AUGMENTED REALITY LEARNING MEDIA FOR COMPUTER ASSEMBLY: SUPPORTING SDG 4 QUALITY EDUCATION

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ABSTRACT

Understanding computer components and assembly procedures is a fundamental competency for information technology students, yet conventional two-dimensional media cannot interactively visualize the shape, position, and correct sequence of component installation. Hands-on practice also carries the risk of hardware damage and requires substantial cost, limiting equitable access to quality technical education. This study develops an Augmented Reality (AR)-based interactive learning platform for computer assembly on the Android platform as a digital innovation supporting SDG 4 (Quality Education). The platform was developed using the Multimedia Development Life Cycle (MDLC) method, comprising concept, design, material collecting, assembly, testing, and distribution stages. Key features include Play AR, marker scanning, 3D component models, component descriptions, tutorial animations, and an interactive quiz. Blackbox testing confirmed that all core features function as designed. A usability evaluation using the System Usability Scale with 25 respondents produced an average score of 81.00, placing the application in the Excellent category and exceeding the score of an earlier VR-based simulation. These results indicate that the platform is feasible as an interactive, low-risk, and cost-effective learning medium that widens access to quality technical education in the digital era.

KEYWORDS

Augmented Reality, Interactive Learning Media, Computer Assembly, Multimedia Development Life Cycle, SDG 4 Quality Education.

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INTRODUCTION

Computers are a central instrument in modern learning, and mastery of computer component materials such as the processor, RAM, and motherboard is fundamental in courses such as Computer Organization and Architecture, Distributed Systems, and Operating Systems and Open Source Programming. Computer assembly is a discipline requiring both conceptual understanding and procedural technical skill: students must not only know the names and functions of components such as the Processor, RAM, Motherboard, SSD, VGA, Power Supply, Casing, and CPU Cooler, but also understand their physical form, installation position, orientation, and the correct installation sequence. Errors in these procedures risk causing system malfunction or even fatal damage to hardware, while conventional practicum also faces obstacles such as limited facilities, high hardware procurement costs, and limited practice time. This confirms the need for learning media capable of presenting clear, interactive, and safe procedural visualization before students engage in physical practice. Studies on Virtual Reality-based computer assembly simulation have shown that immersive three-dimensional visualization can be a safe and realistic learning alternative that reduces the risk of hardware component damage (Umri et al., 2025).

So far, computer assembly learning has largely relied on conventional media such as text, two-dimensional images, presentation slides, or instructional videos. Such media provide basic information but remain limited in delivering an interactive and realistic learning experience: two-dimensional images cannot show the detail of a component's shape from various viewpoints, nor realistically depict the spatial relationships between components. Direct practice using physical hardware, meanwhile, requires an adequate supply of components, laboratory space, and instructor supervision to minimize installation errors. Augmented Reality (AR) is considered capable of closing this gap by integrating virtual objects into the real environment in real time, providing a deeper learning experience through 3D object visualization (Mayer, 2010) and creating a hybrid learning ecosystem that combines digital and physical elements to increase user engagement and conceptual understanding (Azuma, 1997).

The use of Augmented Reality in learning has been widely applied across various fields. Research on geometric-solid learning media shows that AR can help learners visualize three-dimensional objects that were previously difficult to understand through lecture methods and two-dimensional images, improving the average learning score from 49.68 to 74.84 (Umri et al., 2023). Other research on an Android-based human internal-organ learning medium similarly confirms that AR is effective in interactively displaying 3D objects, helping users understand material that was previously difficult to observe directly and making learning more engaging (Musthofa et al., 2024). These findings reinforce AR's position as a highly potential visualization-based learning-media instrument.

In education, AR can increase learning interest and motivation and help users understand complex concepts through 3D visualization. Through the Android platform, AR-based learning media can be accessed independently anytime and anywhere, from component introduction to installation-procedure simulation, contributing academically to the application of AR in engineering education, particularly procedural simulation and human–computer interaction.

Beyond its pedagogical contribution, this research is positioned within the broader agenda of the Sustainable Development Goals (SDGs), particularly SDG 4 on Quality Education, which calls for inclusive, equitable, and technology-enabled learning opportunities for all (United Nations Department of Economic and Social Affairs, n.d.). Integrating digital innovations such as AR into technical and vocational education is one

concrete pathway to accelerate this goal, since it lowers the cost and safety barriers that often limit equitable access to hands-on technical training.

More specifically, this research aligns with several targets under SDG 4. Target 4.3 calls for equal access to affordable, quality technical and vocational education, while Target 4.4 emphasizes equipping learners with the skills needed for employment and decent work, including technical and vocational skills; Target 4.a further calls for upgrading education facilities to provide safe and effective learning environments for all (United Nations Department of Economic and Social Affairs, n.d.). An AR-based computer assembly platform directly supports these targets: it functions as an affordable technical-education resource that runs on an ordinary smartphone rather than requiring a fully equipped hardware laboratory, and it offers a safer learning environment by allowing students to rehearse assembly procedures virtually before handling physical components. In this way, the platform contributes to more equitable and affordable access to quality technical education, particularly for institutions with limited laboratory infrastructure.

A growing number of studies have begun to connect AR and related digital innovations to SDG 4. A large-scale study involving more than 4,000 teachers and students found that combining AR with a cognitive-constructivist approach significantly improved conceptual understanding and narrowed gender disparities, explicitly mapping these results onto SDG 4 targets (Kolil et al., 2025), while AR and VR have also been proposed as tools to raise learners' awareness of SDG 4 itself (Osman, 2025). Mixed-methods research on a progressive web application across vocational schools in marginalized regions of Indonesia reported substantially increased learning access, aligning with targets 4.3, 4.4, and 4.a (Tanggu Mara et al., 2026), and similar connections have been drawn in secondary-school technology units (Del Cerro Velázquez & Morales Méndez, 2018) and in vocational training for the built environment (Akinradewo et al., 2024). Collectively, these studies confirm that AR-based interventions are increasingly recognized as concrete instruments for advancing SDG 4, though none addresses computer assembly specifically.

However, research related to the development of AR-based computer assembly learning media is still quite limited, especially research that integrates 3D model visualization, function descriptions, tutorial animation, interactive quizzes, and usability testing using the System Usability Scale method. Previous literature on computer assembly has mostly used Virtual Reality technology, which requires special devices such as VR headsets (Umri et al., 2025). Therefore, the development of an AR-based computer assembly application on Android devices is highly crucial because it offers ease of access via smartphone, flexibility for independent learning, and functions as a pre-practicum simulation stage before students engage directly with actual hardware.

Beyond this technical gap, the novelty of this research also lies in its more precise framing. As shown above, AR and related digital tools have already been connected to SDG 4 in several other domains, but, to the best of the authors' knowledge, no study has yet applied this framing to AR-based computer assembly learning developed with the MDLC method and evaluated through the System Usability Scale. This research therefore contributes a dual novelty: extending AR-based visualization to the specific domain of Android-based computer assembly, and explicitly positioning the resulting low-cost, low-risk, and scalable learning platform, developed and evaluated using MDLC and SUS, as a digital innovation instrument that supports SDG 4 in the digital era.

Based on these conditions, this research develops an Augmented Reality-based computer assembly learning media application. The application is designed to display computer components in the form of 3D models, provide component function information, and display installation tutorial animation, so that students can learn computer assembly independently before conducting direct practice using physical hardware. This article is an

extended version of the authors' earlier work published in the Journal of Information System Management (Lubna et al., 2026), which reported the development and usability evaluation of the application. The present article substantially extends that work by situating the platform within the SDG 4 framework, adding a comparative evaluation against conventional practicum and the authors' earlier Virtual Reality-based simulation, and presenting a deeper analysis of the usability results together with an explicit statement of the study's limitations.

RESEARCH METHOD

This research is a Research and Development (R&D) study. The product developed is an Augmented Reality (AR)-based computer assembly learning media application for Android devices. The research focus is not only on building the application, but also on testing its functionality and evaluating its usability.

Augmented Reality is defined as a technology that combines the real world with virtual objects, runs interactively in real time, and places virtual objects within three-dimensional space (Azuma, 1997). In education, AR offers a different learning experience from conventional media by integrating digital information into the real world, making it suitable for learning that requires spatial, object, and process visualization (Radu, 2014). AR has also been shown to create a hybrid learning environment that combines digital and physical objects, supporting the development of critical thinking, problem-solving, and communication skills through more interactive learning activities (Akçayır & Akçayır, 2017). Related studies confirm AR's effectiveness across domains, including AR-based plant learning media developed with MDLC and evaluated at a usability score of 79.83 in the Good category (Setiawan et al., 2024); Android-based AR for introducing an adventure area using MDLC (Kamil et al., 2024); AR-based floor-plan application development using marker-based tracking and MDLC (Fahmizher & Hartono, n.d.); and AR-based mushroom-type learning media using marker-based tracking, evaluated with blackbox testing and SUS at a score of 74.78 in the acceptable-to-good category (Wardiana et al., 2025). These findings collectively establish a strong theoretical and empirical foundation for applying AR, marker-based tracking, and MDLC in this study.

The development method used is the Multimedia Development Life Cycle (MDLC). This method was chosen because it is suitable for developing interactive multimedia applications that combine 3D objects, animation, text, images, and user interaction. MDLC helps developers manage each phase of multimedia application production in a more structured and measurable way (Musthofa et al., 2024). Figure 1 below illustrates the MDLC flow used in this research, consisting of six stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution.

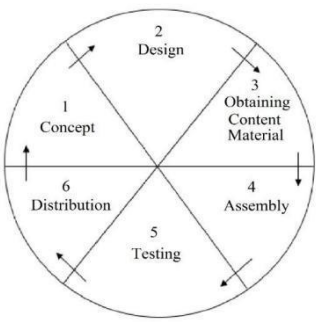


Figure 1. MDLC Flow

Concept

The concept stage is the initial stage to determine the basic concept of the application. At this stage, the application's objectives, target users, main features, and platform are determined.

This application is intended for information technology students or general users who want to learn the basics of computer assembly. The application was developed on the Android platform for easy access via smartphone.

The main features designed in the application include the following:

1. Play AR: a feature for scanning markers and displaying 3D models of computer components.
2. Component Description: a feature that displays information on the name, function, and characteristics of each component.
3. Tutorial Animation: a feature that displays the component installation process into the correct position.
4. Interactive Quiz: an evaluation feature to measure user understanding after studying the material.

Design

The design stage is carried out to design the application structure and user interaction flow. The design was carried out through the creation of a use case diagram, activity diagram, storyboard, and interface design.

The use case diagram is used to describe the interaction between the user and the system. Users can open the application, select the Play AR menu, scan a marker, view the 3D model, read the description, run the tutorial animation, and complete the quiz. The interaction structure and flow design for this research are illustrated in Figure 2 below.

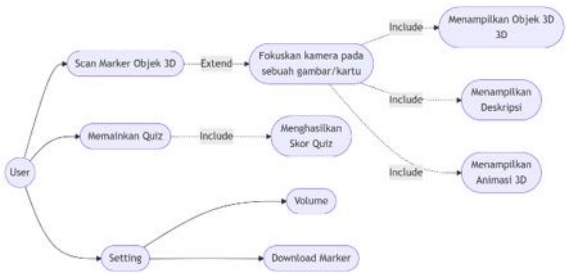


Figure 2. AR Application Use Case Diagram

The use case diagram describes user interaction with the main features of the AR computer assembly application. The user can use the Scan Marker 3D Object feature by focusing the camera on a marker image or card. Once the marker is detected, the application displays the 3D object, component description, and 3D animation as a learning guide. Users can also access the Quiz feature to answer questions and obtain a score as a comprehension evaluation. In addition, the Settings menu provides volume settings and a Download Marker feature. In general, this application supports interactive learning through visualization, animation, evaluation, and supporting settings.

The activity diagram is used to describe the activity flow of each feature. For example, in the Play AR feature, the user opens the AR camera, points the camera at the marker, the system recognizes the marker, and then the system displays the corresponding 3D object.

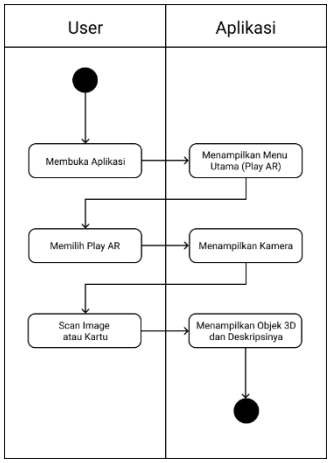


Figure 3. Play AR Activity Diagram

Figure 3 is an activity diagram explaining the flow of using the Play AR feature in the application. The process begins when the user opens the application, after which the system displays the main menu containing the Play AR feature option. After the user selects the Play AR menu, the application activates the camera. The user then scans an image or marker card using the device's camera. If the marker is successfully recognized, the application displays the 3D object along with the component description on the screen. The flow ends once the 3D object and its information have been successfully displayed to the user.

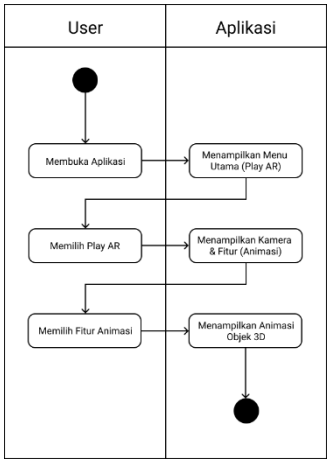


Figure 4. Animation Display Activity Diagram

Figure 4 is an activity diagram explaining the flow of using the Animation feature in the Augmented Reality application. The process begins when the user opens the application, after which the system displays the main menu containing the Play AR option. After the user selects Play AR, the application displays the camera along with additional features, one of which is the Animation feature. The user then selects the animation feature, after which the application displays a 3D object animation containing a simulation or movement of computer component installation.

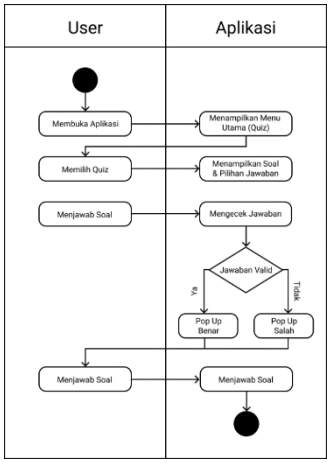


Figure 5. Quiz Menu Activity Diagram

Figure 5 is an activity diagram explaining the interaction flow between the user and the application in the quiz feature, starting from selecting the quiz menu, presenting questions, the answering process, answer checking, up to providing feedback in the form of a correct/incorrect pop-up.

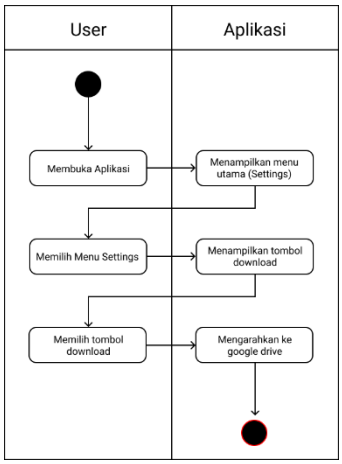


Figure 6. Download Marker Activity Diagram

Figure 6 is an activity diagram explaining the interaction between the user and the application in the process of accessing the Settings menu until the user is directed to Google Drive to obtain the marker file or AR marker card.

Material Collecting

Material Collecting is the stage of gathering all the materials or assets needed in developing the multimedia application (Kadek et al., 2024). At this stage, the developer ensures that all supporting components, such as text, images, audio, video, animation, three-dimensional objects, markers, icons, and interface elements, are available before proceeding to the assembly stage. Material Collecting serves as the foundation for the application integration process, since all collected assets will be used to build the application's main features (Jaza et al., 2024). In the context of this research, the Material Collecting stage was carried out by gathering and preparing 3D models of computer components, AR markers, component description texts, installation tutorial animations, menu icons, and UI elements to be integrated into Unity and the Vuforia SDK.

3D models of computer components were created using Blender. The components used in the application include the processor, motherboard, RAM, SSD, VGA, power supply, casing, and CPU cooler. Each model was created to resemble the shape of the actual component while remaining optimized so that it would not be too heavy to run on an Android device.

Assembly

The assembly stage is the process of combining all assets into Unity. At this stage, the 3D models, markers, interface, animation, navigation buttons, and interactive scripts are integrated into a single application.

The Vuforia SDK is used to enable the Augmented Reality function. Each marker is registered in the system and then linked to the corresponding 3D model. When a marker is recognized by the camera, the application displays the 3D model of the component on top of the marker. The use of Vuforia and Unity was also found in research on AR for geometric solids, in which markers were uploaded to the Vuforia database and then integrated into Unity to display 3D objects (Umri et al., 2023).

Testing

The testing stage is carried out to ensure the application runs according to the design. Testing was carried out using two approaches: blackbox testing and System Usability Scale evaluation.

Blackbox testing is used to test application functions without examining the program's code structure (Ariyana et al., 2023). This included Run Application, Button Clicks, Settings (Music), Quiz Scores, Marker Scanning, and Animation Display for each feature.

The System Usability Scale (SUS) is used to measure the level of application usability based on user experience. Respondents were asked to use the application and then complete the SUS questionnaire consisting of ten statements. The use of SUS is relevant, as it has been used in the evaluation of Android AR applications and VR-based computer assembly simulations (Amali, 2024). SUS data were collected through a questionnaire completed by 25 respondents from students of Universitas Duta Bangsa Surakarta. The questionnaire contained 10 questions based on the UI, animation display, interactive buttons, quiz, marker, and other aspects. The questionnaire results were then calculated using the five-point Likert scale method.

Distribution

The distribution stage was carried out by packaging the application in APK format so that it could be installed on Android devices. The packaged application can be distributed to users for learning purposes and further testing.

System Requirements Analysis

System requirements analysis was carried out to identify the main features, supporting devices, and technical specifications needed in developing the AR-based computer assembly learning media application. This stage is important because an AR application requires not only the design of learning materials, but also the integration of 3D objects, markers, device cameras, user interfaces, and development software. Previous research shows that Android-based AR applications can be used as interactive learning media because they are able to display virtual two- and three-dimensional objects into the real environment in real time (Musthofa et al., 2024). In addition, the use of AR in learning media has proven to help visualize objects that are difficult to understand through

conventional media, such as in geometric-solid learning that requires understanding of three-dimensional shapes.

Functional Requirements

Functional requirements are requirements directly related to the services or functions that the application must provide. In this research, functional requirements were formulated based on the application's objective, namely to help users recognize computer components and understand their installation procedures through AR visualization. The functional requirements of the developed application are as follows:

1. The application is able to display computer components in the form of three-dimensional objects, including the Processor, RAM, Motherboard, SSD, VGA, Power Supply, Casing, and CPU Cooler.
2. The application is able to perform marker scanning using the Android device's camera to display the 3D object corresponding to the detected marker.
3. The application is able to present descriptive information on each computer component, such as component name, function, characteristics, and role within the computer system.
4. The application is able to display installation tutorial animation for computer components so that users can understand the assembly stages visually, sequentially, and interactively.
5. The application provides a main navigation menu consisting of Play AR, Component Description, Tutorial, Quiz, Help, and Exit so that users can access features easily.
6. The application is able to provide an interactive quiz as a means of evaluating user understanding of the component material and computer assembly procedures.
7. The application is able to display quiz results or a final score as feedback on the user's level of understanding after using the application.
8. The application can run on Android devices so that the learning media can be used independently, flexibly, and easily accessed by users.

These functional requirements were formulated so that the application functions not only as a visualization medium, but also as a learning medium that provides information, procedural simulation, and evaluation.

Non-Functional Requirements

Non-functional requirements are supporting requirements related to hardware, software, the development environment, and technical aspects required for the application to run properly. In developing an AR application, non-functional requirements play an important role because the application requires a device with a camera, markers recognizable by the system, and supporting software to build 3D objects and integrate them into the Android application. Based on this, the non-functional requirements in this research are as follows:

1. Android Smartphone
2. Laptop or PC
3. Marker
4. Unity
5. Vuforia SDK
6. Blender
7. Figma
8. Android SDK
9. Android Operating System

Overall, these non-functional requirements are needed so that the application can be developed systematically, tested on real devices, and able to display 3D objects stably.

Beyond technical aspects, the application must also pay attention to usability aspects, such as ease of navigation, use efficiency, and user comfort. Previous usability evaluations of Android AR applications show that the System Usability Scale (SUS) method can be used to measure the effectiveness, efficiency, and ease of use of an application.

RESULT AND DISCUSSION

Application Development Results

The result of this research is an Augmented Reality-based computer assembly learning media application that can run on Android devices.



Figure 7. Application Display

Based on Figure 7, this application has several main features, namely the main menu, Play AR, component description, tutorial animation, and interactive quiz.

On the main menu page, users can select the feature they wish to use. The menu display is designed simply so that it is easy for users to understand. Navigation buttons are made clear so that users can move from one feature to another without difficulty.

The Play AR feature allows users to scan a marker using the Android device's camera. Once the marker is recognized, the application displays a 3D model of the computer component on top of the marker. Users can observe the model directly through the smartphone screen.

3D Computer Component Model Implementation

3D models of computer components were created using Blender. The components displayed in the application include the motherboard, processor, RAM, SSD, VGA, power supply, casing, and CPU cooler. Each model was designed to have a shape resembling the actual component.

The use of 3D models provides a better learning experience compared to two-dimensional images. Users can see the shape of the component more realistically, making it easier to understand the physical characteristics of each component. This approach is in line with research on AR for human internal-organ learning media, which shows that three-dimensional objects can provide a more engaging learning experience than two-dimensional objects (Musthofa et al., 2024).

Component Description Feature Implementation

The component description feature contains information on the component name, function, and role within the computer system. For example, the processor is explained as the component that functions as the central data-processing unit, RAM as temporary

memory, the motherboard as the main board connecting all components, and the power supply as the provider of electrical power.

This feature helps users not only recognize the shape of components but also understand the function of each component. Thus, learning focuses not only on visualization but also on understanding the basic concepts of computer hardware. Figure 8 below shows the display when the camera successfully detects the marker and displays the corresponding description on the marker.

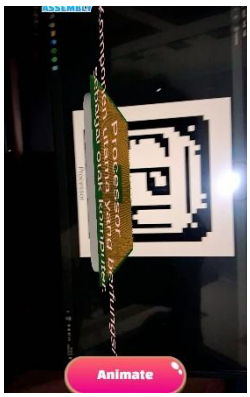


Figure 8. Display on the CPU Marker

Installation Tutorial Animation Implementation

Tutorial animation is one of the important features in this application. This feature displays a simulation of installing components into the correct position. For example, the processor installation animation shows the position of the processor relative to the socket on the motherboard. The RAM installation animation shows the movement of RAM toward the memory slot. The VGA installation animation shows the position of the VGA relative to the PCIe slot. The following is the animation display on the marker when scanned, as shown in Figure 9.



Figure 9. Animation Display on the CPU Marker

Tutorial animation helps users understand the installation procedure step by step. With movement visualization, users can see the installation direction, component position, and the relationship between components. This feature is expected to reduce errors when users perform direct practice using physical hardware.

Interactive Quiz Implementation

The interactive quiz is used as a learning evaluation feature. After studying the material through the AR feature, description, and tutorial animation, users can complete a quiz to measure their understanding.

Quiz questions may cover component functions, installation sequence, component position, and basic terminology in computer assembly. After answering the questions, users can view the results or score obtained. This feature aims to provide feedback to users regarding their level of understanding. The following is the display of the interactive quiz page, presented in Figure 10.



Figure 10. Quiz Menu Display

Blackbox Testing Results

Blackbox testing was carried out to ensure all application features run according to the design. Testing was carried out on several system components, such as navigation buttons, the marker scanning feature, 3D model display, description page, tutorial animation, and quiz.

The blackbox testing results in this research are presented in Table 1 below:

Table 1. Blackbox Testing Results

No	Feature Tested	Test Scenario	Expected Result	Status
1	Play AR Button	User presses the Play AR button	Application opens the AR camera	Valid
2	Scan Marker	Camera is pointed at the marker	3D model appears according to the marker	Valid
3	Component Description	User selects the description menu	Component information is displayed	Valid
4	Tutorial Animation	User presses the animation button	Installation animation runs	Valid
5	Quiz	User answers questions	System displays the quiz result	Valid
6	Back Button	User presses the back button	Application returns to the previous menu	Valid

Based on the blackbox testing results in Table 1, all main application features run according to their designed functions. This shows that the application has met the basic functional requirements as an AR-based learning medium. The application was also tested on 3 different smartphone devices. The test results are presented in Table 2 below:

Table 2. Smartphone Device Testing Results

No	Brand	Android Version	RAM	Result
1	Itel S23	Android 12	8 GB	Unsuccessful
2	Samsung S24 FE	Android 16	12 GB	Successful
3	Samsung Galaxy Tab S10 FE 5G	Android 15	8 GB	Successful

Based on the testing in Table 2, it can be concluded that the application runs on 2 out of 3 devices. On Device No. 1, the application did not run perfectly; there was a bug when running Play AR, and the camera could not be accessed, so marker scanning could not be performed. On Devices No. 2 and 3, the application ran smoothly, including Play AR, marker scanning, starting the Quiz, and Music settings.

System Usability Scale Evaluation Results

Application usability evaluation was carried out using the System Usability Scale. Respondents were asked to try the application first and then complete the SUS questionnaire. This questionnaire was used to determine user perceptions of ease of use, interaction comfort, and the application's feasibility as a learning medium. The final SUS score ranges from 0–100; the higher the SUS score, the better the application's usability level.

In general, the interpretation can be used as presented in Table 3 below:

Table 3. System Usability Scale Score Range and Category

SUS Score	Category
< 50	Not feasible / poor
50 – 68	Marginal
> 68	Acceptable
70 – 80	Good
> 80	Excellent

For each respondent, the SUS calculation was carried out as follows: for odd-numbered questions 1, 3, 5, 7, and 9, the contribution score equals the response value minus 1; for even-numbered questions 2, 4, 6, 8, and 10, the contribution score equals 5 minus the response value. All contribution scores are then summed and multiplied by 2.5 to obtain the final SUS score.

The usability evaluation instrument in this research used the System Usability Scale (SUS), consisting of 10 statements on a five-point Likert scale, ranging from strongly disagree to strongly agree. The questionnaire was administered to 25 respondents after they used the AR-based computer assembly learning media application. The statements in the questionnaire were adapted to the application's main features, namely Play AR, marker scanning, 3D model visualization, component description, tutorial animation, interactive quiz, and ease of navigation. The questionnaire results were then calculated to obtain the SUS score as the basis for assessing the application's level of usability, as presented in Table 4 below.

Table 4. System Usability Scale Evaluation Results (n = 25)

Resp.	1	2	3	4	5	6	7	8	9	10	Total Conv.	SUS Score
R1	5	1	4	2	4	2	4	2	4	2	32	80.0
R2	5	3	4	2	5	2	5	1	3	1	33	82.5
R3	5	3	4	1	4	2	4	2	4	2	31	77.5
R4	4	2	4	2	5	2	4	1	5	1	34	85.0

Resp.	1	2	3	4	5	6	7	8	9	10	Total Conv.	SUS Score
R5	4	2	4	2	3	2	4	2	5	2	30	75.0
R6	5	1	4	1	5	2	4	1	5	3	35	87.5
R7	3	2	5	1	5	2	4	2	3	1	32	80.0
R8	3	2	5	2	5	1	5	3	5	2	33	82.5
R9	4	2	4	2	4	2	3	2	4	2	29	72.5
R10	5	2	4	2	4	3	5	1	5	1	34	85.0
R11	5	1	4	2	3	3	4	2	5	2	31	77.5
R12	5	1	5	2	5	1	5	1	4	3	36	90.0
R13	4	2	5	2	4	1	5	2	4	3	32	80.0
R14	5	2	5	4	4	2	3	2	4	1	30	75.0
R15	5	1	4	1	3	1	4	1	4	1	35	87.5
R16	3	1	4	1	5	2	4	1	4	2	33	82.5
R17	3	2	3	2	5	1	4	2	5	2	31	77.5
R18	5	1	5	2	5	1	4	2	4	3	34	85.0
R19	5	2	3	1	4	1	4	1	3	2	32	80.0
R20	4	1	3	2	5	3	4	1	2	1	30	75.0
R21	5	2	3	2	4	2	5	1	5	2	33	82.5
R22	5	3	4	1	4	1	4	1	5	1	35	87.5
R23	4	2	3	3	5	2	4	2	4	2	29	72.5
R24	3	2	5	1	4	1	5	1	4	2	34	85.0
R25	5	3	5	2	4	2	4	1	4	2	32	80.0

Table 5. Summary of SUS Results

Description	Value
Number of respondents	25
Total conversion score of all respondents	810
Total SUS score of all respondents	2,025
Average SUS score	81.00
Highest SUS score	90.00
Lowest SUS score	72.50
Category	Excellent

Based on the System Usability Scale questionnaire recap presented in Table 5, from 25 respondents the total SUS score reached 2,025 with an average of 81.00. This score falls into the excellent category, so it can be concluded that the AR-based computer assembly learning media application has a good level of usability. These findings show that the majority of respondents rated the application as easy to use. Main features such as Play AR, marker scanning, 3D model visualization, tutorial animation, and quiz were easy to understand, and the application is feasible as a supporting learning medium for understanding computer assembly procedures.

Table 6. Final SUS Calculation Results

Number of Respondents	Total SUS Score	Average SUS Score	Category
25	2,025	81.00	Excellent

Table 6 above shows the final results of the System Usability Scale (SUS) calculation for the AR-based computer assembly learning media application. Based on the evaluation results from 25 respondents, a total SUS score of 2,025 was obtained with an average SUS score of 81.00. This value falls into the Excellent category, so it can be concluded that the application has a very good level of usability. These results indicate that the application is considered easy to use, its features are understandable to users, and the application is feasible for use as an interactive learning medium.

Further Analysis of SUS Results

To obtain a more detailed picture beyond the overall average, the SUS responses were further examined through descriptive statistics and sub-scale analysis. The System Usability Scale can be decomposed into two sub-dimensions, namely Usability, derived from items 1, 2, 3, 5, 6, 7, 8, and 9, and Learnability, derived from items 4 and 10. This decomposition allows the evaluation to distinguish between how easily the application can be operated and how easily it can be learned by first-time users. The results of this further analysis are presented in Table 7 below.

Table 7. Descriptive Statistics and Sub-Scale Analysis of SUS Results (n = 25)

Statistical Measure	Value	Description
Mean SUS score	81.00	Excellent category
Median SUS score	80.00	Close to the mean, indicating a symmetric distribution
Standard deviation	4.89	Relatively small dispersion among respondents
Minimum score	72.50	Still above the commonly used acceptability threshold of 68
Maximum score	90.00	Highest individual assessment
Usability sub-scale	81.38	Perceived ease of operating the application
Learnability sub-scale	79.50	Perceived ease of learning to use the application

As shown in Table 7, the standard deviation of 4.89 indicates that respondent assessments were relatively homogeneous, with no extreme outliers: the lowest individual score of 72.50 still exceeds the commonly cited acceptability threshold of 68, while the highest reached 90.00. The closeness of the median (80.00) to the mean (81.00) further suggests a symmetric distribution of responses rather than one driven by a small number of very high or very low assessments.

The sub-scale analysis shows that the Usability dimension (81.38) scored slightly higher than the Learnability dimension (79.50). Although both fall within a favorable range, the modest gap suggests that respondents found the application somewhat easier to operate than to learn initially. This pattern is plausible for marker-based AR applications, in which first-time users must first understand how to position the camera and marker before the 3D object appears, whereas subsequent interaction with the menus, animation, and quiz is more straightforward. At the item level, item 8 recorded the highest average converted score (3.48), while item 3 recorded the lowest (3.12), although the difference between individual items was small. These findings indicate that improvements to the initial guidance and marker-scanning instructions could be prioritized in future development.

Evaluation of the Platform's Contribution to Digital-Era Technological Innovation and SDG 4

Beyond the blackbox testing and System Usability Scale results reported above, this section evaluates the developed platform specifically against the conference's central theme of accelerating the achievement of the SDGs through innovation in technology in the digital era. This evaluation compares the AR-based computer assembly platform with two existing alternatives conventional practicum using physical hardware, and the previously developed

Virtual Reality (VR)-based simulation (Umri et al., 2025) across four dimensions relevant to SDG 4: accessibility, cost, safety, and scalability.

Table 8. Evaluation of the AR-Based Platform's Contribution to Digital-Era Innovation and SDG 4

Evaluation Dimension	Conventional Practicum	VR-Based Simulation (Umri et al., 2025)	AR-Based Platform (This Study)
Device requirement	Full set of physical hardware components	PC + Oculus Quest 2 head-mounted display, built with Unity	Ordinary Android smartphone
Accessibility	Limited to laboratory hours and availability	Limited to institutions owning VR headsets	Accessible anytime via a personal smartphone
Risk of hardware damage	High	None (fully virtual)	None (virtual overlay on marker)
Relative cost	High (hardware procurement and maintenance)	Moderate-to-high (specialized headset)	Low (uses an existing mobile device)
Usability evidence (SUS)	Not systematically evaluated in this study	**SUS = 74.63 (Grade B)**	**SUS = 81.00 (Excellent)**
Alignment with SDG 4 targets	Constrained by Target 4.a facility requirements	Partially supports Target 4.3 but limited by hardware cost (Target 4.4 barrier)	Directly supports Targets 4.3, 4.4, and 4.a through low-cost, safe, and accessible technical training

As summarized in Table 8, the AR-based platform offers the most favorable profile across all four evaluation dimensions. Unlike VR-based simulation, which still requires a dedicated head-mounted display and therefore reproduces some of the cost and access barriers it seeks to solve, the AR-based platform runs on an ordinary Android smartphone already owned by most students, eliminating additional hardware investment. In terms of usability, the AR-based platform also achieved a higher SUS score than the earlier VR-based simulation (81.00, Excellent, versus 74.63, Grade B), indicating that the Android-based AR approach is not only more accessible but also perceived as more usable by respondents. Combined with this usability evidence, the evaluation indicates that the platform is structurally better positioned to accelerate SDG 4 in the digital era: it removes the cost and infrastructure barriers identified in Target 4.4 and Target 4.a, while directly supporting the equal-access objective of Target 4.3. This evaluation therefore substantiates the platform's contribution as a concrete instance of technological innovation accelerating the achievement of the SDGs in the digital era, consistent with the theme of this conference.

Discussion

The application development results show that Augmented Reality technology can be used as a learning medium that supports computer assembly visualization. This application is able to overcome the limitations of conventional learning media that only display text and two-dimensional images. Through 3D models, users can see the shape of components more clearly and realistically.

The component description feature provides additional information that helps users understand the function of each piece of hardware. Meanwhile, tutorial animation helps users understand the installation procedure visually. The combination of 3D visualization, descriptive text, animation, and quizzes makes the application more interactive and suitable for independent learning.

Compared with previous research, this study shares similarities in the use of three-dimensional visualization and multimedia development methods. The VR-based computer assembly research focused on a fully virtual environment using Unity and the Oculus Quest 2 (Umri et al., 2025), whereas this research focuses on Android-based Augmented Reality, making it more easily accessible via smartphone. Research on AR for geometric solids and

AR for human internal organs shows that AR is effective for visualizing 3D objects in learning (Umri et al., 2023; Musthofa et al., 2024). Therefore, the application of AR to computer assembly has a strong theoretical and empirical basis.

From a practicum safety standpoint, this application can be used as a preparatory stage before students conduct direct practice. By learning the installation procedure through AR, students are expected to be better prepared when interacting with physical hardware. This can help reduce installation errors and the risk of component damage.

Beyond its pedagogical benefits, these results also carry relevance for the SDG 4 agenda. By lowering the cost, facility, and safety barriers that often constrain access to hands-on technical practicum — particularly hardware components and laboratory space — the application widens equitable access to quality, hands-on technical education (United Nations Department of Economic and Social Affairs, n.d.). An SUS score of 81.00 (Excellent) further suggests that this kind of AR-based digital innovation is not only functionally sound but also usable enough at scale to be adopted more broadly across information technology programs, supporting the digital-era transformation called for under the conference's SDGs theme.

Limitations of the Study

Several limitations of this study should be acknowledged. First, the evaluation conducted in this research measured usability rather than learning effectiveness. The System Usability Scale captures how users perceive the ease and comfort of using the application, but it does not establish whether the application improves students' actual understanding of computer assembly procedures. Accordingly, the findings should be interpreted as evidence of the application's feasibility and acceptability as a learning medium, not as evidence of improved learning outcomes.

Second, the evaluation involved 25 respondents drawn from a single institution, and the respondents' academic backgrounds and prior experience with computer assembly practicum were not systematically recorded. The sample size and its institutional scope therefore limit the generalizability of the results to broader student populations. Third, no control group or comparison with conventional learning media was included, so the results cannot be attributed causally to the use of Augmented Reality.

Fourth, device testing revealed that the application did not run successfully on one of the three devices tested, in which the camera could not be accessed and marker scanning could not be performed. The underlying cause of this incompatibility was not investigated further in this study. Since marker-based AR depends directly on camera access and device capability, systematic compatibility testing across a wider range of Android devices, operating system versions, and camera specifications remains necessary before the application can be deployed at scale.

These limitations do not invalidate the results reported above, but they define the boundaries within which the findings should be read and point directly to the priorities for further research outlined in the following section.

CONCLUSION

Conclusion

Based on the development and testing results, it can be concluded that an Augmented Reality-based computer assembly learning media application was successfully developed using the Multimedia Development Life Cycle method. The development stages included Concept, Design, Material Collecting, Assembly, Testing, and Distribution.

This application has main features in the form of Play AR, component description, installation tutorial animation, and an interactive quiz. The Play AR feature can display 3D models of computer components through marker scanning. The description feature helps users understand the function of each component, while tutorial animation helps users understand the installation procedure visually.

The blackbox testing results show that the application's main features run according to their design. Evaluation using the System Usability Scale can be used to determine the application's level of usability based on user experience, with an average score of 81.00 in the Excellent category. Thus, this application is feasible for use as an interactive learning medium to help students understand computer assembly material, while also contributing a low-cost, low-risk, and scalable digital innovation that supports the achievement of SDG 4 (Quality Education) in the digital era.

Recommendations

Further application development can be carried out by adding more computer components, such as a hard disk, SATA cables, casing fans, thermal paste, heatsinks, and other peripherals. Adding components will make the learning material more complete.

In addition, the application can be developed using a markerless AR method so that users do not need to use a marker card. The development of markerless AR is also relevant, as usability research on Android AR shows that a markerless approach can provide a very good level of manipulability and comprehensibility.

Development can also be carried out for the iOS operating system so that the application can be used by more users. From an evaluation standpoint, further research can add learning-effectiveness testing by comparing student learning outcomes before and after using the application.

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