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Development of Adaptive Augmented Reality-Based Learning Media to Improve Students' Visual-Spatial Ability

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ABSTRACT

The rapid advancement of digital technology has created significant opportunities for the development of more interactive and innovative learning media. One of the technologies with considerable potential to support the learning process is Augmented Reality (AR). However, the use of conventional learning media in teaching computer hardware remains challenging, particularly in visualizing abstract and complex components. This study aims to develop an adaptive Augmented Reality-based learning media that is feasible for classroom use and to investigate its potential in improving students' visual-spatial ability and learning outcomes. The study employs a Research and Development (R&D) approach using the ADDIE development model, which consists of the Analysis, Design, Development, Implementation, and Evaluation phases. The developed product is an adaptive AR application capable of displaying three-dimensional computer hardware objects while adjusting the complexity of the presented content according to students' abilities. The research instruments include expert validation sheets, student response questionnaires, and visual-spatial ability tests. The collected data are analyzed using descriptive quantitative analysis and the N-Gain method. The expected outcome of this study is a valid, practical, and effective learning media that supports Informatics education, particularly in computer hardware learning. Furthermore, the adaptive AR-based learning media is expected to enhance students' visual-spatial ability and learning outcomes through interactive visualization and more meaningful learning experiences.

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1. INTRODUCTION

The digital transformation of education has driven the integration of technology to enhance the quality of teaching and learning. One of the persistent challenges in the learning process is delivering abstract and complex subject matter in a way that is easily understood by students. This challenge is particularly evident in Informatics education, especially in computer hardware instruction, which requires students to develop visualization skills and understand the relationships among hardware components within a computer system [1], [2], [3].

Computer hardware learning requires students not only to understand the names and functions of individual components but also to comprehend their structures, spatial positions, and relationships within a computer system. In conventional instructional practices, this material is typically presented through textbooks, two-dimensional illustrations, or verbal explanations, making it difficult for students to construct accurate mental representations of the objects being studied. These limitations of conventional instructional media contribute to students' low visual-spatial ability and unsatisfactory learning outcomes [4], [5], [6].

Visual-spatial ability is a fundamental cognitive skill that plays a crucial role in understanding the shape, position, structure, and spatial relationships among objects. This ability is particularly important in learning contexts that involve three-dimensional visualization, including computer hardware instruction [7], [8]. Students with well-developed visual-spatial ability tend to have a better understanding of the structure and functions of computer hardware components than those with lower levels of visual-spatial ability [4], [9], [10].

One of the technologies that can be utilized to address these challenges is Augmented Reality (AR). AR is a technology that integrates virtual objects into the real-world environment in real time, allowing users to interact directly with three-dimensional objects. In educational contexts, AR provides more engaging, interactive, and contextual learning experiences than conventional instructional media [11], [12].

Numerous studies have demonstrated that the use of Augmented Reality (AR) in education can enhance students' learning motivation, engagement, conceptual understanding, and visual-spatial ability [13], [14]. AR enables students to observe objects from multiple perspectives, manipulate virtual objects interactively, and gain a deeper understanding of the relationships among their components. Nevertheless, most AR-based learning media developed to date remain static, providing the same learning experience for all students without considering individual differences in learning abilities [15], [16].

Differences in students' characteristics and learning abilities necessitate the development of more adaptive learning media. The concept of adaptive learning enables the system to adjust the presentation of learning materials, the level of difficulty, and the forms of interaction according to students' abilities and learning needs. Integrating adaptive learning principles into Augmented Reality (AR) technology results in adaptive AR-based learning media that not only provide interactive three-dimensional visualization but also deliver personalized learning experiences [17], [18].

Adaptive AR-based learning media have great potential to improve students' visual-spatial ability because they can adjust the level of visualization complexity based on users' initial abilities. Students with lower visual-spatial ability can receive additional visual support and guidance, while students with higher abilities can engage in deeper exploration of learning objects. Thus, the learning process becomes more effective and better aligned with the needs of each student [19], [20], [21].

Based on these problems, this study aims to develop adaptive Augmented Reality (AR)-based learning media for computer hardware topics among tenth-grade senior high school students. In addition to producing a feasible learning media product, this study also aims to evaluate the effectiveness of the developed media in improving students' visual-spatial ability and learning outcomes. The findings of this study are expected to contribute to the development of innovative, adaptive, and technology-based learning media that align with the demands of twenty-first-century education [22], [23].

In addition to the limitations of learning media, the learning process of computer hardware topics is often constrained by inadequate school facilities and infrastructure. Not all schools have computer laboratories equipped with sufficient hardware components to support practical learning activities [24], [25]. As a result, teachers frequently rely on textbooks, two-dimensional images, or presentation slides to deliver the material, preventing students from gaining direct experience in observing and recognizing the physical characteristics of each component. This condition makes it difficult for students to comprehensively understand the positions, structures, and relationships among computer hardware components [26], [27].

The utilization of Augmented Reality (AR) technology serves as one of the solutions to overcome these limitations. Through AR-based learning media, computer hardware objects can be presented as three-dimensional representations that closely resemble real-world conditions, allowing students to observe each component from multiple perspectives, enlarge the objects, and explore their structures and functions more clearly [28], [29]. Therefore, even when schools have limited practical equipment, students can still gain more concrete, interactive, and visually enriched learning experiences, thereby improving their understanding of computer hardware concepts.

2. METHOD

This study employs a Research and Development (R&D) method using the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic framework that is suitable for developing technology-based learning media while evaluating the feasibility and effectiveness of the resulting product.

This study applies a **mixed-methods approach**, which combines qualitative and quantitative approaches. The qualitative approach is used to obtain data regarding the feasibility of the developed media through validation by media experts, subject matter experts, and student responses toward the developed learning media. Meanwhile, the quantitative approach is used to measure improvements in students' visual-spatial ability and learning outcomes through the administration of pretests and posttests.

Figure 1. ADDIE Development Model

The Analysis stage was conducted to identify learning needs, students' characteristics, computer hardware topics, and the requirements for developing Augmented Reality-based learning media. In the Design stage, learning objectives, storyboards, application interface designs, media adaptivity mechanisms, and research instruments were developed, including expert validation sheets, student response questionnaires, and visual-spatial ability test instruments.

The Development stage resulted in an adaptive Augmented Reality learning media that presents interactive three-dimensional models of computer hardware components. The developed product was subsequently validated by media experts and subject matter experts, and then revised based on the validators' suggestions and feedback until it was considered feasible for testing.

The Implementation stage was conducted with tenth-grade senior high school students in Informatics learning, specifically on computer hardware topics. Before the learning process using adaptive AR media, students were given a pretest to determine their initial abilities. Subsequently, students participated in learning activities using adaptive Augmented Reality media through Android devices. After the learning activities were completed, students were given a posttest and a response questionnaire to evaluate their learning experiences.

The Evaluation stage aims to determine the feasibility and effectiveness of the developed learning media. Data analysis was conducted using descriptive quantitative analysis on the results of expert validation and student responses. The improvement in students' visual-spatial ability was analyzed using the Normalized Gain (N-Gain) method by comparing pretest and posttest scores. In addition, qualitative descriptive analysis was employed to process feedback and suggestions from validators as a basis for refining the developed media.

The research variables consist of adaptive Augmented Reality learning media as the independent variable and students' visual-spatial ability as the dependent variable. The media is considered successful if it meets the feasibility criteria based on expert evaluations, demonstrates an improvement in students' visual-spatial ability based on the N-Gain analysis results, and receives positive responses from students after being implemented in the learning process.

3. RESULTS AND DISCUSSION

This section presents an example of simulated results to illustrate the presentation of research findings in a journal article. The simulation was conducted in one class consisting of 30 students. After the adaptive Augmented Reality (AR) learning media was implemented in computer hardware instruction, students' responses were measured using a four-point Likert scale questionnaire, consisting of Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD) [30]. The simulation results indicate that most students responded positively to the use of adaptive AR media. The media was considered capable of helping students understand abstract learning materials through interactive three-dimensional object visualization.

Table 1. Example of Student Response Questionnaire Results (Simulated Data)

No	Statement	SS	S	TS	STS	Score
1	The media has an attractive appearance	18	11	1	0	107
2	The media is easy to use	16	13	1	0	105
3	The 3D objects help in understanding the learning materials	20	10	0	0	110
4	The media enhances learning motivation	17	12	1	0	106
5	The learning materials are easier to understand	19	10	1	0	108
6	The media interaction functions well	18	11	1	0	107
7	The media makes the learning process more engaging	21	8	1	0	110
8	The media is suitable for use in learning activities	22	8	0	0	112
	Total	151	83	6	0	865

Based on the simulated data, the majority of students selected the Strongly Agree and Agree categories, indicating that the learning media received positive responses from the students.

Percentage Calculation

The maximum score was calculated based on 30 student respondents, 8 questionnaire statements, and the highest Likert scale score of 4, resulting in a maximum possible score of 960 ($30 \times 8 \times 4$). The total score obtained from the student responses was 865, yielding a feasibility percentage of 90.10%. Based on the established interpretation criteria, where a percentage of 81–100% is categorized as Very Good, 61–80% as Good, 41–60% as Fair, and 40% or below as Poor, the obtained percentage falls within the Very Good category. These results indicate that the developed learning media received highly positive responses from students and is considered highly feasible for use in the learning process.

Discussion

Based on the simulation results, the adaptive Augmented Reality learning media demonstrates potential in improving the quality of Informatics learning, particularly in computer hardware topics. The visualization of three-dimensional objects enables students to observe the shapes, positions, and relationships among computer components more concretely compared to conventional learning approaches.

The positive responses from students indicate that the use of Augmented Reality technology can enhance students' interest and engagement during the learning process. The ease of operating the media and the interactive presentation of learning materials provide more meaningful learning experiences, enabling students to understand the concepts being studied more effectively.

These simulation results are also consistent with previous studies indicating that Augmented Reality can enhance learning motivation, clarify abstract concepts, and support visualization processes in technology-based learning. Therefore, adaptive AR-based learning media has the potential to serve as an effective alternative learning medium for Informatics subjects at the senior high school level.

The Augmented Reality (AR)-based learning media developed in this study was successfully implemented using the Assemblr EDU platform. The testing process was conducted through several stages, including marker scanning, three-dimensional (3D) object visualization, and the placement of virtual objects into the real environment (Augmented Reality). These stages aimed to determine whether the media could be effectively used by students and provide a more interactive learning experience compared to conventional learning media.

Marker Scanning Process

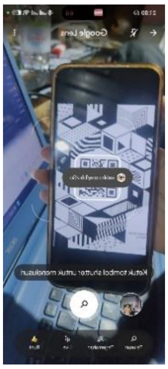

Figure 2. Implementation of Augmented Reality in the Real Environment

Figure 2 shows the marker scanning process using the Google Lens application. The previously created marker was scanned until the system successfully recognized the marker pattern and directed users to the Augmented Reality project that had been published on the Assemblr platform. This stage represents the initial step in using the learning media. The successful recognition of the marker by the system indicates that the marker has good quality and can be detected quickly by the device. The marker functions as a trigger to display the developed virtual objects, allowing students to access the learning media simply by scanning the marker using a smartphone. The ease of access supports more flexible learning, as students do not require the installation of specific applications or complex configurations before using the learning media.

Three-Dimensional (3D) Model Visualization

Figure 3. Three-Dimensional (3D) Model Visualization

After the marker was successfully recognized, the system displayed three-dimensional (3D) models of computer hardware components through the Assemblr platform. At this stage, students were able to observe the complete form of the objects by utilizing the View in 3D feature.

The visualization of three-dimensional objects provides a more realistic learning experience compared to two-dimensional images presented in textbooks. Students can observe the shape, size, and details of each computer hardware component from various perspectives. This feature helps students understand the characteristics of objects that were previously difficult to comprehend through static images alone.

In addition, the simple interface design makes it easier for students to operate the media, allowing them to focus more on the learning content rather than learning how to use the application.

Implementation of Augmented Reality in the Real Environment

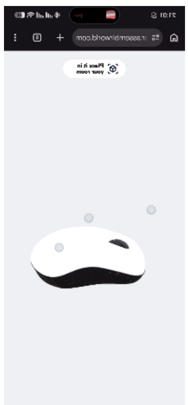

Figure 4. Marker Scanning Process

Figure 4 shows the implementation results of the Place it in Your Room feature, which involves placing virtual objects into the real environment using a smartphone camera. At this stage, computer hardware objects can be projected directly onto real surfaces, making them appear as if they are present in front of the user.

This feature provides a more immersive and interactive learning experience by allowing students to observe three-dimensional virtual objects from multiple perspectives. Students can approach, move away from, rotate around, and inspect the objects in real time using their mobile devices, enabling them to explore the structure, shape, and individual components of computer hardware more naturally than through conventional two-dimensional images. Such direct interaction supports the development of spatial visualization skills, helping students understand the relationships among hardware components, recognize their physical characteristics, and distinguish the functions of each part more effectively. The integration of virtual objects into the real environment also creates a more authentic learning experience by bridging theoretical concepts with realistic visual representations.

Beyond enhancing visualization, the implementation of Augmented Reality (AR) technology promotes greater student engagement and active participation throughout the learning process. Instead of relying primarily on teacher explanations, students are encouraged to independently explore learning materials, manipulate virtual objects, and investigate hardware components through observation and experimentation. This interactive approach shifts the learning process from a teacher-centered model toward a student-centered learning environment, where students actively construct knowledge through exploration, discussion, and problem-solving. The ability to immediately visualize abstract concepts increases students' curiosity, motivation, and confidence in learning while encouraging collaborative interaction during classroom activities.

The findings further indicate that the developed AR learning media operated effectively throughout the implementation process. The marker scanning system successfully recognized the designated markers, three-dimensional models were displayed accurately, and virtual objects were positioned appropriately within the real-world environment, allowing students to interact with the content without major technical obstacles. These technical capabilities ensured that instructional activities could proceed smoothly and supported the integration of AR technology into Informatics learning. Reliable visualization and responsive interaction are particularly important for topics involving computer hardware because students are able to observe components that may not always be physically available in the classroom.

Students' evaluation results also support the positive performance of the developed learning media. The application achieved an overall response percentage of 90.10%, which falls within the Very Good category, indicating a high level of user acceptance. Students perceived the application as easy to operate, visually engaging, and beneficial for understanding computer hardware concepts. The high evaluation suggests that the combination of interactive visualization, multimedia elements, and intuitive navigation contributed positively to the overall learning experience. Nevertheless, these findings should be interpreted as evidence of students' positive perceptions and acceptance of the learning media rather than direct evidence of improvements in learning achievement. Future studies should therefore investigate the effectiveness of the AR application through experimental research designs that compare learning outcomes before and after implementation, while also involving larger and more diverse participant groups to strengthen the generalizability of the findings. Overall, the results indicate that Augmented Reality-based learning media offers considerable potential as an innovative instructional tool for Informatics education, particularly for learning topics that require concrete visualization, spatial understanding, and active student interaction.

4. CONCLUSION

This study successfully developed adaptive Augmented Reality (AR)-based learning media for computer hardware topics as an interactive learning medium that can be used in Informatics learning. The media development process was carried out using the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. The implementation results indicate that the media can function effectively through the processes of marker scanning, three-dimensional object visualization, and the placement of virtual objects in the real environment using smartphone devices.

Based on the evaluation results, the learning media received very positive responses from students. The results of the student response questionnaire showed a percentage of 90.10%, which was categorized as **Very Good**. This indicates that the developed media has an attractive appearance, is easy to use, enhances students' learning motivation, and helps students understand computer hardware materials through interactive three-dimensional object visualization.

The use of Augmented Reality technology provides a more realistic learning experience compared to conventional learning media. Students can observe objects from various perspectives and interact directly with virtual objects, making the learning process more active, engaging, and student-centered. Thus, adaptive Augmented Reality-based learning media has the potential to improve the quality of Informatics learning, particularly in topics that require concrete object visualization.

Future research is recommended to develop learning media with a broader range of subject materials, incorporate automatic adaptive evaluation features, and examine the effectiveness of the media using larger sample sizes and across different educational levels to obtain more comprehensive and generalizable findings.

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