective, meaningful learning occurs when students actively construct knowledge through concrete and interactive experiences, as emphasized in constructivist learning theory [4], [5]. In addition, the Cognitive Theory of Multimedia Learning suggests that integrating visual and interactive elements can enhance students' understanding by optimizing cognitive processing [3]. Therefore, the use of technology that supports visualization and interaction is essential to facilitate effective learning, particularly for abstract subject matter.

One promising technology is Augmented Reality (AR), which enables the visualization of three-dimensional virtual objects in real-world environments in real time. AR allows students to engage in experiential learning (learning by doing), making abstract concepts more concrete, interactive, and easier to understand [6], [7]. Previous studies have demonstrated that AR can improve students' motivation, engagement, and learning outcomes in science education [6], [7]

However, despite these advantages, most previous studies have primarily focused on AR as a learning medium rather than on developing a comprehensive, structured learning model. Existing research often emphasizes learning outcomes or motivation, but fails to integrate essential components such as learning syntax, teacher and student roles, and systematic instructional design. Furthermore, the integration of AR with scientific literacy—defined as students' ability to understand scientific concepts, interpret phenomena, and apply knowledge in real-life contexts—has not been widely explored in a structured manner [8].

This gap indicates that there is still a lack of research that develops an interactive Augmented Reality-based learning model oriented toward scientific literacy, particularly in the context of IPAS learning at the junior high school level. In addition, although technological devices such as smartphones are widely available, their potential has not been fully realized in classroom learning due to the lack of practical, easy-to-implement instructional models.

Based on these problems, this study proposes the development of an interactive Augmented Reality-based IPAS learning model oriented toward scientific literacy. This model is designed systematically by integrating AR technology with structured learning syntax, clearly defined roles of teachers and students, and learning activities that support the development of scientific literacy.

The objective of this research is to develop a valid, practical, and effective AR-based learning model that facilitates students' understanding of abstract concepts and supports the development of scientific literacy.

It is expected that the results of this study will contribute both theoretically and practically. Theoretically, this research enriches the literature on technology-enhanced learning by providing a structured model integrating AR and scientific literacy. In practice, it offers an innovative instructional model that teachers can easily implement to create more interactive, meaningful, and engaging learning experiences. Ultimately, this model is expected to improve students' conceptual understanding, learning motivation, and scientific literacy skills in IPAS learning.

2. METHOD

This study is classified as Research and Development (R&D). This R&D approach was chosen to develop and validate an innovative technological product: an Android-based interactive Augmented Reality (AR) application. The holistic objective of this research is to produce an interactive learning media product that is technically well-developed and proven to be feasible (in terms of validity and practicality) for Integrated Science and Social Studies (IPAS) at the junior high school level, as a solution to the challenge of visualizing abstract concepts [9]. Technology-based learning in this study examines how students learn in an environment that utilizes Augmented Reality (AR) as an interactive learning medium. This approach emphasizes integrating technology, IPAS learning content, and learning processes oriented toward scientific literacy. The developed learning model is designed to enhance students' motivation to learn and conceptual understanding through more concrete, interactive learning experiences. The main focus of this methodological activity lies in the stages of product development and feasibility evaluation of the resulting prototype [10].

Three main elements adapted from Saummita et al. [11] are used in developing this learning model, namely:

a. evidence, where learning is based on findings from previous studies related to the use of Augmented Reality technology, learning motivation, and scientific literacy relevant to learning conditions;
b. theory, which refers to learning concepts and theories used as the foundation in model development, such as constructivism, multimedia-based learning, and scientific literacy that can generate testable predictions; and
c. application, which involves the implementation of theoretical principles in designing the learning model, learning syntax, and the use of AR applications in the learning process that can be empirically tested.

To ensure a systematic and well-organized development process, this study adopts the Waterfall Development Model [12]. The selection of the Waterfall Model is based on its characteristics as a sequential, linear framework, in which each phase must be completed in full before proceeding to the next[13]. This step-by-step approach is highly relevant in the development of software and learning media development, as it ensures that each AR component is developed through a series of rigorous validation testing processes to achieve optimal product quality [14], [15].

The research procedure is summarized into four main stages of the Waterfall Model, with adjustments to the context of R&D in learning media, which fundamentally relies on expert- and user-based evaluations for quality assurance:

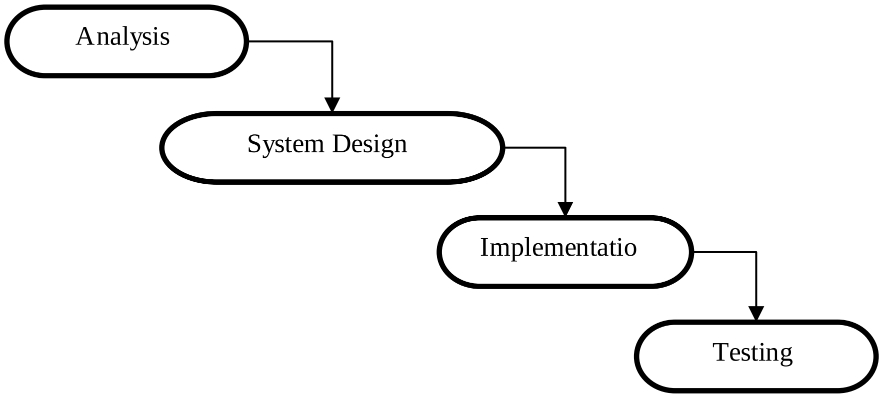

Figure 1. Waterfall Development Method

1. Requirements Analysis

This initiation stage is a crucial phase that requires in-depth contextual analysis. The primary focus includes identifying IPAS subject materials categorized as abstract, analyzing the availability and requirements of technological infrastructure (hardware and software specifications) [16], and examining the profiles and characteristics of junior high school students as the main users. This analysis is conducted through an extensive literature review, a thorough examination of the current IPAS curriculum, and preliminary surveys (e.g., structured interviews and questionnaires) with teachers and students. The objective is to map the gap between ideal and actual learning conditions and identify essential features to be integrated into the AR application to address visualization challenges [17], [18].

2. System Design

After all requirements are explicitly identified, this stage focuses on formulating the technical architecture and functional design. Core activities include designing the overall architecture AR the AR application system, developing a user-friendly, intuitive User Interface (UI), creating detailed storyboards to guide AR interaction flows, and designing accurate 3D object models to represent abstract IPAS concepts [19], [20]. The output of this stage is a set of design blueprints ready for implementation.

3. Implementation/Coding

This phase transforms the design blueprints into a fully functional application. Essential activities include coding the Android-based AR application, integrating 3D models and virtual assets using Unity 3D and the Vuforia SDK [21] dan [12], and embedding interactive features such as simulations, animations, and quizzes as previously designed [22]. The output of this stage is a complete application build (prototype) [23] ready for further evaluation (Sabir, 2022).

4. Testing/Verification

The testing stage represents the methodological culmination aimed at verifying and validating the product's feasibility and addressing the research objectives. Testing is conducted in multiple layers to ensure both technical functionality (Black Box Testing) and pedagogical/academic feasibility [18].

- Validity Testing (Judgment Test):
  The product is evaluated by expert validators, including subject-matter experts (IPAS lecturers/teachers) and media/technology experts, to obtain a theoretical and substantive feasibility justification.
- Practicality Testing (User Response):
  Pilot testing (limited trials) is conducted with actual users (IPAS teachers and a sample of junior high school students) to measure usability, operational efficiency, and the media's attractiveness in enhancing conceptual understanding [24].

The subjects in this study are divided into two main categories:

1. Expert Validators: Involving at least two IPAS subject matter experts and two media/technology experts (from academics or practitioners) who are responsible for conducting product validity testing. Expert validation is a critical stage in the Research and Development (R&D) model to ensure both content and technical feasibility [25].
2. Product Users: Consisting of IPAS teachers at the junior high school level and a representative sample of students from SMPN 1 Susukanlebak who participate in small-scale trials to assess the practicality of the media in real learning environments.Instrumen dan Teknik Analisis Data

Data Collection Instruments

1. Expert Validation Questionnaire: This instrument uses a Likert scale (ranging from 1–5 or 1–4) to measure content feasibility, construction quality, and technical aspects of the developed AR application [22]
2. Teacher and Student Response Questionnaire: This instrument also uses a Likert scale to assess practicality and users' affective responses to ease of use, attractiveness, and thesefulness of the media in supporting the learning process [23].

The data from the judgment test (in the form of feedback and constructive suggestions from expert validators) serves as the primary basis for revising and refining the prototype [23]. Meanwhile, quantitative data from validation and practicality questionnaires are analyzed using Percentage Descriptive Analysis techniques [26]. The results are calculated using the mean score, defined as the total score divided by the number of data points, as shown in the following equation:

$$\bar{x} = \frac{\sum x}{N}$$

Learning outcome improvement is calculated based on the difference between the average post-test and pre-test scores obtained before and after the learning process, as shown in the following equation:

$$\Delta = \bar{X}Post - \bar{X}Pre$$

Thus, this research method is expected to produce an Augmented Reality-based IPAS learning model that is valid, practical, and effective in improving students' learning motivation and scientific literacy.

$$Eligibility\ percentage\ (\%) = \frac{score\ obtained}{ideal\ maximum\ score}\ X\ 100\%$$

The percentage results of these calculations are then converted to a qualitative feasibility scale (Very Feasible, Feasible, Fairly Feasible, Not Feasible) to draw final conclusions on the validity and practicality of the developed Augmented Reality application.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Printed Book-Based Learning Method

At this initial stage, learning was conducted using printed book media, which is inherently static. Eighth-grade junior high school students were presented with relatively complex IPAS materials, such as cell structure or the respiratory system, delivered only in the form of two-dimensional diagrams. Based on the test results, the increase in the average score was only 14.1%.

The analysis indicates that reliance on printed books creates cognitive barriers to students' development in comprehensive scientific literacy. The low post-test scores are attributed to "limited imagination," where students tend to memorize terminology without truly understanding the underlying scientific processes. At this stage, students' scientific literacy remains at a nominal level, where they are familiar with terms but fail to connect them to real-world phenomena due to the lack of dynamic visual representations in the learning media.

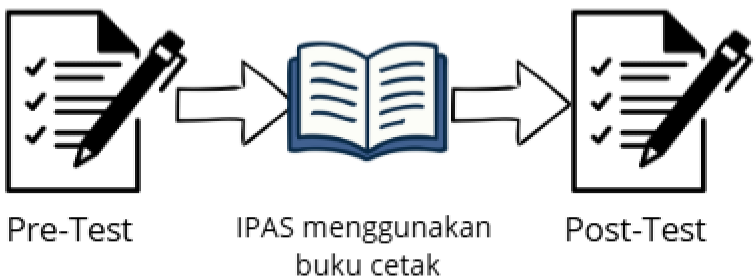

Figure 1. Learning Flow

Table 1. Descriptive Analysis

No	Statistical Measure	Pre-test	Post-test
1	Number of Students (N)	32	32
2	Mean Score	64.2	78.3
3	Minimum Score	55	70
4	Maximum Score	75	90
5	Range	20	20

$$Testing_{result(1)} = Mean\ of\ post_{test} - Mean\ of\ pre_{test}$$

$$Testing_{result(1)} = 78.3\% - 64.2\%$$

$$Testing_{result(1)} = 14.1\%$$

3.1.2. Augmented Reality (AR)-Based Learning Method

The implementation in the second stage focused on the independent use of an interactive Augmented Reality (AR) application without the support of printed textbooks. Students explored scientific phenomena through 3D digital objects. The improvement in learning outcomes, reaching 19.69%, indicates that AR technology is effective in enhancing students' enthusiasm and visual engagement. For junior high school students, this medium is particularly helpful in visualizing complex biological or physical structures.

However, qualitative findings suggest that without structured written guidance (such as textbooks), students tend to focus primarily on digital interaction. While their visual understanding has improved significantly, they still require stronger narrative structures to enhance their scientific literacy, particularly in developing deeper scientific reasoning and argumentation skills.

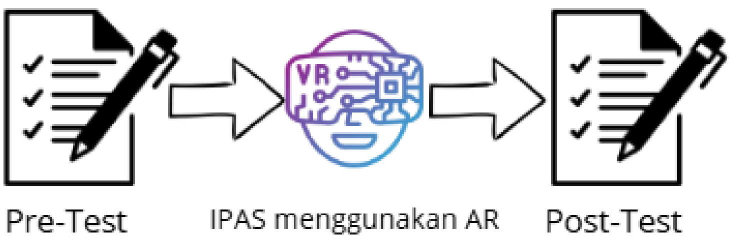

Figure 2. Learning Flow

Table 2, Descriptive Analysis

No	Statistical Measure	Pre-test	Post-test
1	Number of Students (N)	32	32
2	Mean Score	57.18	76.87
3	Minimum Score	40	60
4	Maximum Score	75	95
5	Range	35	35

$$Testing_{result(1)} = Mean\ of\ post_{test} - Mean\ of\ pre_{test}$$

$$Testing_{result(1)} = 76.87\% - 57.18\%$$

$$Testing_{result(1)} = 19.69\%$$

3.1.3. Combined Learning Method (Printed Book + AR)

The implementation at this stage emphasizes integrating interactive Augmented Reality (AR) technology with supporting learning materials. Students explore IPAS content through 3D digital object projections that can be directly manipulated, while still being guided by structured written resources. The 30.3% improvement reflects the effectiveness of this combined approach in increasing junior high school students' learning interest and achievement. AR visualization enables students to "see" previously abstract concepts in a more concrete and meaningful way. In terms of scientific literacy, the use of AR enhances students' observational skills and visual analysis. At the same time, the presence of written guidance (such as textbooks) provides a stronger narrative structure, helping students develop deeper conceptual understanding and more systematic scientific reasoning. The findings indicate that this combined method successfully balances visual engagement and conceptual reinforcement. While AR strengthens cognitive engagement and motivation, its integration with structured learning materials ensures that students do not merely focus on visual interaction but also develop a comprehensive, well-organized scientific understanding.

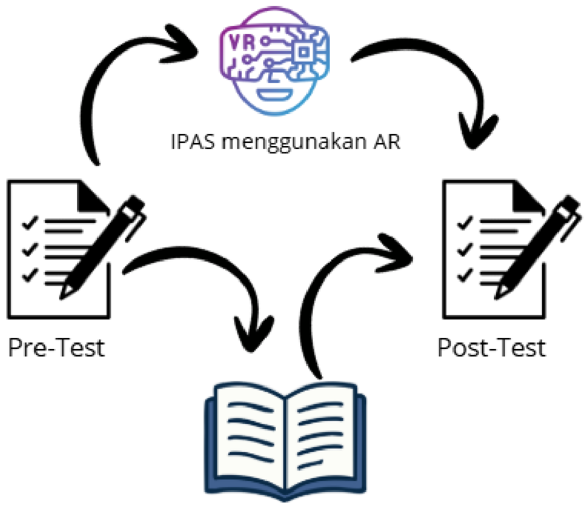

Figure 3. Learning Flow

Table 3, Descriptive Analysis

No	Statistical Measure	Pre-test	Post-test
1	Number of Students (N)	32	32
2	Mean Score	50.1	80.4
3	Minimum Score	35	70
4	Maximum Score	65	95
5	Range	30	25

$$Testing_{result(2)} = Mean\ of\ post_{test} - Mean\ of\ pre_{test}$$

$$Testing_{result(2)} = 80.4\% - 50.1\% = 30.3\%$$

3.2. Discussion

This study aims to identify problems related to students' learning motivation and their understanding in Integrated Science and Social Studies (IPAS) at the junior high school level, particularly with abstract materials. Based on the data analysis results, it was found that students' learning motivation is still relatively low, with an average of only 38.4%. In addition, students' level of understanding of IPAS materials, such as the human skeletal system and historical buildings, is also low, with an average of 40%. This indicates a correlation between low learning motivation and low conceptual understanding among students.

In line with previous studies, learning motivation is an internal factor that influences students' success in understanding learning materials. Low learning motivation can be caused by a lack of variation in teaching methods and minimal use of instructional media that can attract students' attention. The delivery of material through conventional methods without the support of interactive visual media makes it difficult for students to understand abstract concepts, which ultimately affects their learning outcomes [27].

Therefore, external factors, such in innovative learning media, are needed to improve students' motivation and understanding. In this study, Augmented Reality (AR) technology is proposed as a solution to address these issues. AR enables the presentation of learning objects in an interactive three-dimensional form, allowing students to observe and understand the material more concretely. This is supported by several studies indicating that AR use in learning can enhance students' interest, motivation, and understanding of the subject matter.

In its implementation, the AR-based IPAS learning application is designed to run on the Android platform using software such as Unity and Vuforia. The application features a navigation structure that connects various features, including the main menu, learning materials, 3D object visualization (human skeletons and historical buildings), and other interactive features. The navigation structure is hierarchical, making it easier for users to access each feature within the application.

The application interface is designed to be simple and user-friendly for students. The main page displays a primary menu with a "Learn" section and options to select science or social studies learning. The "Learn" menu provides access to AR-based learning materials, while the information section presents 3D designs accompanied by descriptions for each selected object. With its interactive and user-friendly design, the application is expected to enhance student engagement in the learning process.

Thus, the use of Augmented Reality-based learning media not only serves as a visualization tool but also enhances students' motivation and understanding in IPAS learning. The results of this study indicate that developing innovative learning media is essential to creating more effective, engaging, and meaningful learning experiences for students.

Figure 4. The screen displays the Main Menu

The results of the development of the Augmented Reality (AR)-based IPAS learning application are demonstrated through an interactive and user-friendly interface. In the topic of the human heart, the application provides 3D visualizations that allow students to observe the structure and blood flow more concretely. Quiz and discussion features also support students' active engagement in understanding the material.

For historical buildings, such as the Egyptian pyramids and Borobudur Temple, the application offers an AR Scan feature that enables 3D objects to appear in the real world through the device's camera. Students can rotate, examine details, and directly explore the structure of these buildings, making previously abstract concepts easier to understand.

In addition, the presentation of learning materials, complemented by descriptions and brief explanations, helps students gradually understand concepts. The integration of 3D visualization, quizzes, and discussion features makes the application not only an informational medium but also an interactive learning tool.

Thus, the use of Augmented Reality in IPAS learning enhances a more engaging, interactive, and effective learning experience, while also improving students' motivation and understanding compared to conventional methods.

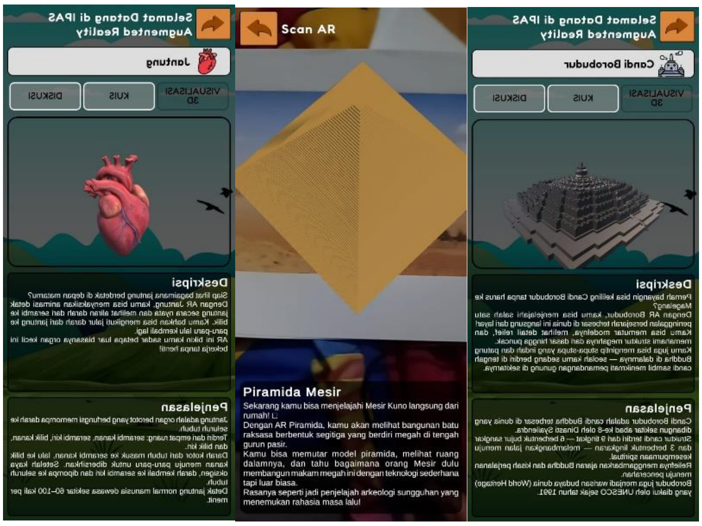

Figure 5. screenshots from the 3D model menu and AR scans

The first interface displays the main menu of the Augmented Reality application featuring the human skeletal system material, which provides functions such as 3D visualization, quizzes, and discussion. The next interface shows the quiz results in a pop-up, displaying a score of 60 after the user completes the questions. Furthermore, one of the quiz questions is presented, focusing on the function of the human skeletal system, accompanied by several answer choices.

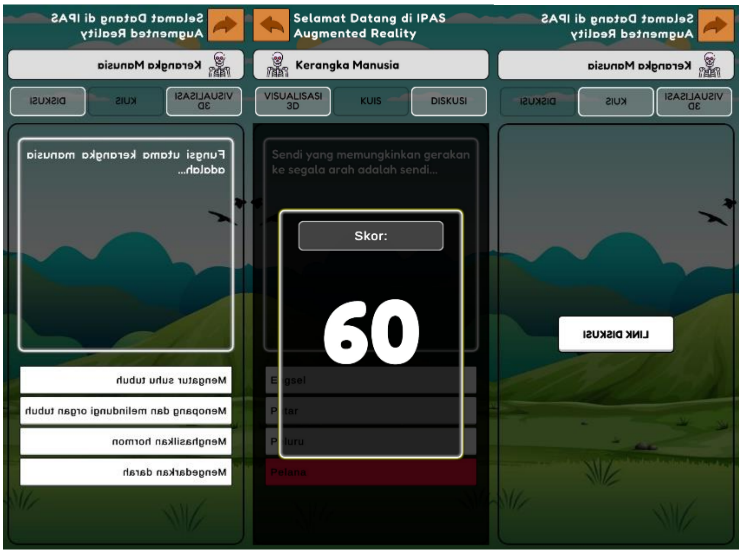

Figure 6. Discussion and quiz menu

4. CONCLUSION

This study concludes that the development and implementation of an interactive Augmented Reality-based IPAS learning model oriented toward scientific literacy meaningfully improve students' understanding of abstract concepts. The integration of AR technology into a structured learning model enables students to engage in more concrete, interactive learning experiences, allowing them to construct knowledge actively rather than rely on memorization. This finding aligns with the need for student-centered learning approaches that facilitate deeper conceptual understanding in abstract subject matter.

In addition, the study indicates that integrating Augmented Reality into a systematic instructional model—not merely as a supporting medium—can enhance the quality of the learning process. The model supports the development of scientific literacy by enabling students to interpret scientific phenomena, connect concepts to real-world contexts, and engage more actively in learning. Thus, the proposed model addresses the limitations of conventional teaching methods that rely heavily on two-dimensional materials and passive learning.

From a practical perspective, this research implies that teachers can adopt structured AR-based learning models to create more engaging, interactive, and meaningful classroom experiences. The model also demonstrates that widely available technologies, such as smartphones, can be effectively utilized to support learning innovation when integrated with appropriate pedagogical design.

However, this study is limited to a specific educational context and focuses primarily on the development and initial implementation of the learning model. It does not extensively examine long-term learning outcomes, broader population applicability, or variations in student characteristics that may affect the model's effectiveness.

Therefore, future research is recommended to test the model in diverse educational settings, involve larger and more varied student populations, and explore its long-term impact on students' scientific literacy development. Further studies may also investigate integrating this model with other pedagogical approaches or emerging technologies to enhance its effectiveness.

Overall, this study contributes to the field of technology-enhanced learning by providing a structured and applicable Augmented Reality-based learning model oriented toward scientific literacy. For the broader community, this research highlights the importance of utilizing digital technology not only as a tool but as an integral part of pedagogical innovation to improve the quality of education in the digital era.

ACKNOWLEDGEMENTS

The author expresses sincere gratitude to Almighty God for the completion of this research on the Interactive Augmented Reality-Based IPAS Learning Model. The author would like to extend deep appreciation and sincere thanks to the Principal, as well as all teachers and administrative staff of SMPN 1 Susukanlebak, for granting permission to conduct the research, providing technical assistance, and offering facilities and infrastructure that greatly supported the data collection process. Special thanks are also extended to fellow eighth-grade science teachers for their constructive discussions and valuable input during the development of this learning model, as well as to all eighth-grade students of SMPN 1 Susukanlebak who actively and enthusiastically participated as respondents in this study. The author acknowledges that the success of this work would not have been possible without the moral support and guidance from various parties who have encouraged the completion of this research. It is hoped that the assistance and dedication provided will be rewarded and contribute meaningfully to the advancement of knowledge, particularly in the digitalization of learning at the junior high school level.

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