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Designing Interactive Learning Media Using Mobile Augmented Reality for Electrical Circuit Education

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Abstract: This research aims to develop interactive Augmented Reality (AR)-based learning media for electrical circuit courses. The method used is prototype development, with three stages: user needs analysis, prototype development, and pilot testing. In the first stage, the needs of users such as students and lecturers were identified through interviews and questionnaires, which showed 90.9% of students supported the use of AR to improve their understanding. The second stage involved designing 3D objects and their integration into the AR application using Blender and Unity. Testing was conducted through the black box method to assess the functionality of the application. The results showed that the application functioned well, especially in visualizing the concept of electrical circuits interactively. This application facilitates understanding through 3D simulations, videos, and practice questions, and can be accessed through mobile devices. In conclusion, this AR-based learning media is effective in supporting the teaching and learning process of electrical circuit courses.

Keywords: Augmented reality; Educational technology; Electrical circuit; Mobile learning

Introduction

Technological developments at this time are increasingly sophisticated in various fields, especially in the field of education (Almufarreh et al., 2023; Amani, 2021; Kovalchuk et al., 2023). Indonesia is currently adjusting and keeping pace with technological developments in the field of education (Ismail et al., 2023; Pakpahan et al., 2023; Rulinawaty et al., 2023). One of the government's efforts in preparing education graduates in this technological era is to implement a technology-orientated curriculum in every learning process (Ahyanuardi et al., 2020; Widjaja, 2023). Encouraged by the rapid development of world technology both for the development of learning innovations and in the completeness of educational facilities and infrastructure (Adi et al., 2021).

In the development of learning innovations, Souza et al. (2024) have conducted literature review research related to concepts, innovative technologies, learning approaches, and trending topics in education 4.0. Learning innovations that are currently developing include media innovations using mobile learning, Virtual Reality (VR), Augmented Reality (AR), and Artificial Intelligence (AI). This learning innovation can certainly create opportunities for researchers and educators to develop media that can help the learning process to be better and optimal (Daryanes et al., 2023; Eradze et al., 2023; Rajaram, 2023).

Learning media is one of the factors that can affect the quality of education (Lin et al., 2023; Qureshi et al., 2023). Choosing and using learning media that is appropriate to the context of the learning material provided is one way to produce and improve the quality and effectiveness of learning (Racionero-Plaza et al., 2023; Prasetya et al., 2023; Sanulita et al., 2023). Learning media is a device that can be used as a communication tool to support the interaction between educators and students in learning (Arifianto & Izzudin, 2021; Liu,

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2022). Learning media can be both hardware and software.

One of the learning media tools that is currently developing to be able to help the learning process is a smartphone (Boari et al., 2023; Hidayat et al., 2023; Indahsari et al., 2023). Smartphones are devices that are easily accessible and owned by most people, providing a great opportunity to optimise the teaching and learning process. According Ash-Turner (2024), there are 4.88 billion smartphone users worldwide, which means that by 2024 60.42% of all people will own a smartphone. On the other hand, 73.2 million people in Indonesia, or 27.4% of the total population, are smartphone users. In addition, the results of observations made on students on campus about smartphone users show that all students have a smartphone on average.

Smartphones, as portable and easily accessible devices, are now an important tool in supporting the teaching and learning process (Abduljawad & Ahmad, 2023; Chindia & Wawire, 2024; Salhab & Daher, 2023). Besides being able to access various educational resources anytime and anywhere, smartphones also enable the use of technologies such as Augmented Reality (AR), which can improve the quality of learning. This technology is increasingly used in various fields, including in teaching concepts that require detailed visualisation, such as electrical circuit courses. In the context of higher education, especially in electrical circuit courses, AR has great potential to improve students' understanding of complex material.

Electrical circuits are one of the fundamental courses for electrical engineering students. This course is often challenging due to its abstract concepts and requires an in-depth understanding of both theory and practice.Visualisation of electrical circuits, either in the form of two-dimensional images or computer simulations, is often not enough to make students truly understand the relationship between electrical components such as resistors, capacitors, inductors, and voltage sources. This makes the learning of electrical circuit courses require more interactive and dynamic media to explain how these components work in an interrelated system.

Based on the results of the needs analysis from interviews with lecturers and student questionnaires, the development of Augmented Reality (AR) based learning media is needed to improve student understanding and engagement. Currently, the learning methods used are still limited to whiteboards and PowerPoint, which are less than optimal in displaying real-time simulations. Lecturers acknowledge the need for more interactive media, such as AR, for the visualisation of electrical circuit components. Based on a questionnaire from Electrical Engineering students, 78.6% of the total 56 respondents experienced difficulties in understanding this course, mainly due to the dense material and limited lecture time. The need for a more effective learning strategy is increasingly clear, given the importance of a deep understanding of electrical circuits to support advanced courses such as electrical machinery and power generation.

To overcome the learning problems faced, researchers developed mobile-based learning media with Augmented Reality (AR) technology. AR was chosen because it can create an immersive learning environment, allowing learners to interact with real-world simulations and interactive learning resources such as video, audio, animation, and 3D objects (Dargan et al., 2023; Sriadhi et al., 2022; Hidayat et al., 2024; Waskito et al., 2024). The application of AR in learning electrical circuits can clarify concepts that are difficult to understand through conventional methods. For example, concepts such as Kirchhoff's law, Ohm's law, or the time response of RC and LC circuits can be explained more easily through interactive visual representations. Students can see firsthand how changes in one component can affect the entire circuit. This not only enhances theoretical understanding, but also helps students in developing analytical and problem-solving skills.

In addition, the use of AR in learning electrical circuits allows students to learn independently outside the classroom. Using AR-based learning media, students can access materials anytime and anywhere through their devices. This is very helpful in increasing students' engagement in the learning process, as they can repeat the material and virtual experiments as needed without time or place restrictions. This flexibility is an invaluable advantage in supporting an effective and efficient learning process.

In the context of higher education in Indonesia, the utilisation of AR as a learning medium is still relatively new and has not been widely applied. However, along with the development of technology and the need for innovation in the learning process, more and more institutions are starting to adopt this technology to improve the quality of education. The electrical circuit course in the electrical engineering study programme is one of the potential areas to integrate AR in the learning process, given the high need for visualisation and interaction in understanding electrical concepts.

Therefore, the design of Augmented Reality-based learning media for electrical circuit courses in higher education is an innovative effort that can help overcome various challenges in learning. In addition to increasing student understanding and engagement, the use of AR can also change the way lecturers deliver complex material to be more easily understood. The purpose of this article is to create a prototype application that serves

as an interactive and alternative media. It is hoped that this research will be a reference for developers and educators in learning electrical circuits that have applications in the academic world.

Method

The method used in designing learning media using augmented reality-based mobile is a prototype development model. It is hoped that the system in this method can develop into interactive media that presents interactive learning media in electrical circuit courses. According (Fortuna et al., 2023), the prototype model was developed in three stages. The following diagram shows the path of the steps:

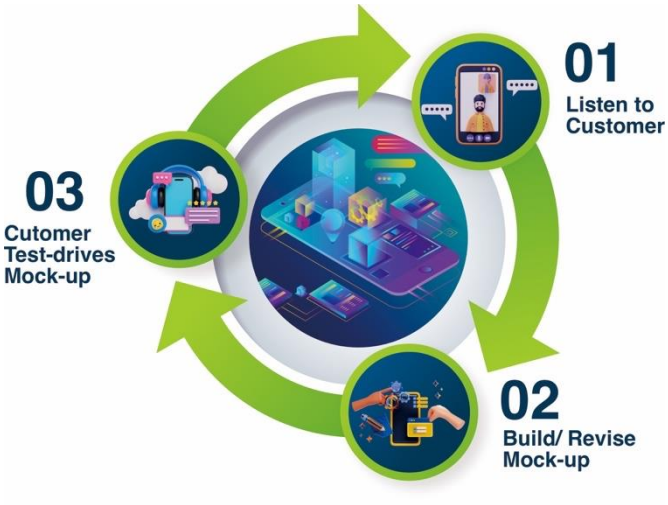

Figure 1. Prototyping method

In the first stage, i.e. listening to users, the developers met with target users - such as students, and course lecturers to establish clear educational objectives and collect comprehensive data. This data is sourced from various references including literature reviews, textbooks, academic papers, journals, and other relevant materials related to interactive learning media development. In the context of designing interactive learning media using mobile Augmented Reality (AR) for electrical circuit education, this phase is critical to understanding user expectations, technical requirements, and content relevance. A thorough needs analysis is conducted during this stage to identify key areas of electrical circuit theory and practical applications that should be incorporated into the AR experience. This process ensures that the learning medium is aligned with the curriculum, enhances learner engagement, and addresses existing challenges in understanding complex electrical circuit concepts. In addition, feedback from users helped determine which specific features, such as interactive simulations, real-time problem solving, and immersive visualisations, most effectively supported learning outcomes. This careful collection of data and feedback formed the foundation for developing a robust, user-centred AR learning tool.

In the second stage of the Design of Interactive Learning Media Using Mobile Augmented Reality for Electrical Circuit Education, the development or revision of mockups for prototype design is actively carried out using software, which is tailored to the specific needs of users-such as students and educators in the field of electrical engineering. The first step was to create 3D objects representing electrical circuit components, which was done using Blender, a 3D modelling application. Once the 3D assets, such as resistors, capacitors, and circuit boards, were created, they were exported to Unity, Android Studio, and Vuforia SDK. These tools allow the 3D models to be integrated into an interactive Augmented Reality environment. Finally, the application was compiled into a functional mobile AR application that aligned with the system requirements, offering users an immersive hands-on learning experience to learn about electrical circuits. This process ensures that the AR medium not only visualises electrical concepts but also enables interactive simulations that enhance learners' understanding.

In the third stage of the Interactive Learning Media Design Using Mobile Augmented Reality for Electrical Circuit Education, the target users, such as university students in conducting trials to evaluate the developed prototype, to ensure it has met their educational needs. The application undergoes a black box testing process, focusing on whether the AR-based learning tool works as intended, especially in visualising and interacting with the concept of electrical circuits. If the testing showed that the app did not fully match the user's expectations or course requirements, the development team would reassess and address the shortcomings. These improvements are made by following the established development methodology to refine the AR learning tool and ensure that it effectively enhances students' understanding of electrical circuits.

Result and Discussion

Result

The research results on the development of interactive learning media prototypes using Augmented Reality (AR) in electrical circuit education begin with the listen to customer stage which focuses on analysing the needs of users, which is an important basis in designing the concept of the system to be built. Next, the build/revise mock-up stage is creating an initial prototype (mock-up) that reflects the desired design.

Furthermore, the customer test-drives mock-up stage is testing through the black box testing method to assess the functionality of the application. This process ensures that the resulting application can function according to the design that has been made.

Listen to Customer

The listen to customer stage is done by analysing the needs in the development of interactive learning media using Augmented Reality (AR) for electrical circuit education. The needs analysis was conducted through questionnaires and interviews to identify the challenges faced in learning. The results show that 78.6% of students have difficulty in understanding this course, and the learning media used today is considered less interesting. Most students (73.2%) recognised that learning media could improve their understanding, and 90.9% of them supported the use of AR as a learning tool. Meanwhile, interviews with lecturers revealed that current learning methods are still limited to traditional media, such as whiteboards and PowerPoint, which are not interactive enough to show real-time simulations. Lecturers expressed the need for learning media that can present visualisation of electrical circuit components in real-time, with great potential for using AR technology.

AR-based mobile learning media is developed based on identified needs, ensuring optimal user experience. In addition, this application offers visualisation of electrical materials with physical structure analysis represented in the form of 3D objects, circuits and simulations, allowing students to better understand the concept of electrical circuits. AR technology that can be accessed through smartphones allows students to learn the material outside the classroom, increasing the flexibility and effectiveness of learning, and the application is designed to be easy to navigate by providing Augmented Reality menu, marker menu, learning video menu, and question and discussion menu, so that students can learn independently and interactively.

Build

The build stage in the design of interactive learning media based on Mobile Augmented Reality (AR) for electrical circuit education includes designing and creating interfaces and application functions. At this stage, researchers design and create initial prototypes (mock-ups). After the mock-up is created, revisions are made based on feedback from users or testers. This process includes improving visual elements, user interaction, and adjusting AR features to suit the needs of learning electrical circuits. This revision continues until the mock-up is suitable for the next stage of development. The build/revise stage consists of design that produces use case diagrams and activity diagrams, while the manufacturing process produces a prototype display of learning media applications.

Use case diagram is used to explain the functionality of the system from the user's point of view. The diagram illustrates the interaction between the user and the system, showing how the user utilises the features in the AR-based learning media in the electrical circuit course. This use case maps the scenario of using the system by users to visualise electrical circuits through Augmented Reality technology. The design of the use case diagram made in this study is in Figure 2.

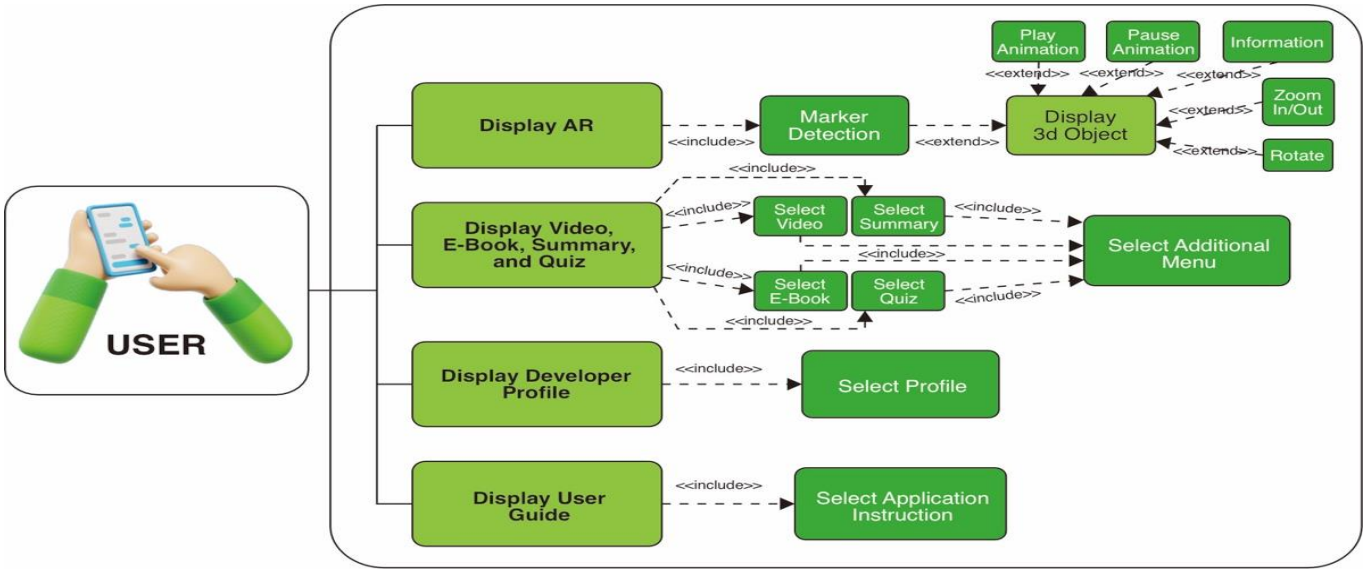

Figure 2. Use case diagram

Figure 2 shows the interaction between users and various features in augmented reality (AR)-based applications. Devices such as cameras, display screens, and special tools are required to interact with virtual

objects in AR. When the application is run, the camera automatically detects objects from predefined markers, then displays 3D objects. Users can choose to display AR features that involve marker detection and display animations that can be rotated, paused, and zoomed or rotated. In addition, users can access various media such as videos, e-books, summaries, and quizzes through an additional menu. The app also provides an option to view the developer's profile and a user guide that includes instructions on using the app.

In addition to creating a use case diagram, researchers also create an activity diagram that serves as a guide to the flow or activity in the use of AR-based learning media. This diagram is designed in the form of a blueprint to model the workflow, with a grouping of views of the system built using dissemination. This activity diagram displays the sequence of activities that occur in the application, according to the event model in the use case diagram. This activity diagram process is shown in Figure 3.

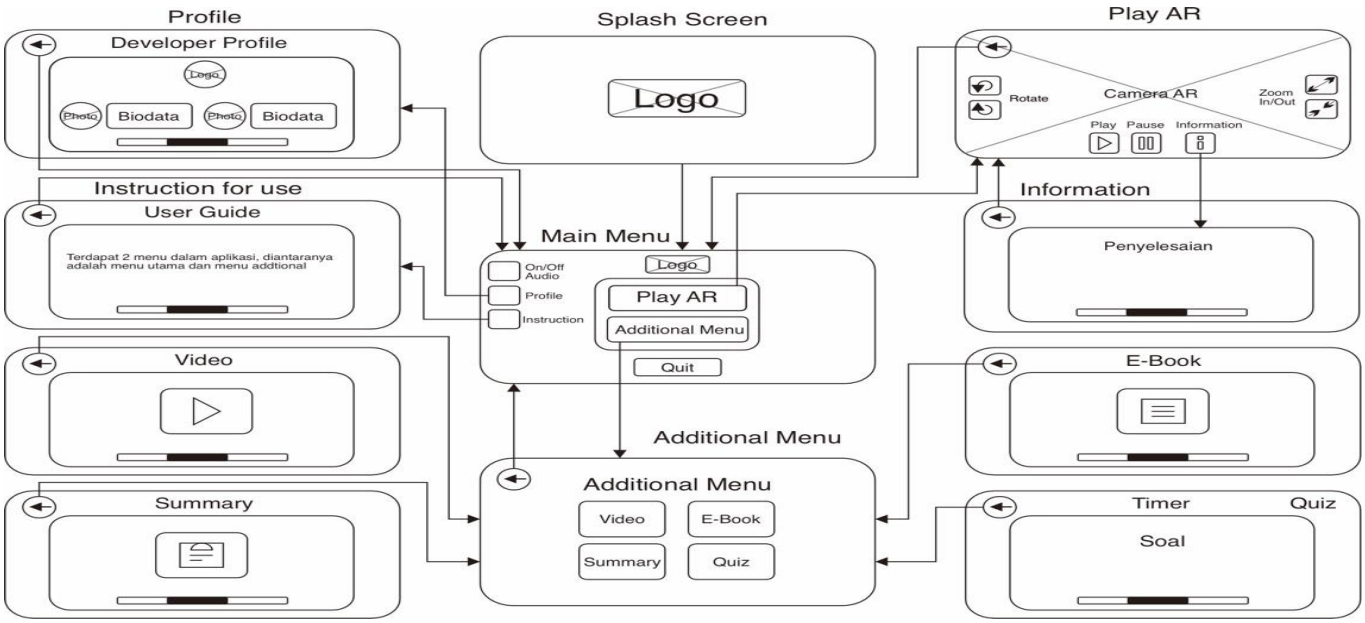

Figure 3. Activity diagram

Figure 3 shows the interface and navigation between pages in the Augmented Reality (AR) based application. The activity diagram starts from the Splash Screen that displays the application logo, followed by the Main Menu that provides several main options such as Play AR, Additional Menu, Profile, and Instruction. In the Play AR menu, users can utilise the AR camera with features such as Rotate, Zoom In/Out, and Play and Pause animation controls. The Additional Menu directs users to additional content, including Video, E-Book, Summary, and Quiz. The Profile menu allows access to the developer's bio, while the User Guide provides instructions for using the app. Each menu has a back icon for easy navigation between pages. This diagram includes interaction flows that make it easy for users to efficiently access the app's various features.

After the results of the design process, the results of the manufacture are obtained which results in the appearance of the main menu page. The results obtained from making learning media using augmented reality-based mobile are the initial appearance of the learning media application, especially on the main menu, which functions as a home page that regulates user navigation in running the application according to the guidelines provided, until exiting. This main menu includes several sub menus, including developer profile, play AR sub menu, information on the play AR series, Application Usage Instructions feature, additional menu features, video features, e-book features, summary features, and quiz features.

(a) Main menu (b) Developer profile

Figure 4. Display of the main menu and developer profile

The main menu of the AR-based learning media application is shown in Figure 4 (a). The Play AR button is one of the features that will take users to the camera feature that converts 2D photographs into 3D. Additionally, there is another menu with several submenu features, such as a quiz, e-book, video, and summary. The developer profile, sound volume options,

and application usage instructions are among the features located in the left-hand corner. The developer profile that creates this AR-based learning media application is displayed in Figure 4 (b).

(a) Application Instructions (b) Play AR Menu

Figure 5. Application instructions display and play AR menu

Figure 5 (a) shows the display of the AR-based learning media application's instructions for use feature. The user manual page provides an explanation of the functions of the buttons and features of the learning media, as well as instructions on how to run Augmented Reality. Figure 5 (b) shows a Play AR display that can convert 2D photos to 3D using a camera capability. Among the many capabilities of the Play AR display is the play feature, which runs the 3D circuit simulation. To momentarily halt the 3D circuit simulation, use the pause option. The form of the 3D circuit image is rotated to the left and right by the rotating feature on the left. Zoom-in and zoom-out buttons are located on the right side of the screen, respectively, to enlarge and reduce the size of the 3D circuit image. Multiple video, e-book

(a) Information feature (b) Additional menu

Figure 6. Display of information feature and additional menu

Figure 6 (a) shows the information used to complete the current, voltage, and resistance calculations for each circuit that appears in the figure. You can drag or move the information to any explanation or solution related to the circuit. While the video feature, e-book feature, the summary feature, and quiz functions are included in Figure 6 (b).

(a) Video sub-menu (b) E-book sub-menu

Figure 7. Display of video sub-menu and e-book sub-menu

Short movies are used to help students review and repeat what they have learned. Figure 7 (a) is a representation of a video submenu. As seen in Figure 7 (b), the e-book sub-menu provides a digital book summary of the entire content.

(a) Summary sub-menu (b) Quiz sub-menu

Figure 8. Display of summary sub-menu and quiz sub-menu

The summary submenu display, intended to give a broad overview of the content covered in the electrical circuit course, is seen in Figure 8 (a). On the other hand, Figure 8 (b) shows the quiz submenu display that uses the AR-based learning media application to gauge students' understanding of the electrical circuit course material.

Customer Test-drives Mock-up

The final stage, the testing stage is an important process for finding errors in an application. A good test case must be able to reveal hidden errors, and testing is declared successful if it successfully detects errors that were not previously found. One of the methods used in application testing is Black Box Testing (Altulaihan et al., 2023; Fatmawati et al., 2023). Where testers only focus on inputs and outputs without knowing the internal details of the system being tested.

Black Box Testing is used to ensure that all application functions run according to the target and user needs. This test involves testing various cases, both valid and invalid, to check whether the application functions as it should. In the context of electrical circuit learning, this test ensures that features such as electrical circuit visualisation and Augmented Reality interaction can run well and effectively in supporting students' understanding of the material.

Table 1 shows the results of Black Box Testing on Mobile Augmented Reality-based learning applications designed to support electrical circuit education. This test involves various test scenarios designed to evaluate the functionality of each application feature. In the Main Menu section, users are asked to select menus such as Play AR and other sub-menus, with the results showing that the application successfully displays the appropriate page based on the selected menu. In addition, when the user selected Developer Profile, Application Instructions, and Information Feature, the app was able to display these pages perfectly, confirming that the user interface was well-designed and easily accessible. Tests on the AR feature showed that the app's camera was able to detect the indicated

marker and visualize a 3D simulation of an electrical circuit, which is a key element of AR-based learning.

Further testing of additional features such as Learning Video, E-book, Summary, and Quiz also showed positive results. These features successfully displayed learning video content, e-books, material summaries, and quiz questions, all of which functioned well. These test results show that the app is able to provide an interactive and rich learning experience, with various learning resources available in one platform. By utilizing Augmented Reality technology, this application not only facilitates the real visualization of electrical circuit components but also provides flexibility in the teaching and learning process, allowing students to access materials outside the classroom.

Table 1. Application Black Box Testing

Testing	Test Scenario	Succes Parameters	Test Results	Category
Main Menu	Select Play AR, and additional	Move to the next page according to the menu that has been selected.		Succeed
Developer Profile	Select the developer profile	Developer profile page successfully displayed		Succeed
Application instructions	Select the application instructions feature	The application instructions feature page is successfully displayed		Succeed
Play AR Menu	The camera focused on electrical circuits marker	The electrical circuit image on the marker can display a 3D circuit simulation		Succeed
Information feature	Select the information feature	The information feature page is successfully displayed		Succeed
Additional Menu	Select the additional menu	Move to the additional sub menu display page that features videos, e-books, summaries, and quizzes.		Succeed
Learning video feature page	Select the video feature	Learning video successfully displayed		Succeed
E-book feature page	Select the e-book feature	E-book successfully displayed		Succeed
Summary feature page	Select the summary feature	Summary successfully displayed		Succeed
Quiz feature page	Select the quiz feature	Quiz successfully displayed		Succeed

Discussion

The development of Mobile Augmented Reality (AR)-based learning media for electrical circuit education, as shown in this study, begins with the user needs analysis phase through the listen to customer stage. This stage is important to understand the

fundamental needs of users, which will form the basis of designing learning media. Based on the survey results, it was found that most of the students experienced difficulties in understanding the concept of electrical circuits and felt that the existing learning media were less interesting. Interestingly, 90.9% of students support the use of AR technology as a learning tool. The results of interviews with lecturers also show that more interactive and visual learning media are needed, especially those that can facilitate real-time simulation of electrical components. Therefore, this AR application is designed to meet these needs, with the main feature being the visualization of electrical circuits in 3D that can be accessed through a smartphone. Other studies supporting the use of AR in learning have also found that this technology can improve students' understanding and engagement in technical and visual learning (Q. Liu et al., 2023; Oueida et al., 2023; Sidiq & Muskhir, 2020; Tanjung & Louise, 2024).

In the build/revise mock-up stage, the development team designs a prototype of the app that reflects the interface design and desired functionality. This prototype is tested through user feedback to ensure that the app is performing as expected. After several revisions, testing was conducted using black box testing methods that focus on assessing input-output without knowing the internal details of the system. The results of this test showed that the main features of the app, such as Play AR, learning videos, e-books, and quizzes, functioned well. The process of visualising electrical circuits using AR was also successful, with the app able to display a 3D simulation of the circuit based on markers scanned by the camera. Previous research supports the use of black box testing as an effective method for evaluating the functionality of AR-based applications, ensuring that the application is not only functional but also fulfills the user's needs thoroughly (Braker et al., 2023; Fortuna et al., 2023; Pattiasina et al., 2024).

Conclusion

Augmented Reality-based learning media for electrical circuits course has been successfully developed with prototyping method, based on the results of functional and non-functional requirements analysis. Black box testing ensures all features, such as the main menu, user guide, learning video, 3D AR simulation, as well as exercises and question discussions, function as expected. The app is designed to facilitate interactive visualisation of electrical circuits, allowing students to learn concepts in greater depth. Limited user trials provided insights for further improvements, making this app relevant and effective in technology-based electrical circuit education.

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Author Contributions

Writing—original draft preparation, methodology, Analysis, AL; Conceptualization, review, MM; Editing, formal analysis, HE; Conceptualization, review, NJ.

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Conflicts of Interest

The authors declare no conflict of interest.

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