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Designing and Evaluating a Marker-Based Augmented Reality Teaching Module for Visualizing Quantum Physics Concepts

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ABSTRACT

The 2019 National Physics Examination study by the Indonesian Center for Assessment and Learning revealed that high school students still struggle with solving problems presented in visual representations. The current reliance on 2D media for learning support has not fully met students' visualization needs. With the integration of technology in education, there is a significant opportunity to innovate through the development of Augmented Reality (AR) integrated teaching modules. This technology provides a new method for visualizing abstract physics concepts, enhancing deeper understanding. This research focuses on developing a Marker-Based Augmented Reality teaching module, with the PyLo-AR application as the final product. The aim is to assess the validity of the teaching module and evaluate the quality of the PyLo-AR module according to ISO 9241-11 standards. The development process followed the design thinking model. Data were gathered through content and system validation by experts, surveys, and user feedback. Analysis results showed a Gregory internal coefficient of 1.00 for content and 0.76 for the system. The quality of PyLo-AR, based on effectiveness and efficiency measures using completion rate and overall relative efficiency, yielded scores of 95.10% and 95.17% respectively, with user satisfaction falling into categories D (marginal low) and C (marginal high). These results suggest that the marker-based Augmented Reality teaching module is effective, efficient, and suitable for use in the learning physics.

Keywords: Augmented reality, ISO 9241-11, teaching module, usability, visualization

INTRODUCTION

The rapid development of digital technology in the 21st century is driving fundamental transformations in the world of education. The integration of technology in education is driven by the increasing reliance on digital tools in everyday life. Recognizing the importance of technology in shaping the future of education, the G20 Education Working Group (2022) has made the use of digital technology a key focus in its education revitalization agenda. With the utilization of technology, the learning process can offer more engaging, effective, and personalized learning experiences that better meet the needs of students (Sunandi et al, 2023; Pratiwi, 2022).

The interviews with Physics teachers at SMA 2 Makassar provided insights into the dynamics of learning and the difficulties students face in the subject of physics. The use of learning media still predominantly relies on 2D visualizations, which are insufficient due to their limited flexibility for understanding concepts. This finding aligns with the results of the 2019 National Physics Examination for high school levels (SMA/MA) released by the Center for Assessment and Learning, which indicated that students tend to struggle with physics problems requiring reasoning and integrated conceptual understanding, particularly those presented in visual forms such as tables, images, or graphs

(Pusmenjar, 2019). A solution to this issue is to provide engaging teaching materials that can help students better understand physics concepts.

Technology has become an inseparable part of the teaching and learning process (Pratiwi, 2022). One of teaching material that can be developed is a Marker-Based Augmented Reality (MAR) teaching module. By adopts Design Thinking model (Willmott, 2022), this educational module integrates Augmented Reality (AR) to provide in-depth and interactive 3D visualizations for students, particularly in understanding abstract quantum phenomena concepts. The development of an Augmented Reality (AR) teaching module for quantum phenomena is expected to make a significant contribution to providing innovative and effective learning solutions, particularly for abstract material. Previous research by Khunaeni et al. (2020) found that AR-based physics modules are effective in visualizing abstract physics concepts and providing interactive visualizations. Further, findings by Riyanda et al. (2021) show that AR-based simulations of the photoelectric effect can enhance students' understanding of the material. Research by Rahmatullah et al. (2021) indicates that AR technology has a positive impact on students' learning success. This study will focus on the development and evaluation of a marker-based AR teaching module through a series of tests.

LITERATURE REVIEW

Teaching module and AR technology

According to the Indonesian Minister of Education and Culture Decree No. 56/M/2022 on curriculum implementation guidelines for learning recovery, a teaching module is a document that includes objectives, steps, learning media, and assessments required within a unit based on the learning goals. The application of teaching modules aligns with curriculum demands that are student-centered (Najuah et al., 2020). Yani (2021) explains that the use of teaching modules aims to effectively achieve educational objectives, facilitate self-directed learning, and help students with self-assessment. However, according to Chaeranti et al. (2018), there are still few modules that provide adequate visualization for abstract physics concepts. A good teaching module is one that can effectively and efficiently achieve educational goals, including assisting students in understanding the material through visualization (Najuah, 2020).

One of the technological advancements now widely used across various fields is Augmented Reality (AR). Augmented Reality is a technology that can overlay content such as text, images, and videos onto the real world (Vari & Bramastia, 2021). This technology can combine the real world with digital elements in real-time, allowing graphics, visuals, audiovisuals, or text to be integrated into modules through AR (Arifitama, 2017; Khunaeni et al., 2020). In the field of education, AR has paved the way for the development of more innovative learning media. AR-based multimedia presentations and simulations can present information in a more engaging and interactive visual format (Purnamawati, 2021).

The AR development method used in this research is marker-based tracking, which operates based on the principles of tracking and reconstruction (Virtual Reality, 2020). First, the AR system detects the marker using various algorithms and then reconstructs that information within the real-world coordinate system (Yani, 2021). Vari and Bramastia (2021) mention that engaging and interactive use of Augmented Reality can enhance student interest and involvement in learning. Therefore, AR technology is a solution for understanding abstract physics material, such as quantum phenomena. The limitations of physical models and practical activities to observe quantum phenomena directly are major issues (Riyanda et al., 2022). By utilizing Augmented Reality technology, it is hoped that students can gain a more comprehensive understanding of quantum phenomena.

Design thinking

Design thinking is a creative, human-centered approach to finding innovative solutions to complex problems (Willmott, 2020; Pressman, 2019; Aflatoony et al., 2018). The d. school (The Hasso Plattner Institute of Design at Stanford) divides design thinking into five stages: empathize, define, ideate, prototype, and test. The empathize stage involves building a deep understanding of the subject to ensure that the solutions developed truly address their needs. The identified problem is then framed in the define stage to create the appropriate solution. The ideate stage is the phase of generating as many ideas and solutions as possible based on the results from the define stage through brainstorming methods. The developed design is then tested in the form of a prototype. The test stage is an opportunity to refine

the prototype and evaluate the alignment between the problem, needs, expectations, and the developed solution
.
Teaching module usability
Usability is a measure of the quality of software in terms of how efficiently users can complete their tasks, as well as how easy the software is to learn and use. Usable software should be beneficial, efficient, effective, satisfying, easy to learn, and accessible (Dhillon, B.S, 2013; Rubin & Chisnell, 2008). The level of usability is a determining factor for the long-term sustainability and usefulness of a system (Putri R.A, 2020). Currently, there are various criteria that can be used to test usability, one of which is the ISO 9241-11 standard. The International Organization (ISO) 9241-11 standard covers three aspects of usability measurement: 1) Effectiveness, which is the measure of the user's ability to complete tasks using the system; 2) Efficiency, which relates to the level of effectiveness achieved and the use of resources, including effort, mental or physical, time, and cost; and 3) Satisfaction, which is the measure of how satisfied users are with their experience using the system (Wahyuningrum, 2021; Brooke, J, 1995).

METHODOLOGY

This study is a Research and Development (R&D) project that adapts the Design Thinking model. The development results were tested with two physics teachers and students from grades X and XII at SMA Negeri 2 Makassar for the 2023/2024 academic year.

Development
The development process began with the empathize stage, followed by define, ideate, prototype, and concluded with the test stage.

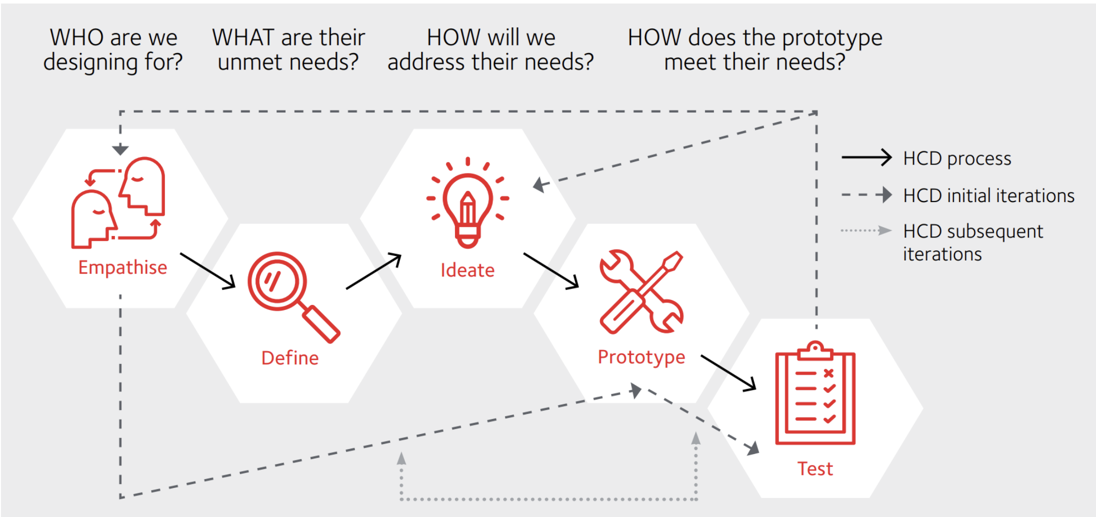

Figure 1. Design Thinking Scheme
Source: Willmott (2020)

The development process began with the empathize stage, where the researchers identified the users and delved into the problems and needs of the subjects. In this stage, the researchers determined the problem area from their perspective, created a design challenge, and validated the problem. The problems and solutions were then validated or redefined based on the subjects' perspectives, documented in personas, empathy maps, and user journeys. In the ideate stage, the results from redefining the problems and solutions were used as a basis for generating ideas and solutions through brainstorming methods. From the brainstorming results, the developed product was named PyLo-AR (Physics Learning of Augmented Reality), along with its features. The ideas obtained in the ideate stage were then translated into a prototype. The prototype includes the User Interface (UI) design and the development of the PyLo-AR application system. The PyLo-AR application system was built using

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Unity version 2021.3.28. f1, Canva, and Blender version 3.6. Canva was used to design the markers for each quantum phenomenon visualization. Below is the screenflow of PyLo-AR.

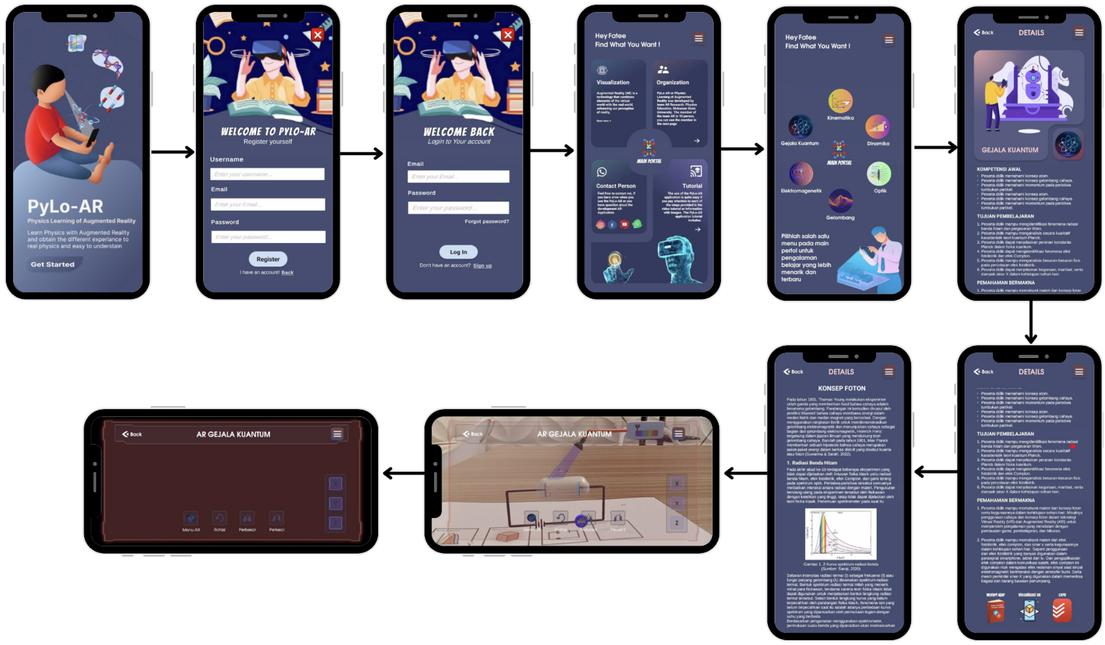

Figure 2. PyLo AR Screenflow

The final stage of this development is the product testing. This stage aims to evaluate the validity of the PyLo-AR application for quantum phenomena content and system, assess the effectiveness and efficiency of the application in learning, and determine user satisfaction with the PyLo-AR teaching module from the perspectives of both teachers and students.

Evaluation

Based on the research objectives, the feasibility of the PyLo-AR application is measured to assess how well the application can be implemented in learning activities.

Validation test

The measurement involves testing the validity of the PyLo-AR system and content, conducted by experts using an instrument sheet with several assessment criteria. The results are then analyzed using Gregory's formula. Gregory, as cited in Retnawati (2016), describes the expert agreement index for content validity as the ratio of the number of items rated as having strong relevance by both experts to the total number of items mapped in the cross-tabulation, as shown in the table below.

Table 1. Gregory Formula

Gregory's Table		Validator 1	
		Score 1 – 2 (Weak Relevance)	Score 3 – 4 (Strong Relevance)
Validator 2	Score 1 – 2 (Weak Relevance)	A	B
	Score 3 – 4 (Strong Relevance)	C	D

The results of the validator assessment were then analyzed using Gregory's formula as follows.

$$content\ validity\ coefficient = \frac{D}{A+B+C+D}$$

The criteria for determining whether the development is valid are that the content validity coefficient must be ≥ 0.75

Effectiveness and efficiency

The effectiveness and efficiency of the application system are tested through a task scenario method with 49 participants who were asked to complete various tasks using the PyLo-AR application. Below is a list of tasks that users need to complete.

Table 2. List of testing tasks for the PyLo-AR application system

Task List
1. User opens the PyLo-AR application
2. User creates an account by entering a username, email, and password
3. User clicks on the material icon
4. User clicks on the Teaching Material icon to read the material
5. User clicks on the AR Visualization icon to display the 3D visualization
6. User initiates AR scanning by selecting a marker in the AR Menu
7. User running the 3D visualization by scanning the marker
8. User explores the 3D visualization from various angles
9. User clicks the back button to navigate to the previous scene
10. User close the application by pressing the exit button

User satisfaction

User satisfaction is measured using the System Usability Scale (SUS), which is an efficient method for collecting statistically valid data and providing clear and accurate scores (Brooke, 2013; Setiawan & Rafianto, 2020). SUS is a questionnaire that uses a Likert scale to measure the usability of a system. It consists of ten statements related to various aspects of usability, and respondents rate their agreement with these statements on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Here is a list of SUS questionnaries.

Table 3. SUS questionnaire

No	Question	Scale				
		SD	D	N	A	SA
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I thought the system was easy to use.					
4	I think that I would need the support of a technical person to be able to use this system.					
5	I found the various functions in this system were well integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very cumbersome to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could get going with this system.					

Data from the System Usability Scale (SUS) questionnaire for each respondent were analyzed using the following formula (Wahyuningrum, 2021):

$$SUS = 2{,}5 \times \left[\sum_{n=1}^{5} (U_{2n-1} - 1) + (5 - U_{2n})\right]$$

System Usability Scale (SUS) score for each respondent is calculated by summing all the respondent scores and then dividing the result by the number of participants. The formula for calculating the SUS score is as follows:

$$\underline{x} = \frac{\Sigma x}{n}$$

RESULT AND DISCUSSION

The final result of this research is an application named PyLo-AR. This application utilizes Augmented Reality (AR) technology and is specifically designed for Android smartphones.

Validation test

The validity of the PyLo-AR application was theoretically tested using content and system validation instruments with Gregory's agreement analysis technique. The content validation sheet consists of 14 statements covering 4 assessment aspects: content appropriateness, material organization, language, and impact on learning strategies. A score of 14 was obtained from the evaluation of two validators, with a value of 1.00 indicating a strong relevance category. This indicates that the PyLo-AR application is deemed suitable for use because its content is relevant, well-structured, and effective in supporting the learning process. The system validation sheet consists of 34 statements regarding system feasibility, divided into 8 aspects: system status visibility, alignment between the system and the real world, user control and freedom, consistency and standards, user flexibility and efficiency, aesthetic and minimalist design, assistance in error recognition, diagnosis, and recovery, and help and documentation. The Gregory internal consistency coefficient for system validity is 0.76, indicating that the PyLo-AR application system can be used in the learning process.

Testing the quality of the marker-based augmented reality teaching module application

The quality of the application is measured based on three aspects: effectiveness, efficiency, and user satisfaction with the system. Testing is conducted using task scenarios for effectiveness and efficiency, while user satisfaction is assessed using the SUS (System Usability Scale) questionnaire.

Effectiveness and efficiency of the system

Effectiveness and efficiency of application use indicate the performance of the product (Wicaksono, 2023). Both are measured through application testing. Testing is conducted using task scenarios with 49 participants who were asked to complete various tasks using the PyLo-AR application. Effectiveness is measured using completion rate analysis, resulting in the following outcomes.

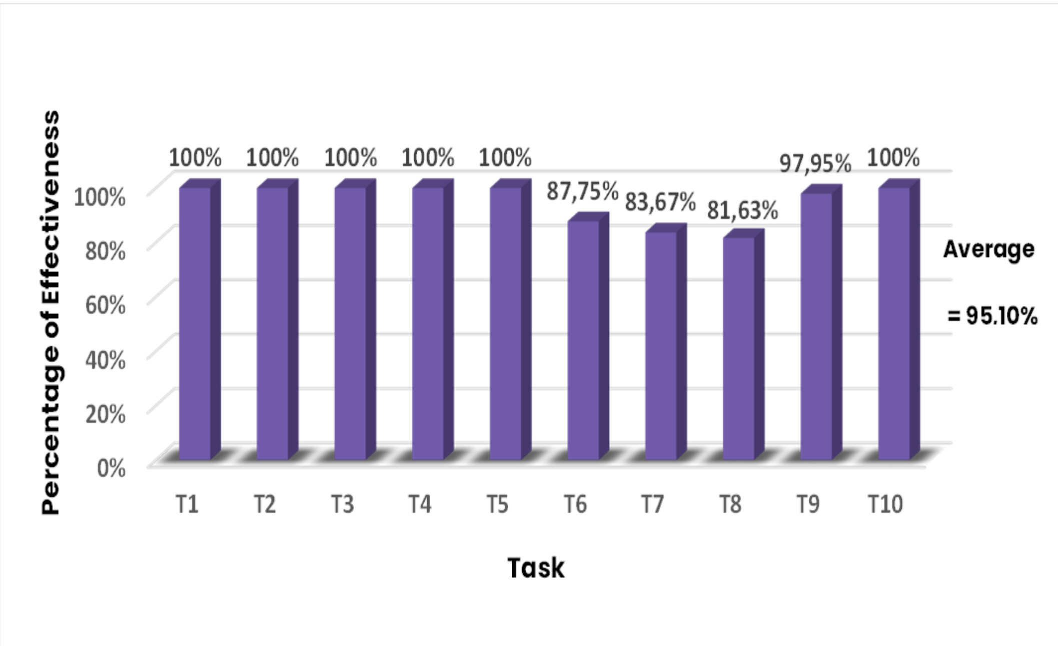

Figure 3. Effectiveness percentage of each task

The effectiveness of the application use was analyzed using completion rate analysis, resulting in an effectiveness score of 95.10%, categorized as "good" (Wahyuningrum, 2021). Figure 3 shows that some respondents failed to complete tasks 6, 7, 8, and 9, as listed in Table 2. Factors affecting the

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effectiveness of the PyLo-AR application during testing include smartphone specifications that do not support AR camera performance well, causing some application functions to not operate effectively. The efficiency of using the PyLo-AR application was measured based on the participants' success in completing tasks and the time required to complete those tasks. Application efficiency was analyzed using overall relative efficiency. This analysis provides insights into how efficiently the application supports participants in completing their tasks, considering the time taken and the success rate in completing each task.

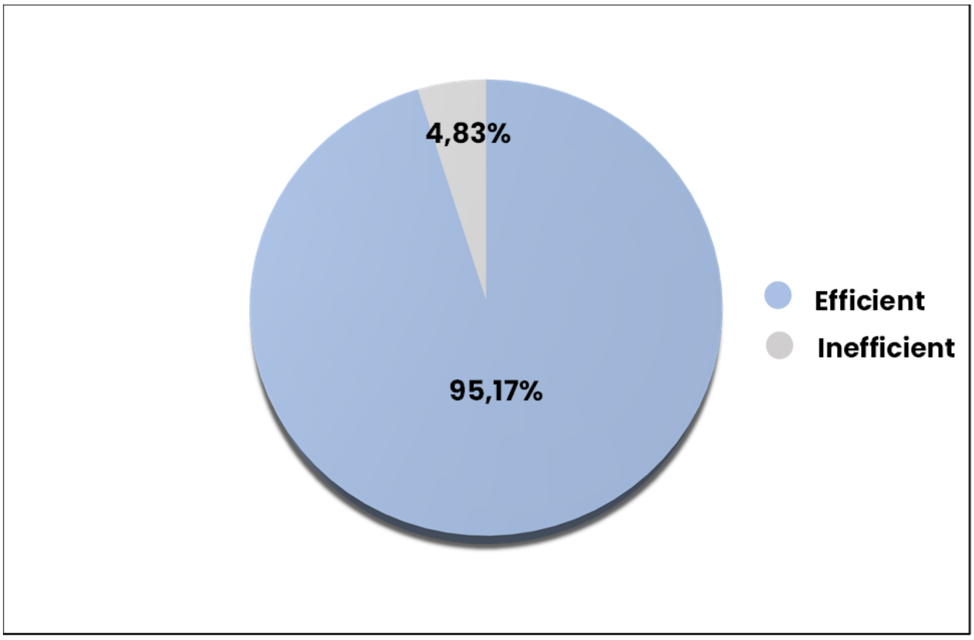

Figure 4. Efficiency percentage of PyLo-AR usage

Efficiency was analyzed using overall relative efficiency, resulting in an efficiency score of 95.17%. This score indicates that, on average, users required 95.17% of the total time to successfully complete the tasks. With an efficiency score of 95.17%, which is higher than the system efficiency standard of 78% (Marti & Mahedy, 2021), the PyLo-AR application is considered efficient. Both analysis results indicate that the PyLo-AR application is effective and efficient for physics learning purposes (Wahyuningrum, 2021).

Satisfaction

The usability of the application from the perspectives of both teachers and students was evaluated using the System Usability Scale (SUS) method and analysis. The SUS score provides an interpretation of various aspects of user evaluation of the application, including: 1) Adjective rating, which determines the rating of the application assessed; 2) Grade Scale, which assesses the quality of the application; and 3) Acceptability rating, which determines the level of acceptance of the application by users (Aisyah et al, 2021; Maricar & Pramana, 2020). The testing involved 24 respondents from class X and 25 respondents from class XII. The results indicated that the SUS score for class X respondents was 53, while for class XII respondents it was 70.

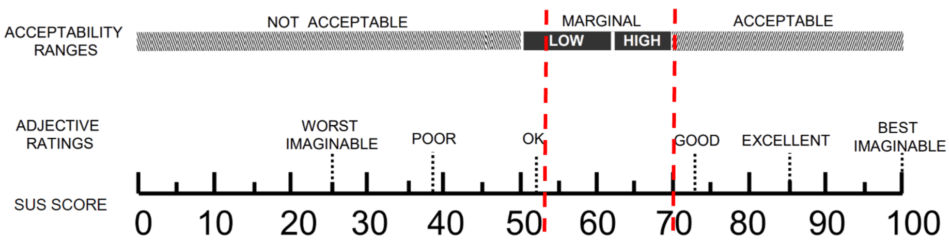

Figure 5. SUS Scale

Based on Figure 5, a score of 53 indicates that the quality of the PyLo-AR application is at level D, with an "Ok" rating and the application's user acceptance falling into the marginal low category. This means that class X respondents consider the application usable with some improvements and that it meets the minimal criteria for use in learning. In contrast, the testing results for class XII respondents yielded a score of 70, indicating that the application's quality is at level C, with an "Ok" rating and user acceptance falling into the marginal high category. Thus, the PyLo-AR application is rated as quite good, usable, and accepted by users (Aisyah et al., 2021; Sauro & Lewis, 2018; Bangor et al., 2009).

The difference in SUS scores between the two respondent groups indicates a gap in user responses to the application. Class X respondents scored highest on statement 1 (see table 3), indicating they would use the application for learning activities but still require additional help and need to get accustomed to the application. Meanwhile, class XII respondents found the application easy to use with functioning features, although they encountered some initial obstacles.

CONCLUSION

Based on the research findings, the conclusions are as follows:

1. The Marker Augmented Reality-based teaching module developed is validated by the evaluators and is deemed suitable for use in the learning process.
2. The Marker Augmented Reality teaching module (PyLo-AR) is effective, efficient, and usable based on the software quality testing.

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