Can Mobile-Based Augmented Reality Improve Learning in Electrical Circuit Education?

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***Abstract*—This research aims to develop and validate an Augmented Reality (AR)-based mobile learning tool designed for electrical circuit courses, improving students' understanding through interactive simulations. This study adopted the Borg and Gall development model, which was simplified into five main stages: analysis, development, validation, pilot testing, and implementation. The study used a one-group pre-test-post-test design involving 30 students. The validation results showed high content validity, with scores of 0.81 from material experts and 0.93 from media experts, confirming its suitability for teaching. The practicality test revealed high usability, scoring 81.63% in the limited trial and 88.23% in the full implementation. The effectiveness test showed significant learning improvement, with an N-Gain score of 0.48 (medium) and t-test results (*p* = 0.001) showing statistically significant performance improvement. These findings highlight the ability of AR tools to improve engagement, understanding, and performance in electrical circuit courses, offering an immersive and scalable learning solution. However, the focus of this study was limited to electrical circuits, without exploring the adaptation of AR for other subjects. In addition, issues such as access to compatible devices and the digital literacy gap were not fully addressed. Future research should explore AR applications in other fields, examine the long-term impact on knowledge retention, and incorporate personalization features to increase inclusivity. This research contributes to the use of mobile AR in education, demonstrating its potential for wider adoption in engineering and technical disciplines.**

***Keywords*—augmented reality, electrical circuit, mobile learning**

I. Introduction

Mobile learning is a learning method that utilizes smartphone technology that can be used in various conditions to produce an effective learning process [1–3]. According to Ash Turner (2024), smartphone users worldwide are 4.88 billion, meaning that 60.42% of the world's population has a smartphone in 2024. In Indonesia, the number of Smartphone users is 73.2 million or as much as 27.4% of the total population [4]. In addition, from the observations of students on campus related to smartphone users, the results obtained are 100% that the average student has a smartphone. Smartphones have become essential to human life, similar to housing, food, and clothing. The fast-paced growth of smartphone technology is unavoidable, as individuals rely on these devices for communication, gathering information, and accessing knowledge through the internet [5].

Despite their potential, smartphones are not yet fully utilized for educational purposes. Most learners tend to use them primarily for activities like gaming, browsing social media, taking selfies, shopping online, and similar tasks [6, 7]. At the same time, smartphones have various features that can be utilized to access learning content easily and interactively [8]. The ability of smartphone technology is an opportunity in education to develop an innovation in learning to be more efficacious [9, 10].

In the current digital era, the use of mobile learning to utilize Augmented Reality (AR) technology as a learning medium has become a topic of increasing interest to researchers in the field of education for its ability to deliver immersive and interactive learning experiences [11, 12]. Empirical studies have demonstrated that AR enhances learner engagement and understanding through visual and interactive elements that align closely with real-world contexts [13, 14]. Research by Demircioglu (2023) found that using AR in science education significantly improved students' conceptual understanding and critical thinking skills [15]. By leveraging AR on smartphones, learning can occur anywhere, anytime, making the process more flexible and inclusive [16, 17].

However, although AR technology has been shown to provide benefits in an educational context, its use in highly technical courses such as electrical circuits is still limited. In this context, although there have been a number of studies that show the potential of AR to improve the understanding of abstract and complex material, the gap that still exists is the limited use of AR in electrical engineering courses, especially in teaching electrical circuits. This shows a gap in the existing literature, which encourages this research to further explore the application of AR in the context of learning electrical circuits to improve student understanding independently. This research aims to fill this gap by developing AR-based learning media that is more effective for use in electrical circuit courses, as well as increasing student interaction and understanding of the material more deeply.

The electrical circuit course is one of the basics in the scientific field of electrical engineering. Based on the needs analysis from interviews with lecturers and student questionnaires, the development of Augmented Reality (AR) based learning media in electrical circuit courses is needed. Interviews with lecturers reveal several important aspects that indicate the need for AR-based learning media. Although the current learning process goes according to plan, there is still room for improvement, especially in student engagement and understanding. Lecturers use adaptive learning methods to accommodate diverse learning speeds among students. However, the learning media currently used is still limited to whiteboards and PowerPoint. Although effective to some extent, these two media have limitations in showing real-time simulation and direct interaction with learning materials. Lecturers expressed the need for media that can display electrical circuit components in real time, which supports the idea of using AR.

While the needs analysis obtained from the questionnaire of electrical engineering students who have studied the electrical circuit course, there are important findings that indicate significant opportunities to improve the learning process. First, a large number of students (78.6%) out of a total of 56 people experienced difficulties in learning this course, indicating that the current learning method may not be optimal. The next problem is that the learning process followed by students is also limited by the short duration of lecture time, especially in the electrical circuit course which has very dense material. The need for a more effective learning strategy becomes clear, given the complexity of electrical circuit material that often requires visualization of abstract concepts. Several other studies were also found related to student difficulties in learning electrical circuit courses [18]. Even though the electrical circuit course is an important course for students. If students do not understand this course in depth, they will face obstacles in studying other courses related to electrical circuits, including electrical machinery courses, automatic settings, electrical builders, etc.

To overcome the various problems described earlier, researchers are trying to develop mobile-based learning media with Augmented Reality (AR) technology. Augmented Reality technology was chosen because it has shown significant potential in supporting the learning process. AR-based learning media can create an immersive learning environment for students [19]. AR-based learning media also allows learners to experience the learning process through simulations that resemble the real world and have access to various interactive learning resources such as video, audio, animation, or 3D objects [20, 21]. This research uses mobile devices as a medium to develop augmented reality technology. Learning media using augmented reality-based mobile has become an interesting research topic for researchers in the field of education. Some studies show that the application of augmented reality-based learning media improved both motivation and academic performance [22–26]. However, limitations of AR, such as the potential for technical issues and the need for compatible devices, must also be considered [27]. Addressing these challenges requires critical engagement with the strengths and weaknesses of Augmented reality to design effective educational tools.

Based on the background that has been described, the researchers made the development of learning media using mobile-based augmented reality to support the learning process independently. This learning media provides a choice to organize the learning process creatively, effectively, and fun. Especially seen in the selection of media that pay attention to the level of learning independence of learners. One of the learning media options that can be used is Augmented Reality (AR) in the context of electrical circuit courses. The utilization of AR aims to make it easier for students to understand the material in more depth independently. AR media provides opportunities for educators to develop materials and support learning strategies independently. AR media is expected to make learning materials easier for students to understand, motivate them to be active in learning, and develop thinking skills and creativity.

II. Methodology

A. Research Methods

This study uses the Research and Development (R&D) model. The R&D model is a development model in which the results of development are in the form of new products and procedures, where these products will be tested, evaluated, and refined to achieve the specified criteria both in terms of quality, effectiveness, and practicality [28].

The Borg and Gall technique offers researchers the ability to modify the stages of growth and features flexible, methodical procedures. A five-stage version of the Borg and Gall technique was developed by the Center for Policy Research and Innovation [29]. The Borg and Gall stages were reduced to five stages: a) analysis; b) development; c) validation; d) trial; e) implementation. The condensed methodology of the five stages analysis, development, validation, trial, and implementation makes them especially appropriate for this study and fits in nicely with the iterative nature of technology-based educational solutions.

The need for an organized yet workable framework that can support the quick prototyping and improvement needed for AR-based learning materials led to the choice of the Borg and Gall method, particularly its five-stage adaption. The reduced version of the 10-stage method reduces complexity while retaining rigor by concentrating on important stages pertinent to the development of educational technology. This streamlining allows the research to prioritize essential processes such as analysis, validation, and implementation without sacrificing depth. Although this simplicity reduces resource limitations and speeds up development, it may limit the amount of detailed feedback from intermediate processes. However, the time efficiency and practical emphasis required for AR-based educational advances justify the trade-off.

B. Research Procedures

The Borg and Gall method, which consists of 10 stages is simplified to 5 stages as simplified by the Center for Policy Research and Innovation [29]. The Borg and Gall stages were reduced to five stages; a) analysis; b) development; c) validation; d) testing; and e) implementation. The choice to reduce the Borg and Gall technique to five steps guarantees that the procedure stays effective and focused, especially while creating AR-based solutions. Nevertheless, this method might limit the chances for gradual feedback in between the initial phases. However, the advantages of resource optimization, simplified design, and quicker prototyping exceed any possible disadvantages, making the five-stage framework ideal for this research.

This research focuses on creating mobile-based learning media using augmented reality (AR) technology to improve the learning and teaching experience in electrical circuit courses. The development process follows several stages, as depicted in Fig. 1.

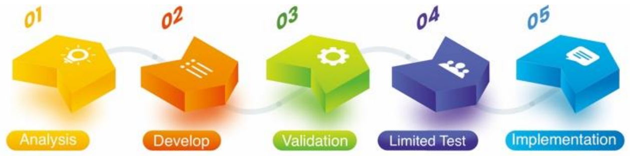


Fig. 1. The steps of research and development of the 4D model.

The research stages follow a systematic approach that includes several main stages: analysis, development, validation, limited test, and implementation. At the analysis stage, the focus was on understanding the current state of learning in the electrical circuit module and identifying trends in the use of AR (Augmented Reality) technology in education. This stage also included a literature review and the identification of educational needs, which resulted in survey findings and needs analysis publications. In the development stage, the design process begins with creating AR-based media prototypes and collecting objects for the application. After that, instrument testing and media design were completed.

The next stage is media validation and revision, which involves obtaining input from subject matter experts and AR-based learning media. This includes gathering input from experts, improving content, and ensuring the material is relevant. After validation, product trials were conducted on small groups of students to assess the practicality of the media. Suggestions from students are used to improve the media further. Finally, at the implementation stage, the AR-based learning media was tested in a real classroom environment, where its effectiveness and practicality were analyzed through the evaluation of learning outcomes in the electrical circuit course. The final results include practicability analysis data, effectiveness results, and publications.

C. Research Subject

This study involved seven experts, consisting of one instrument questionnaire expert, three material experts, and three media experts, to assess the validity of learning media using AR-based mobile in electrical circuit courses. Material experts assess the suitability of content with the curriculum, while media experts evaluate design, interactivity, and ease of use. User trials were conducted on 30 students of the electrical engineering department of the engineering faculty of Padang State University. These students were selected based on their involvement in the electrical circuit course, thus ensuring their relevance to the research objectives. The students provided feedback on the usability, concept understanding, and interactivity aspects, which then became the basis for improving the learning media. The user trial participants consisted of a balanced gender mix with representatives from different levels of academic achievement to capture diverse perspectives. However, it should be noted that all participants were from the same institution and department, which may limit the generalizability of the research findings. The research focus on a single institution may introduce institutional bias, as the results may reflect the unique characteristics of the faculty, curriculum, or resources at Universitas Negeri Padang, rather than the general higher education context.

D. Research Instruments Data

The research instruments were used to measure the validity, practicality, and effectiveness of the developed learning media. This instrument consists of validity, practicality, and effectiveness instruments. Some of the instruments used in this study are observation sheets to analyze material problems in electrical circuit courses and questionnaires used to obtain evaluations from experts and students regarding the learning media developed. The validity level of augmented reality (AR)-based learning materials in electrical circuit courses is assessed using a validation questionnaire as the validity instrument. Media and material professionals make up the validators.

This questionnaire is designed using a Likert scale and is filled in by validators after thoroughly assessing the media and learning materials. Although the Likert scale offers a methodical framework for evaluation, its application may result in biases like excessively favorable evaluations because of social desirability or misinterpretations of the scale's questions. Additionally, observation sheets could miss some subtleties of classroom interactions, which could restrict how thoroughly the information is analyzed. It is important to recognize and resolve these restrictions to guarantee the validity of the results. After being declared valid, the media was tested and implemented for students.

Students are given a questionnaire to complete to assess the usability of AR learning materials. Assessment factors like usability, time efficiency, and student comprehension of the content are incorporated into the practicality sheet's lattice. Data from this questionnaire is used to assess how the media can be applied effectively in learning. It is crucial to remember that response biases can skew self-reported data like that obtained from questionnaires. Due to these biases, students may give responses they feel are appropriate or expected rather than ones that reflect their true feelings, which could affect the evaluation as a whole. This could be lessened by using other qualitative techniques, such as interviews, to supplement the questionnaire data and provide a deeper understanding.

The product effectiveness instrument was assessed through a learning outcome test conducted before and after the use of AR media. The validity of the questions was tested using the biserial correlation coefficient formula, reliability with the Kuder Richardson 20 (KR-20) formula, and questions were assessed from the level of difficulty and differentiating power. Only questions deemed valid, reliable, and possessing strong discriminative characteristics were used to measure the improvement of student learning outcomes. This rigorous process ensures that the data collected from the tests accurately reflects the media's impact on learning effectiveness.

E. Data Analysis Technique

Instruments used in this study include validity instruments, practicality instruments, and effectiveness instruments. This study used a one-group pretest-posttest design, which is an experiment involving one group without a comparison group [30]. The effectiveness test was conducted in three learning series. Each learning series, before the treatment begins with a pretest and after the learning is done posttest. The product trial design is presented in Fig. 2.

Fig. 2. Research design on one group pretest posttest.

Description:

O1: Pretest on series 1 learning which was conducted before treatment.

O2: Pretest on series 2 learning which was conducted before treatment.

O3: Pretest on series 3 learning which was conducted before treatment.

X: Treatment is given to students by using AR-based mobile learning media.

O4: Posttest on series 1 learning which is carried out after being given treatment.

O5: Posttest on series 2 learning which is carried out after being given treatment.

O6: Posttest on series 3 learning which is carried out after being given treatment.

1) Analysis of media validity

The analysis technique used in learning media validation aims to assess and evaluate by experts in determining the feasibility of learning materials and media before proceeding to the testing stage and being used in the learning process. Media validity assessment was conducted using a Likert scale. The results of the product validity analysis were calculated using Aiken's V statistics presented in Eq. (1), while the validity assessment of this learning media is presented with two categories of validity levels contained in Table 1.

$$V = \sum s/[n(c-1)] \quad (1)$$

Description:

V = Index validated

S = r – Io

n = Number of validators

Io= The lowest validity score (in this case = 1)

c = The highest validity score (in this case = 5)

r = The number given by a validator

Table 1. The scale of validity criteria

No	Level of Achievement	Category
1	0.60–1.00	Valid
2	< 0.60	Not Valid

2) Analysis of media practicality

In the practicality analysis of the product, trial data were collected through questionnaires filled out by students participating in the trials. These questionnaires were designed to gather feedback on how well the developed media met learning needs and ease of use. The evaluation of media practicality was conducted using a Likert scale, which allows for measuring the degree of agreement or disagreement among respondents on various assessed aspects. The raw scores obtained from the questionnaires were collected from all respondents, summed up, and analyzed using specific calculation methods to determine the product's level of practicality. This analysis aims to provide a clear picture of the practicality of the developed media and identify areas that may need improvement or adjustment based on student evaluations. The results of the practicality analysis, calculated using Aiken's V statistics, presented in Eq. (2).

$$Practicality\ Score = \frac{\sum The\ score\ obtained}{\sum The\ expected\ score} \times 100\% \quad (2)$$

Description:

The score obtained = Total score of respondents

The expected score = Total number of maximum scores

After the practical results are obtained using the prescribed formula, the media criteria used by students can be determined. These categories include impractical, less practical, practical, and very practical, corresponding to the practicality scale shown in Table 2.

Table 2. The scale of practicality criteria

No	Achievement Results (%)	Category
1	0–25	Not Practical
2	26–50	Less Practical
3	51–75	Practical
4	76–100	Very Practical

3) Analysis of Media effectiveness

Effectiveness analysis is done by comparing student learning outcomes before using the media and after using AR-based learning media in electrical circuit courses. Effectiveness testing uses the one-group design method, with only one sample group without a comparison group. AR-based learning media is considered effective if the value of student learning outcomes after using the media is higher than before using the media. Testing the effectiveness of the media is done by using the classical completeness rate and gain score. To find out the percentage of students' classical completeness is calculated using the formula in Eq. (3), while the percentage determination based on the interval of learning provisions is presented in Table 3.

$$PK = \frac{JT}{JS} \times 100\% \quad (3)$$

Description:

PK = The percentage of completeness

JT = Number of completed students

JS = The total number of students

Table 3. The scale of media effectiveness criteria

No	Achievement Results (%)	Category
1	0–39	Very Less
2	40–55	Less
3	56–65	Simply
4	66–79	Good
5	81–100	Very Good

The effectiveness of this study was also evaluated through the gain score aspect, which is used to determine the improvement of student learning outcomes based on the difference between pretest and posttest scores. First, the test subjects were given a pretest, and a posttest was given after the learning was completed. After the individual student completeness data was obtained, the number of students who achieved completeness was calculated. Next, the pretest and post-test scores were compared. The increase in learning outcomes from pretest to posttest was analyzed using the N-Gain score formula found in equation 4 and for the gain score category in Table 4.

$$N - Gain = \frac{Spost - Spare}{Smaks - Spare} \times 100\% \quad (4)$$

Description:
Spost = The average posttest score
Spare = The average pretest score
Smaks = The ideal maximum score

Table 4. The scale of media effectiveness criteria

No	Achievement Results (%)	Category
1	N–gain > 70	High
2	30 ≤ N gain ≤ 70	Medium
3	N–gain < 30	Low

III. Result and Discussion

A. Result

This research aims to develop independent learning media using mobile-based Based Augmented Reality for Electrical Circuit courses that are valid, practical, and effective. This media development was carried out using the Borg and Gall model which was simplified into five stages: analysis, development, validation, trial, and implementation.

1) Analysis stage

The analysis stage aims to understand research trends in the use of AR technology in education, especially in the field of vocational technology. The results of this analysis show that the use of AR in the field of vocational education is still rare, with only 103 related publications between 2013 and 2023. Cluster bibliometric analysis shows the relationship between digital learning, learning outcomes, and the effectiveness of AR in improving understanding through interactive visualization.

A needs analysis was conducted through questionnaires and interviews to identify challenges in learning Electrical Circuits. The results show that 78.6% of students have difficulty understanding this course, and the learning media currently used is considered less interesting. Most students (73.2%) recognized that learning media could improve their understanding, and 90.9% supported using AR as a learning aid. AR provides real-time and interactive visualization opportunities that can strengthen the understanding of electrical circuit concepts.

From interviews with lecturers, it was 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 visualization of electrical circuit components in real-time, with great potential for using AR technology. AR technology can be accessed through smartphones, enabling students to learn the material outside of class, increasing the flexibility and effectiveness of learning.

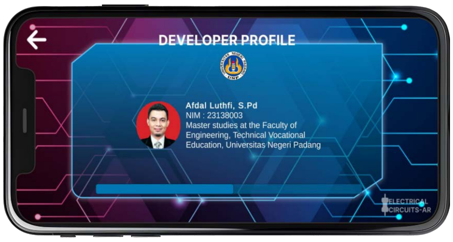
Finally, the analysis of the RPS shows the main materials that need to be visualized, such as the basic laws of electricity, series-parallel circuits, and Nodal and Mesh analysis. These materials were chosen because they are important for basic learning of electrical circuits. With AR, students can visualize components and current flow in 3D, helping them understand the material better. The simulation feature allows students to do deeper repetition and interaction, strengthening their understanding of the concepts taught.

2) Development stage

The development stage aims to make research products in the form of learning media using AR-based mobile in electrical circuit courses. This stage includes several steps, namely: (a) Sketching, by designing Mobile Based Augmented Reality learning media for electrical circuit courses; (b) Collection of design objects, which involves selecting material references that are relevant to the topics to be discussed. In addition, the objects needed such as UI/UX design for the application background, 3D images of each component in the electrical circuit, circuit animation, and simulation by the material on the electrical circuit; (c) Making Mobile Based Augmented Reality applications. There are several features in the application including:

Fig. 3 (a) is the main menu of the AR-based learning media application. Several features, including the Play AR button, will direct users to the camera feature used to make 2D images into 3D. Furthermore, an additional menu consists of several sub-menu features, including video, e-book, summary, and quiz. In the left corner, several features include sound volume settings, developer profile, and application usage instructions features. Meanwhile, Fig. 3 (b) shows the developer profile that makes this AR-based learning media application.

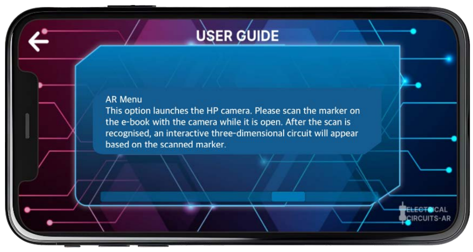
(a) Main menu



(b) Developer profile

Fig. 3. Display of the main menu and developer profile.

The directions for usage feature of the AR-based learning media application is displayed in Fig. 4 (a). In addition to providing instructions on how to operate Augmented Reality, the user manual page describes the features of the learning media and how the buttons work. A Play AR display with a camera capability that can turn 2D images into 3D is depicted in Fig. 4 (b). The play feature, which simulates a 3D circuit, is one of the Play AR display's many features. Use the pause option to stop the 3D circuit simulation temporarily.



(a) Application instructions

(b) Play AR menu

Fig. 4. Application instructions display and play AR menu.

Fig. 5 (a) shows the data used to complete the calculation of the current, voltage, and resistance for each circuit shown in the image. The data can be dragged or transferred to any explanation or solution about circuits. On the other hand, the available quiz, e-book, video, and summary elements are shown in Fig. 5(b).

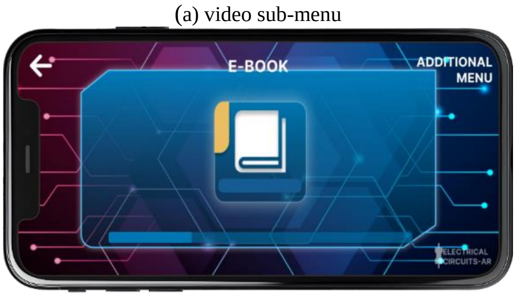
(a) Information feature

(b) Additional menu

Fig. 5. Display of information feature and additional menu.

Fig. 6 (a) is a video sub-menu display that serves to provide understanding to students in reviewing and repeating learning in the form of short videos. Fig. 6 (b) displays the e-book sub-menu, which summarizes the complete material in the form of a digital book.

(a) video sub-menu



(b) e-book sub-menu

Fig. 6. Display of video sub-menu and e-book sub-menu.

(a) summary sub-menu

(b) quiz sub-menu

Fig. 7. Display of summary sub-menu and quiz sub-menu

Fig. 7 (a) illustrates the summary submenu display, designed to provide an overview of the material covered in the electrical circuit course. In contrast, Fig. 7 (b) depicts the quiz submenu display to assess student comprehension of the electrical circuit course content through the AR-based learning media application.

3) Validation stage

Validation aim to ensure that the learning media has achieved the expected quality before the media is tested and implemented. Aiken's V value and the classification for instrument validity—which comprises practicality, media expert validation, and material expert validation—are shown in a table that summarizes the evaluation's findings. The instrument questionnaire validation consists of several aspects including clarity of instructions, accuracy of content, relevance, validity of content, unbiased, and accuracy of language. Table 5 is the result of the validity of the instrument questionnaire that will be used in the study.

Table 5. Instrument validation results

Instrument	Validation Results	Category
Material Expert Validation Sheet	0.89	Valid
Media Expert Validation Sheet	0.87	Valid
Product Practicality Sheet	0.82	Valid

The validity of the instrument sheet used to evaluate the product, media, and material specialists' viability is displayed in Table 5. According to the results, the material expert validation sheet had an Aiken's V value of 0.89, the media expert validation sheet had an Aiken's V value of 0.87, and the product practicality sheet had an Aiken's V value of 0.82. The three instruments' Aiken's V values, when categorized appropriately, range from 0.60 to 1.00.

Based on validators' recommendations, several enhancements were performed throughout the instrument validation phase. The Material Expert Validation Sheet was revised to include more specific explanations and refinement of less precise sentences; the Media Expert Validation Sheet was revised to improve sentences and separate double items; the Product Practicality Sheet was revised to rearrange irrelevant items and separate double items. Following the change, the tool was deemed more understandable and appropriate for research use.

After ensuring the validity of the instrument, the next step is to validate the material and media contained in the learning media using AR-based mobile in the electrical circuit course. Three media experts and three material experts were handed the media validation questionnaire. Learning design, learning quality, and the advantages of learning media are the three components of material validity. Additionally, there are three components for media validity: display quality, software and navigation, and interactive and communicative. Aiken's V statistical model was used to analyze the assessment findings for each aspect that the validators evaluated. These results contribute to the validation of the content found in AR-based educational materials. Tables 6 and 7 provide an overview of the material and media validation results from multiple perspectives.

Table 6. Material expert validation results

No	Material Aspect	Validators			Aiken's V	Category
		1	2	3		
1	Design of learning	0.94	0.70	0.80	0.81	Valid
2	Quality of learning	1.00	0.80	0.80	0.87	Valid
3	Benefit of learning	0.94	0.70	0.80	0.75	Valid
Average					**0.81**	**Valid**

Overall, the evaluation of the material aspects of the application yielded an average score of 0.81. Based on the validity assessment criteria, this score places the material expert's evaluation in the "valid" category, indicating that the application is appropriate for use as interactive AR-based learning media in electrical circuit courses.

Table 7. Media expert validation results

No	Media Aspect	Validators			Aiken's V	Category
		1	2	3		
1	Display quality	0.93	0.93	0.93	0.93	Valid
2	Navigation and software	0.95	0.95	0.95	0.95	Valid
3	Interactive and communicative	0.84	0.95	0.9	0.92	Valid
Average					**0.93**	**Valid**

The evaluation of the media aspects in this AR-based mobile learning application achieved an average score of 0.93. According to the validity assessment criteria, this score places the media experts' evaluation in the "valid" category, indicating that the application is suitable for use as AR-based interactive learning media in electrical circuit courses.

Although mobile AR-based learning media is declared valid for use, improvements are still made based on suggestions from media and material expert validators for further improvement. Improvements include improving the quality of 3D images, adjusting current flow animations, accurately reading measuring instruments, adding color codes to resistors, and improving the appearance of user guide features and quiz features. With this revision, the feasibility of learning media is better, and it is ready to be tested on a limited basis and implemented in learning.

4) Limited test stage

Limited test aim to obtain initial information on learning media that has been validated. Ten students who were enrolled in and had previously completed electrical circuit courses at Padang State University's Department of Electrical Engineering, Faculty of Engineering, were the subjects of the limited exam. In this small group, students were instructed to use augmented reality on mobile devices as an independent learning tool for electrical circuit classes. Students in this small group studied the material in the book by utilizing mobile-based augmented reality. Table 8 presents the practicality assessment of AR-based learning media. According to the findings of an examination of the usefulness of ten students' limited trials in the learning process of electrical circuit courses using AR-based learning materials, the usefulness of utilizing AR-based mobile devices has an average value of 81.63%, falling into the "very practical" category.

Table 8. Practicality test results on limited test

No	Media Aspect	Percentage (%)	Criteria
1	Ease of use	81.5	Very Practical
2	Efficiency of Time Use	81	Very Practical
3	Easy to Interpret	81.5	Very Practical
4	Has equivalence	82.5	Very Practical
	Average	**81.63**	**Very Practical**

5) Implementation stage

Implementation aims to test the use of learning media on a large scale. In the usage trial, experiments were carried out on 30 students who had studied the electrical circuit course. Based on the research agenda that has been carried out, researchers make observations of learning media using AR-based mobile in electrical circuit courses used by students in this usage test. At the last meeting, the researcher asked for student responses to the media that had been learned during learning. Student responses are used to assess the practicality of learning media using AR-based mobile in electrical circuit courses. The learning outcomes of students in electrical circuit courses before and after utilizing learning media with AR-based mobile devices demonstrate the medium's efficacy. Table 9 displays the findings of the practicality assessment derived from student replies. The practicality of using an AR-based mobile device has an average value of 88.23% with the category "very practical," according to the findings of the analysis of the usage trial conducted by students in the electrical circuit course.

Table 9. Practicality test results on implementation

No	Media Aspect	Percentage (%)	Criteria
1	Ease of use	86.08	Very Practical
2	Efficiency of Time Use	87.83	Very Practical
3	Easy to Interpret	88.83	Very Practical
4	Has equivalence	90.17	Very Practical
	Average	**88.23**	**Very Practical**

While testing the effectiveness of learning media using the one-group design method (sample test design with one group). At the first meeting of the experiment, researchers conducted a pretest on 30 students using 30 objective questions that had been tested for item validity. Pretest was conducted to see student learning outcomes before being given treatment or using AR-based mobile. After the pretest, 30 students involved in this pilot test were given treatment using AR-based mobile in the electrical circuit course. The discussion topics that students learn in the media are the topics that are on the pretest and posttest questions.

At the last meeting of the experiment, researchers conducted a posttest on 30 students who had used AR-based mobile in electrical circuit courses. Posttest is used to see student learning outcomes after treatment. Data from pretest and posttest results are used to see the effectiveness of AR-based mobile. To analyze the level of effectiveness or not of this AR-based mobile, researchers used three ways, namely the effectiveness test based on gain score and t-test. The results of the effectiveness analysis based on the gain score of 30 students who have taken the pretest and posttest can be seen in Table 10.

Table 10. Effectiveness test results based on gain score

N	Rata-rata		N-Gain Score	% N-Gain Score
	Posttest-Pretest	S_Ideal-Pretest		
30	25.77	48.97	0.48	48
Category			Medium	

The average N-Gain Score of 0.48 was found to be in the moderate category based on the effectiveness test analysis results using the gain score of the pretest and posttest scores of 30 students. We may infer that using AR-based mobile devices as learning tools works well.

The normality test of the learning outcomes data is completed before determining the efficacy based on the comparison of learning outcomes using the t-test. The normalcy test aims to determine whether or not the data on student learning outcomes follow a normal distribution. The Shapiro-Wilk Test, with an error rate of 5% or 0.05, is the data normalcy test that is employed. Decisions regarding the Shapiro-Wilk Test normality test are informed by the significant value obtained from the test findings. If the significance value (Sig.) is less than 0.05, the test data is considered not normally distributed; if it is larger than 0.05, the test data is considered regularly distributed. Software from IBM SPSS 29 is used to help with the analysis of normality tests. Table 11 displays the results of data normality tests.

Table 11. Normality test results

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-Test	0.136	30	0.162	0.969	30	0.511
Post-Test	0.142	30	0.126	0.935	30	0.066

a: Liliefors Significance Correction

The significance value (Sig.) for the pretest data is 0.511, and the posttest value is 0.066, according to the Shapiro-Wilk Test normalcy test. Based on these findings, it can be said that the pretest data is normally distributed because the Sig. value (0.511) is higher than 0.05. Additionally, the post-test data was found to be normally distributed (Sig. = 0.066), which is greater than 0.05. The statistical test employed in the study is a parametric statistical test in the form of a t-test once it is shown that the data on learning outcomes from the pretest and posttest are normally distributed.

Decisions based on the t-test are made using the significance value (sig.) obtained from the test results. If there is a significant difference and the value (sig.) is less than 0.05, H0 is rejected. However, if the value (sig.) is more than 0.05, H0 is accepted, meaning that there is no significant difference. The results of the t-test data analysis are displayed in Table 12.

The results of the parametric statistical test (t-test) yielded a sig. value of 0.001. Because the t value (0.001) is less than 0.05, it may be concluded from these results that either H0 is rejected or that there is a significant difference in the learning outcomes of students who use AR-based mobile as a learning medium in electrical circuit classes. When the t-count and t-table values are compared, it is evident that the t-table value for df (29) is −1.69. Consequently, it can be said that the *t*-count value (−8.7) < (−1.69) t-table indicates that either H0 is rejected or that student learning results differ significantly after employing AR-based mobile as a learning tool in electrical circuit classes.

Table 12. Normality test results

			Pair 1 Pre-Test – Post-Test
Paired Differences	Mean		−25.8
	Std. Deviation		16.250
	Std. Error Mean		2.967
	95% Confidence Interval of the Difference	Lower	−31.8
		Upper	−19.7
t			−8.7
df			29
Significance Two-Sided p			< 0.001

B. Discussion

Learning in today's digital era presents various challenges as well as opportunities in delivering material to students. Developing an interesting and captivating learning environment is one of the most difficult tasks, particularly in classes like Electrical Circuits. Using technology-based learning resources has grown in popularity as a way to help students better grasp difficult ideas. One of the technologies that could be developed as self-learning media is mobile-based augmented reality, which combines virtual items and the actual environment on a single screen on mobile devices.

Augmented reality (AR) allows users to view virtual objects that are replaced by the real environment, creating an immersive and interactive experience. AR-based learning media is an Android platform-based application designed as an interactive and practical learning media to help students during the learning process [22, 31–33]. This application is equipped with features such as learning materials in 3D circuit simulations, audio, and video tutorials, interactive quizzes, and others that help students understand learning more efficiently and fun. Students can access the application through their smartphone or tablet device. Moreover, this application allows learning to occur anytime and anywhere, free from traditional learning methods' time and location constraints [34]. This flexibility gives students more options to learn the subject matter. The AR-based learning media used in this study was developed based on the curriculum and materials of the electrical circuit course, as well as the needs and characteristics of students. Before being used, AR-based learning media has gone through various stages of testing. The test results start from the validation analysis given by validator lecturers with expertise in electrical circuit material and learning media.

These findings demonstrate how the validator's evaluation of the interactive learning materials based on augmented reality aligns with the objectives and subject matter of the electrical circuit course. However, the application of AR-based media is not free from challenges. Some students reported technical difficulties in operating the application, especially in the 3D simulation feature and navigation between features. In addition, the need for devices with medium to high specifications is an obstacle for students who have devices with lower specifications. This shows that although AR offers great potential, the accessibility of the technology is a challenge that needs to be overcome so that the benefits can be felt equally by all students. Nonetheless, student evaluations showed that the practicality of the app was rated highly, indicating that its features of text, sound, images, video, and 3D electrical circuit simulation have been effectively integrated into the learning process.

In addition, the significant increase in learning outcomes indicates that the AR-based learning media in the electrical circuits course is visually appealing interactive, and effective in helping students understand complex material. The dramatically improved classical completion indicates that this media can meet the various learning needs of students, from high achievers to those who may need more assistance. The N-Gain Score, which is in the medium category, shows that although there is room for improvement, this media has significantly impacted learning.

The study's findings suggest that AR-based learning resources can enhance technical learning quality and have significant promise for application in technology and vocational education. Additional research supports these conclusions, demonstrating the substantial advantages of implementing AR in the classroom, such as enhanced motivation, learning outcomes, and student engagement. AR-based learning media in electrical circuit courses can be adapted for other courses or disciplines, offering a more effective and efficient approach to developing students' skills and knowledge.

Previous studies have developed interactive learning media for electrical circuit courses using Android platforms. Research by Kurniadi, for instance, created a multimedia system application model for electrical circuits aimed at facilitating learning and comprehension of electrical circuits, thereby supporting the completion of electrical circuit practice activities [35]. Research published by Doni suggests that Android-based interactive learning media can serve as an alternative for implementing effective, innovative, and adaptive learning methods, leveraging technological advancements in vocational education for electrical circuit courses [36]. At the same time, research that is following this research is AR-based learning media on electrical circuits produced by Ang Yong Yi's research, which makes mobile educational applications for learning electrical circuits using marker-based AR technology developed on the Android platform to assist users in exploring knowledge about electrical circuits through an immersive environment [37]. It is just that AR-based learning media in electrical circuit subjects are developed for elementary school students. In contrast to Ang Yong Yi's research, this study focuses on developing AR-based media specifically for higher education students in electrical engineering, which provides an immersive environment for advanced learning.

Researchers developed AR-based learning media based on various references to similar research in developing electrical circuit learning media, an innovation that has not been widely found and developed. Therefore, this presents a new opportunity and solution for researchers to advance AR technology as an interactive media in electrical circuit course. This research also shows how AR can be adapted to the cognitive and technical needs of engineering students. In addition, this research opens up further opportunities for the integration of AR in other technical subjects, providing a basis for wider application.

IV. Conclusion

Based on the research results on the development of Mobile-Based Augmented Reality (MBAR) learning media as an independent learning media in electrical circuit courses, it can be concluded that this research has succeeded in developing media by learning needs. The validity test results show that this media is considered valid by material and media experts, with an average score of 0.81 and 0.93, respectively. The limited trial showed that this media was practical, with a practicality score of 81.63%, while during implementation, practicality increased to 88.23%. The use of AR-based learning media in electrical circuit courses significantly improved learning outcomes, according to the effectiveness test of media implementation with the one-group design method. This was demonstrated by a t-test with a significance value of 0.001 and an N-Gain Score of 0.48 (medium category).

This study highlights significant implications for education, especially in electrical engineering and vocational training. AR enhances learning by making it more interactive, boosting student motivation, and aiding comprehension of abstract concepts through visualization and simulation. It also serves as a flexible tool for self-learning, enabling access to materials anytime, anywhere. However, the study focuses solely on electrical circuits, leaving AR's application in other subjects unexplored. Challenges like device compatibility and digital literacy gaps remain unaddressed. Future research should expand AR applications to other fields, assess long-term knowledge retention, and integrate personalization for inclusivity. This research underscores mobile AR's potential for broader adoption in technical education.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Writing—original draft preparation and analysis of the data, AL; Methodology, review, MM; Editing, formal analysis, HE; Conceptualization, review, NJ; Editing, formal analysis, A.D.S.; Review, editing, V.S. All authors had approved the final version.

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