E-Worksheets with Augmented Reality Technology in Laboratory Learning: Examining Their Effectiveness on Students' Learning Performance

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***Abstract*—Virtual reality technology, such as Augmented Reality (AR), is becoming increasingly popular in learning. However, its integration with other learning media needs continuous innovation, and the effectiveness of its use in the learning process must also be empirically analyzed, as each learning process has its uniqueness and characteristics. This research discusses the effectiveness of E-Worksheets with Augmented Reality (E-WAR) in the laboratory learning process for Electrical Machine Courses (EMC) in higher education. E-WAR is an innovative, technology-based practical learning medium that integrates AR technology with Electronic Worksheets (E-Worksheets). A quasi-experimental research with a non-equivalent control group design, consisting of experimental and control groups, was applied in this research. The study involved 68 students as research subjects. Data on student practicum learning outcomes were collected using the Performance Assessment Rubric (PAR). The effectiveness of E-WAR was evaluated based on the analysis of differences in post-test results between the experimental and control groups using the independent sample t-test. Cohen's d Effect Size Analysis was also used to measure the effect size of using E-WAR. The research showed significant differences in post-test results between the experimental and control groups, with the experimental group scoring higher than the control group. Furthermore, the effect size analysis results indicate that the influence of using E-WAR falls into the large category. These findings suggest that E-WAR is an effective technology-based learning medium that greatly improves student learning performance in the laboratory learning process.**

***Keywords*—augmented reality technology, e-worksheets with augmented reality, laboratory learning, higher education**

I. Introduction

In the digital era, technological advances in education are transforming teaching and learning, especially in the context of higher education. Augmented Reality (AR) technology and e-worksheets have shown great potential in increasing students' interactivity and understanding across various disciplines [1–3]. AR is a technology that combines the real world with virtual objects in the form of computer-generated images, videos, or animations [3, 4]. This technology allows users to view and interact with virtual objects displayed in a real-world context via devices such as smartphones, tablets, or AR headsets [3, 5, 6]. E-worksheets are digital versions of traditional worksheets used in the laboratory learning process. They are designed to be accessed and completed via digital devices such as computers, tablets, or smartphones, offering greater flexibility and accessibility compared to traditional worksheets [7–9].

Although various studies have explored the use of AR technology and e-worksheets separately in educational contexts, research that integrates these two technologies in laboratory learning, especially in electrical machine courses (EMC), is still limited, with fewer than twenty published studies addressing this specific integration based on ScienceDirect database [3, 8–10]. Most previous studies have focused on the application of AR for concept visualization or the use of e-worksheets for managing students' assignments and exercises, without exploring the potential synergies between the two [3, 4, 11, 12]. Additionally, many existing studies use research designs with less stringent controls, making the results difficult to generalize [13, 14]. Therefore, this research aims to fill this gap by evaluating the effectiveness of integrating E-Worksheets with Augmented Reality (E-WAR) in improving the learning outcomes of electrical engineering students in the laboratory learning process, particularly in EMC.

Laboratory learning in the context of electrical machines is crucial because it allows students to apply theoretical knowledge to real practice. Students face the challenge of understanding and manipulating electrical machine components, which are often complex and pose high risks if not handled properly [12, 15]. This practical experience not only enhances conceptual understanding but also develops the technical skills required in the workforce [15–17]. However, limited laboratory equipment, restricted time, and safety risks often hinder hands-on laboratory learning [17, 18]. Therefore, the use of E-WAR is expected to be an effective solution, enabling students to study virtually before moving on to physical practice, thereby increasing their readiness and minimizing the risk of errors and accidents in real laboratories.

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Recent research in the field of higher engineering education indicates significant developments in the use of AR technology and e-worksheets to enhance learning effectiveness [1, 3, 10]. AR technology has visualized complex concepts, enabling deeper interactions and more intuitive learning experiences [3, 19]. E-worksheets offer flexibility and accessibility, facilitating a learning process that is more adaptive and responsive to student needs [2, 7]. Previous studies have demonstrated that AR can significantly boost learning motivation and enhance concept understanding in laboratory learning contexts [1, 5, 10]. However, integrating AR with e-worksheets in a structured and interactive format, such as E-WAR, is still in the exploratory stage. This research aims to empirically test the effectiveness of this integration in laboratory learning for EMC. Specifically, this research aims to: (1) measure the differences in learning performances between students who use E-WAR and those who use conventional worksheets without AR, and (2) analyze the magnitude of the effect (effect size) of using E-WAR on improving students' learning performance. Through these objectives, the research is expected to provide a comprehensive understanding of the benefits and impact of E-WAR as a technology-based learning media in the context of electrical engineering education.

The main contribution of this research lies in providing empirical evidence of the effectiveness of E-WAR in enhancing student learning performances in laboratory learning. This study introduces novelty through a unique integration between e-worksheets and AR technology in laboratory learning, an area that has not been extensively explored in previous literature. Moreover, this research adds value by employing a rigorous quasi-experimental design and conducting in-depth statistical analysis to ensure the validity and reliability of the findings. Thus, this study not only enriches existing literature but also offers a practical approach that can be implemented by educators and higher education institutions to enhance the quality of technical learning in the digital era.

II. Literature Review

A. Augmented Reality Technology

AR is a technology that integrates the real world with virtual objects in the form of computer-generated images, videos, or animations [3, 20]. This technology enables users to view and interact with virtual objects displayed in a real-world context via devices such as smartphones, tablets, or AR headsets [4, 10, 21]. AR offers a more immersive and interactive learning experience by presenting digital content that can interact with the user's physical environment. In education, AR is utilized to visualize abstract and complex concepts, such as atomic structure, machine mechanisms, or biological processes, thus facilitating students' comprehension of subject matter more concretely and engagingly [10, 13, 14].

AR technology offers several advantages, including (1) enabling students to interact with learning content more dynamically and engagingly, thereby increasing engagement and learning motivation; (2) the ability to display complex three-dimensional models and simulations, assisting students in understanding difficult concepts more easily; (3) allowing the placement of virtual objects in real-world contexts, enabling students to observe real-life applications of the concepts they are learning; and (4) with mobile devices being commonly used, AR can be accessed by many students without requiring significant investments in specialized equipment [14, 21–23]. However, several studies have also identified limitations of AR technology, such as requiring significant costs and time, as well as technical expertise. Additionally, AR relies on hardware and software, which may lead to technical issues such as lag or inaccuracies in motion tracking [10, 24–26].

B. E-Worksheets

E-worksheets are an electronic or digital form of conventional worksheets designed to support the teaching and learning process in various educational settings [9, 27]. Like conventional worksheets, E-Worksheets aim to provide structure, guidance, and instruction to students during the laboratory learning or experimentation process [2, 7, 28]. The difference lies in the digital format, which can be accessed via electronic devices such as computers, laptops, tablets, or smartphones. These resources can come in a variety of formats, including PDF files, text documents, special applications, or online learning platforms that provide information, directions, and assignments relevant to a particular course material or practice session [2, 7, 8].

E-worksheets offer advantages in flexibility and accessibility. They are easily updated, upgraded, or adapted to suit evolving learning needs [7, 28]. Additionally, their digital nature allows for a higher level of interactivity, by including embedded videos, dynamic images, hyperlinks, or other multimedia elements aimed at enhancing understanding of concepts engagingly [2, 7, 27]. Utilization of E-worksheets also facilitates smooth collaboration between students and teachers, thereby enabling effective distance or blended learning methodologies [2, 8]. Their online access also helps reduce printing costs and ensures easy access for students regardless of geographic location [7, 9, 28].

C. E-Worksheets with Augmented Reality (E-WAR)

E-WAR is a combination of E-worksheets and AR technology in a laboratory learning context. This approach merges the advantages of E-Worksheets in providing digitally structured directions, instructions, and assignments with the potential of AR to add virtual elements to the real world [7, 10, 29]. In E-WAR, electronic worksheets are presented via a digital platform or application containing information, instructions, assignments, or guides related to a specific learning topic or practical exercise. Simultaneously, AR technology is utilized to incorporate virtual elements, such as animations, 3D objects, or additional information, onto physical objects that exist in the real world, which students observe and access via AR-enabled devices such as smartphones or tablets [3, 30].

Through E-WAR, students can access worksheets containing experimental instructions or assignments digitally. Additionally, they may view additional information, visual guides, or virtual objects superimposed on the physical objects they are examining in a laboratory or practical environment. This approach has the potential to increase interactivity, conceptual understanding, and student engagement in the learning process [21, 31, 32]. Utilizing E-WAR allows students to access additional information directly from the physical environment they observe, providing more interactive and in-depth guidance in carrying out experiments or practical assignments.

III. Methods

A. Research Design

The main objective of this research is to conduct an empirical analysis of the effectiveness of implementing E-WAR in the laboratory learning process for EMC. To achieve this goal, quasi-experimental research [21, 33] was carried out with a Non-equivalent Control Group Design [34–36] as presented in Fig. 1. This research comprised an experimental group and a control group. At the beginning of the research, a pre-test was conducted on the experimental group (O_1) and the control group (O_2) to determine the value of student learning performance in the laboratory learning process in the EMC. This value is used to ensure that the average initial learning ability of students in the experimental and control groups is relatively the same or does not have a significant difference. The next stage involved research action carried out in the two groups, in the form of a laboratory learning process using E-WAR in the experimental group (X_1) and conventional worksheets in the control group (X_2) as laboratory learning media in the EMC. After conducting research actions, a final assessment of student learning performance (post-test) was carried out. The post-test was conducted to assess the learning performance of students in the experimental (O_3) and control (O_4) groups after receiving each research action. The results of this post-test are used as essential data to analyze the effectiveness of implementing E-WAR in the laboratory learning process for EMC.

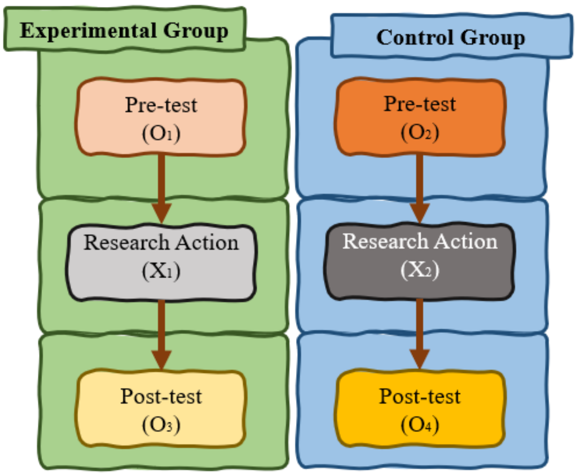


Fig. 1. Research design.

B. Research Instrument

This research utilizes a Performance Assessment Rubric (PAR) as a research instrument. This instrument is employed by lecturers as research observers to evaluate the performance of each student in the laboratory learning process for EMC, both for the pre-test and the post-test. The instrument comprises 5 dimensions, each consisting of several statements adapted from various literature sources as presented in Table 1 [21, 37–41]. This instrument employs answer choices with the Guttman scale [36, 40]. Before its implementation, this instrument underwent testing and analysis for validity and reliability. This was conducted to ensure that the instruments used could validly collect the desired data.

Table 1. Dimensions and indicators of PAR

Dimensions	Indicators
Knowledge	K.1. Students understand the working principles of a 3-phase induction motor.
	K.2. Students can explain the relationship between speed, frequency, and the number of poles in a motor.
	K.3. Students identify the main components of a 3-phase induction motor.
	K.4. Students explain the function of each motor component.
	K.5. Students apply induction motor theory in practical situations.
Skills	S.1. Students measure the current and voltage of a 3-phase induction motor accurately.
	S.2. Students correctly install and connect a 3-phase induction motor.
	S.3. Students operate the motor with the correct parameters.
	S.4. Students maintain laboratory equipment properly.
	S.5. Students complete practical assignments on time.
Analysis	A.1. Students can compile experimental data correctly.
	A.2. Students can analyze experimental data accurately.
	A.3. Students correctly interpret measurement results.
	A.4. Students can analyze comparative test results using various theories.
	A.5. Students can conclude the results of data analysis from experimental outcomes.
Work Quality	WQ.1. Students complete the motor installation accurately.
	WQ.2. Current and voltage measurements are performed with a high degree of accuracy.
	WQ.3. Students tidy up the installation after the practicum is finished.
	WQ.4. Students return tools and materials neatly.
	WQ.5. Students prepare practical reports thoroughly.
	WQ.6. Work results meet safety and quality standards.

The PAR underwent testing to ensure its validity and reliability before being widely used in student assessment. Validity was analyzed using the Pearson Product Moment Correlation [40, 41], while reliability was evaluated using Cronbach's Alpha reliability analysis [10, 42]. However, before testing the instrument's use, a content validity test was conducted. This test involved 10 experts reviewing each statement in the rubric and providing feedback about its relevance to the learning material. The analysis results showed that each statement in the rubric reflects important aspects of the learning material that can be used to effectively evaluate student understanding and skills.

Based on the validity analysis results after testing, it was found that the calculated r value for all indicators exceeds the r table value (0.619 > 0.444) with a significance value below 0.05. This indicates that all indicators in the research instrument are considered valid [11, 42, 43]. The Cronbach's alpha analysis yielded a value of 0.791, which exceeds the threshold of 0.60 (0.791 > 0.600), indicating that the research instrument can be considered reliable [11, 43]. The validity and reliability testing results of this instrument confirm its suitability for use as an instrument for assessing student performance in the laboratory learning process for EMC.

C. Research Participants

This research involved 68 second-year students in the Industrial Electrical Engineering Study Program at Universitas Negeri Padang, Indonesia. These students comprised 34 students in the experiment group and 34 students in the control group. The technique used for selecting participants in the experimental and control groups was a simple cluster random sampling technique, with the assumption that students' initial abilities were relatively the same and that there were no significant differences based on the results of student learning performance assessments conducted before the research was carried out (pre-test) [21, 44]. These students participated in the laboratory learning process for the EMC.

D. Technique of Data Analysis

The data obtained based on the research design were analyzed using several stages of data analysis, regarding the research data analysis scheme presented in Fig. 2. These main analyses were chosen in this research to ensure the research objective, which is to reveal the effectiveness of the implementation of E-WAR in the laboratory learning process for the EMC can be achieved [21, 33, 34]. However, before the data is analyzed using these analyses, the research data must first undergo tests to meet the analysis requirements, namely normality and homogeneity tests [21, 45].

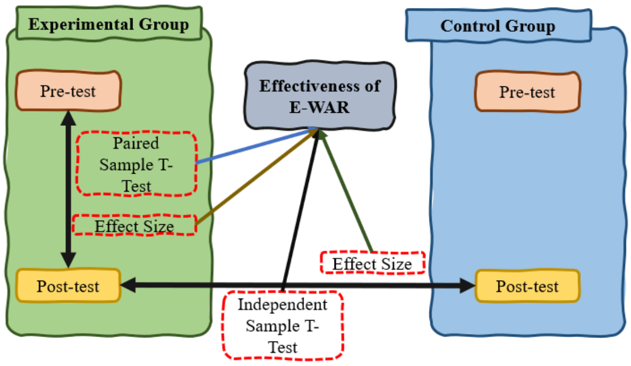


Fig. 2. Research data analysis scheme.

First, the analysis of differences in student learning performance assessments in the pre-test and post-test in the experimental group was conducted using paired-sample t-test analysis [21, 45]. This analysis is employed to examine differences in student learning performance before and after implementing E-WAR, thus assessing the effectiveness of E-WAR in the laboratory learning process. If there is a significant difference between the pre-test and post-test results, and the post-test score is better than the pre-test, it can be concluded that the implementation of E-WAR is effective [21, 36]. Second, the effect size analysis using Cohen's d Effect aims to determine the magnitude of the effect of implementing E-WAR in the laboratory learning process for EMC after E-WAR is deemed effective [36, 37, 42].

Third, the analysis of differences in post-test results between the experimental and control groups was conducted using the independent-sample t-test [33, 34, 46]. This analysis aims to compare the learning outcomes of students who use E-WAR with those who do not (conventional worksheets). The purpose is to strengthen and emphasize the analysis of the effectiveness of implementing E-WAR in laboratory learning by comparing it with learning processes that use media other than E-WAR. If there is a significant difference between the post-test results of the experimental group and the control group, where the post-test score of the experimental group is better than that of the control group, then the application of E-WAR in the laboratory learning process is effective in improving student learning performance [21, 33, 46]. Finally, the effect size analysis with Cohen's d Effect was conducted again, but this time considering the post-test scores between the experimental and control groups [3, 33, 37]. The aim is to determine the magnitude of the influence of implementing E-WAR in the laboratory learning process by considering different datasets.

IV. Result and Discussion

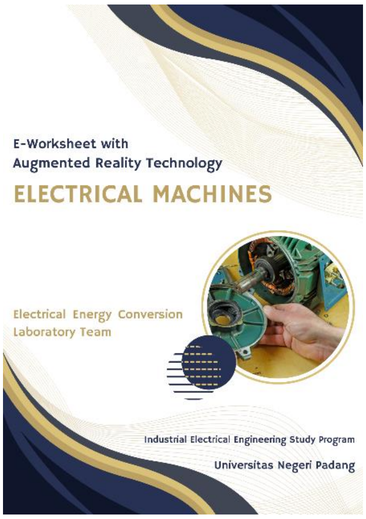
A. Results

1) E-WAR for laboratory learning in the electrical machine course

The application of E-WAR in the laboratory learning process for EMC offers an innovative approach that can enhance the quality and effectiveness of learning. The EMC requires an in-depth understanding of the working principles and characteristics of various types of electrical machines, such as motors and generators. Learning in these courses often necessitates concrete visualization and hands-on practice to grasp complex and abstract concepts effectively.

E-WAR combines the benefits of AR technology with e-worksheets to provide a more interactive and immersive learning experience. In the context of the EMC, E-WAR allows students to view three-dimensional models of various electrical machine components, such as rotors, stators, and coils, produced by AR technology. By using devices such as smartphones or tablets, students can visualize how these parts work dynamically within a system. This approach helps overcome the difficulties that students often face in understanding the internal structure and operation of electrical machines when relying solely on static images or verbal explanations. Additionally, E-WAR provides interactive simulations that allow students to observe various electrical and mechanical phenomena occurring in electrical machines. For example, students can view animations showing the flow of electric current, the resulting magnetic field, and the interaction between the magnetic field and the electric current that causes motor rotation. These simulations not only clarify theoretical concepts but also allow students to experiment with various operational conditions, such as changes in rotational speed or mechanical loads, and directly observe their effects.

The E-WAR framework, specifically designed for laboratory learning in EMC, includes several key elements: course identity, laboratory learning topics, laboratory learning objectives, concise theory integrated with AR technology, tools and materials integrated with AR technology, experimental illustrations using AR technology, occupational safety and health guidelines, experimental procedures, observation tables, and tasks. AR technology is integrated into sections that require visualization and simulation before students proceed to hands-on laboratory work. The E-WAR interface implemented in this research is presented in Fig. 3.



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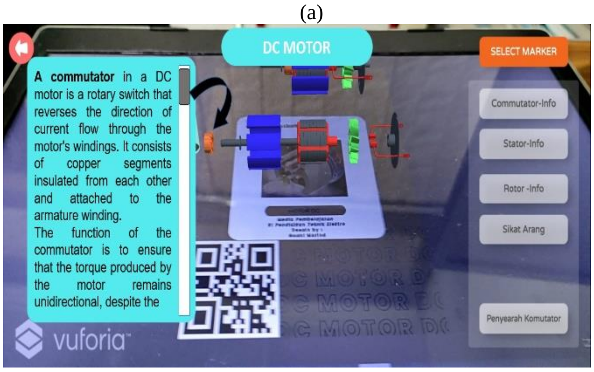


(c)

Fig. 3. The view of E-WAR: (a) E-WAR cover; (b) AR display in E-WAR.

2) *Research data*

The research data primarily consists of pre-test and post-test data collected from both the experimental and control groups. Pre-test data reflects students' initial learning performance in the laboratory learning process for both groups before any research intervention. Post-test data, on the other hand, captures student learning performance after the research intervention in each group. The pre-test and post-test data for the experimental and control groups are detailed as follows.

a) Pre-test data

The pre-test is an initial performance assessment of students to evaluate their basic abilities before implementing E-WAR in the experimental group and conventional worksheets in the control group. Pre-test data was obtained through student performance assessments using PAR, and evaluated by the lecturer as a research observer. This data is needed to ensure that the initial abilities of students in both groups do not have significant differences. The analysis of pre-test data for both the experimental and control groups showed that the averages were relatively similar between the two groups. Additionally, the distribution of minimum and maximum values was also relatively the same between the experimental and control groups. A descriptive analysis of the pre-test data for both groups is presented in Table 2.

Table 2. The descriptive analysis results of the pre-test data

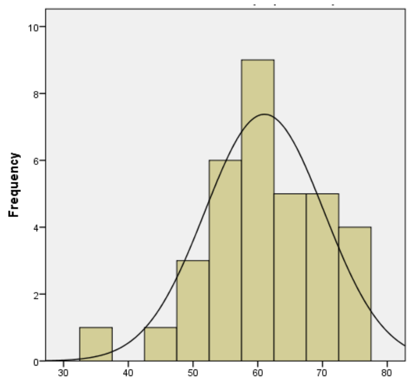
		Pretest (Experimental)	Pretest (Control)
N	**Valid**	34	34
	Missing	34	34
Mean		61.03	60.15
Median		60.00	60.00
Mode		60	60
Std. Deviation		9.193	8.918
Variance		84.514	79.523
Minimum		35	40
Maximum		75	75

The pre-test data first underwent a normality test before being used for further data analysis. The results of the normality analysis of the pre-test data for both groups, using the Shapiro-Wilk and Lilliefors tests, are presented in Table 3 [3, 14, 42]. The analysis shows that the pre-test data in both groups were normally distributed. The Lilliefors p-value (Sig) for the experimental group (0.076) and the control group (0.087) are greater than the significance level (0.05). Thus, the data for each group is normally distributed [33, 37]. Additionally, the Shapiro-Wilk test p-values for the experimental group (0.281) and the control group (0.263) are also greater than the significance level (0.05), indicating that the pre-test data from both groups are normally distributed based on the Shapiro-Wilk test [21, 46]. The histogram of the pre-test data for the experimental and control groups, along with a normal curve generated from SPSS application, is presented in Fig. 4.

Table 3. Normality test results of pre-test data

Pretest	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
Group	**Statistic**	**Df**	**Sig.**	**Statistic**	**df**	**Sig.**
Experiment	0.143	34	0.076	0.962	34	0.281
Control	0.140	34	0.087	0.961	34	0.263

a. Lilliefors Significance Correction



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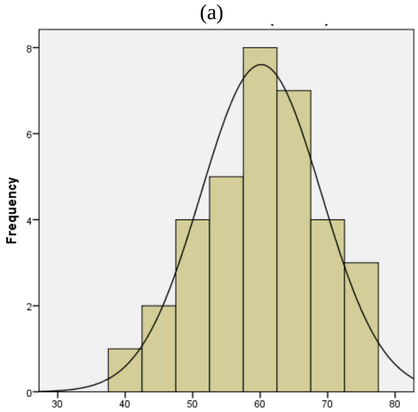


(b)

Fig. 4. Histogram of pre-test data with normal curve: (a) experiment group; (b) control group.

Homogeneity analysis of variance using Levene's Test method was conducted on the pre-test data to ensure that the initial abilities of students in the experimental and control groups were relatively similar or did not have significant differences [34, 46]. The results of the homogeneity test on the pre-test data between the experimental group and the control group, presented in Table 4, show that the Levene value (based on Mean) is 0.130 with a p-value of 0.720, which is greater than the significance level value (0.05). This indicates that the pre-test data between the experimental and control groups were homogeneous [21, 34].

Table 4. Homogeneity test results of pre-test data

		Levene Statistic	df1	df2	Sig.
Pretest Data	Based on Mean	0.130	1	66	0.720
	Based on Median	0.041	1	66	0.840
	Based on Median and with adjusted df	0.041	1	64.509	0.840
	Based on trimmed mean	0.145	1	66	0.705

b) Post-test data

The post-test assesses students' final learning performance after they receive the research intervention, which involves implementing E-WAR for the experimental group and conventional worksheets for the control group. Post-test data were collected through student performance assessments using the PAR. This data is crucial for analyzing the effectiveness of implementing E-WAR. Descriptive analysis of the post-test data from both the experimental and control groups revealed relatively different averages. Additionally, the distribution of minimum and maximum values also appears to differ, with the experimental group showing higher values than the control group. Detailed results of the descriptive analysis of post-test data are presented in Table 5.

Table 5. The descriptive analysis results of the pre-test data

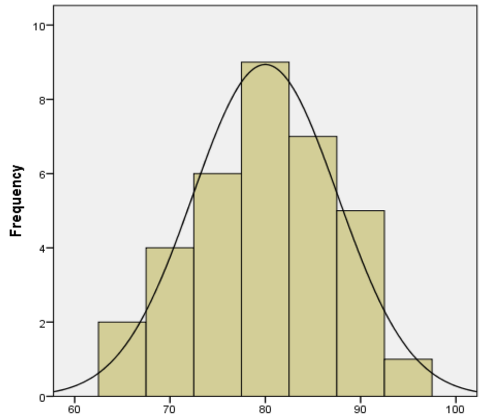
		Posttest (Experiment)	Posttest (Control)
N	**Valid**	34	34
	Missing	34	34
Mean		80.00	67.06
Median		80.00	67.50
Mode		80	70
Std. Deviation		7.588	9.623
Variance		57.576	92.602
Minimum		65	50
Maximum		95	90

The post-test data needs to undergo a normality test before it can be used for further data analysis according to research needs. The results of the normality test analysis of post-test data for the experimental and control groups, based on the Shapiro-Wilk and Lilliefors tests as presented in Table 6, indicate that the post-test data in both groups were normally distributed. The Lilliefors p-value (Sig) for the experimental group (0.114) and the control group (0.121) is greater than the significance level (0.05), indicating that the data for each group is normally distributed. Similarly, the p-value of the Shapiro-Wilk test for the experimental group (0.533) and the control group (0.576) is also greater than the significance level value (0.05), confirming that the post-test data from both groups are normally distributed based on the Shapiro-Wilk test. The histogram of the post-test data, along with a normal curve generated from SPSS application, is presented in Fig. 5.

Table 6. Normality test results of post-test data

Pretest Group	**Kolmogorov-Smirnov[a] Statistic**	**df**	**Sig.**	**Shapiro-Wilk Statistic**	**df**	**Sig.**
Experiment	0.147	34	0.114	0.962	34	0.533
Control	0.121	34	0.121	0.961	34	0.576

a. Lilliefors Significance Correction



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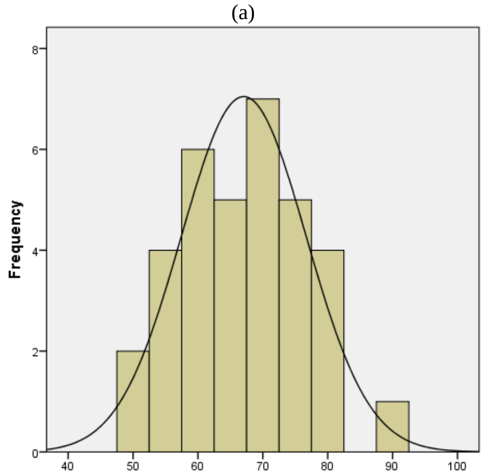

(b)

Fig. 5. Histogram of Post-test data with normal curve: (a) experiment group; (b) control group.

3) Effectiveness analysis of E-WAR

The effectiveness of implementing E-WAR in the laboratory learning process for EMC was evaluated through several statistical tests. First, paired-sample t-test analysis was conducted to determine significant differences in student learning performance before and after participating in the laboratory learning process using E-WAR. The analysis results, presented in Table 7, indicate that the t-count value is greater than the t-table value, and the alpha significance value is smaller than the significance level value (0.05). Therefore, it can be concluded that there is a significant difference between student learning performance in the pre-test and post-test, with the post-test results being superior to the pre-test results. This is evidenced by the average student learning performance during the post-test being higher than the average during the pre-test. The results of this analysis demonstrate that E-WAR is effective as a learning media in the laboratory learning process at EMC, particularly in terms of enhancing student learning performance.

Secondly, an effect size analysis was conducted using Cohen's d Effect based on the pre-test and post-test data in the experimental group. The results of the effect size analysis showed an effective index value of 1.63. According to the effect size criteria table, this effect size falls within the category of a large influence. Therefore, it is evident that the application of E-WAR is effective and has a large impact on improving student learning performance in the laboratory learning process at EMC.

Table 7. The results of paired-sample T-test

	Paired Differences			t	Sig. 2-tailed
	Mean	Std. Deviation	Std. Error Mean		
Posttest score – Pretest score	18.971	11.856	2,033	9.330	,000

Thirdly, an independent sample t-test analysis was conducted to determine significant differences between the learning performances of the experimental group and the control group. This analysis aims to reinforce the statement regarding the effectiveness of implementing E-WAR in the laboratory learning process by comparing it with a group of students who do not use E-WAR but still use conventional worksheets. However, before this analysis is carried out, it is essential to ensure that there are no outliers in the data for each group [21, 45]. Based on the stem-leaf diagram, there are no extreme values above and below the stem-leaf. Additionally, outlier detection can also be identified through box plot graphs generated from SPSS application, as shown in Fig. 6, which do not display any plots above and/or below the box plot, indicating the absence of outliers [3, 14, 45].

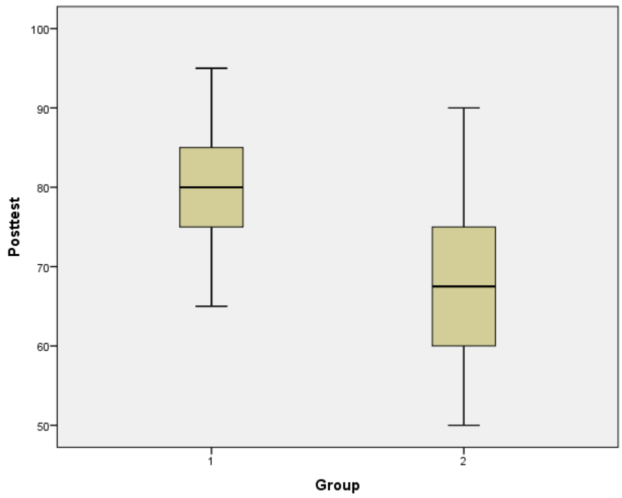

Fig. 6. Box plot graphs of post-test data.

The results of the independent sample t-test analysis in Table 8 demonstrate a significant difference between the learning outcomes of students in the experimental and control groups after undergoing different research interventions. The learning outcomes of students who participated in the laboratory learning process using E-WAR were superior when compared to those who utilized conventional worksheets. These findings further reinforce the effectiveness of E-WAR application in the laboratory learning process at EMC compared to conventional worksheets in enhancing learning outcomes or student learning performance.

Table 8. The results of independent-sample T-test

	t-test for Equality of Means				
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	6.158	66	0.000	12.941	2.102
Equal variances not assumed	6.158	62.595	0.000	12.941	2.102

Finally, an effect size analysis using Cohen's d Effect was also conducted again, this time between the experimental and control groups. This analysis aims to further reinforce the statement regarding the effectiveness of E-WAR applied in the laboratory learning process by determining the extent of its impact. The results of the effect size analysis revealed an effective index value of 1.57, indicating a large influence category. This further strengthens the evidence that the application of E-WAR has a large impact on the improvement of student learning performance. All the results of this data analysis demonstrate that E-WAR is effective for application in the laboratory learning process and has a significant impact on improving student learning performance. E-WAR stands as an alternative technology-based practicum learning media that is effective and adaptable to emerging technologies applied in the learning process.

B. Discussion

The results of this research reveal that the application of E-WAR in laboratory learning in the EMC demonstrates significant effectiveness compared to the use of conventional e-worksheets. Pre-test analysis shows that there is no significant difference in students' initial learning performance between the experimental group and the control group before the implementation of E-WAR, with relatively similar average scores. This ensures that both groups have equivalent initial abilities, making the research results more reliable in assessing the effectiveness of E-WAR in its application to the laboratory learning process.

After implementing E-WAR, post-test data showed a significant increase in student learning performance in the experimental group. The experimental group's post-test score was proven to have a significant difference from the pre-test score, where the post-test score was higher than the pre-test score. This indicates that E-WAR makes a positive contribution to improving student learning performance compared to before using E-WAR. Then, when comparing the experimental group with the control group, the post-test data shows a significant increase in student learning performance in the experimental group, who used E-WAR. The post-test scores of the experimental group were proven by statistical analysis to have a significant difference compared to the control group, which still used conventional worksheets. The experimental group's post-test score was also higher than the control group's post-test score. These results further strengthen the research findings that E-WAR is effectively applied to the laboratory learning process, enhancing student learning performance.

Furthermore, effect size analysis with Cohen's d shows that the influence of E-WAR falls within the large category. Cohen's d values in the pre-test and post-test analysis of the experimental group, as well as in the post-test analysis between the experimental and control groups, indicate that E-WAR has a significant impact on improving student understanding and performance. This large effect size confirms that the integration of AR technology with e-worksheets can create a more in-depth and effective learning experience.

Overall, the results of this research show that E-WAR is an effective and innovative learning media for laboratory learning in the EMC. The integration of AR technology into e-worksheets provides a richer learning experience, improves learning performance, and enhances understanding of complex technical concepts. These findings have the potential to encourage wider adoption of similar technology in various scientific disciplines, not only limited to electrical engineering but also in other fields that require visualization and deep interaction in learning.

The research results, which demonstrate that E-WAR in laboratory learning significantly enhances student learning performance, align with the findings of previous studies indicating that the utilization of AR technology in science learning can enhance learning outcomes and improve students' understanding of concepts [1, 3, 10, 13]. The outcomes of these studies underscore that AR can render abstract subject matter more tangible and comprehensible, thereby facilitating students' understanding [1, 3, 10, 13]. The similar outcomes in this research exhibit consistency in the effectiveness of AR technology when employed as a learning medium, which is adaptive to technological advancements.

Furthermore, other research on the use of AR in engineering education supports the finding that this technology is effective in enhancing learning activities, learning outcomes, or student performance [1, 5, 6, 19, 24]. These studies have shown that students who used AR in engineering education demonstrated significant improvements in understanding technical concepts compared to those who used conventional media. Additionally, these studies reported increased engagement and interest in learning among students [1, 5, 6, 21, 24]. This is consistent with the finding that E-WAR effectively enhances student performance in laboratory learning processes in engineering education.

The results of this research are also in line with findings from other studies, which examined the impact of AR in laboratory learning in physics courses [6, 19, 22, 23]. These studies found that AR is not only effective in increasing students' learning activities but is also effective in helping them visualize abstract material before they carry out practicums in hands-on laboratories [6, 19, 21, 23]. This research strengthens the argument that AR is effective to be applied in several scientific disciplines to improve the quality of learning. The finding that E-WAR is effective in improving the learning performance and understanding of electrical engineering students shows the broad potential of AR technology in education.

However, not all studies show entirely positive results regarding the use of AR in education. For example, some research indicates that while AR can improve conceptual understanding, its implementation requires adequate technological infrastructure and extensive educator training [1, 10, 29]. These challenges have been considered and addressed in the implementation of E-WAR. This research acknowledges that while E-WAR is effective, its success also depends on technological readiness and the instructor's skills in utilizing AR to its full potential. Therefore, lecturers must ensure that these prerequisites are met before implementing E-WAR so that its benefits and advantages can be optimally utilized.

Finally, previous studies on the implementation of e-worksheets in the practicum learning process indicate that digital technology can enhance student academic performance [4, 5, 13, 29]. However, integrating AR into e-worksheets, as done in this study, brings additional benefits, such as improved visualization and higher engagement. This research reveals that E-WAR, with AR integration, provides a richer learning experience compared to e-worksheets without AR technology, demonstrating the potential for this innovation to be more widely adopted in higher education.

Based on research results and comparisons with other relevant studies, it is evident that E-WAR significantly enhances student learning performance in laboratory learning for EMC. This research confirms that E-WAR not only effectively improves students' conceptual understanding but also effectively increases their learning performance during the learning process. These findings align with previous research highlighting the benefits of AR in various disciplines, despite the challenges of implementing this technology, such as the need for adequate infrastructure and educator training [4, 5, 13, 14]. Nonetheless, E-WAR offers an innovative and effective learning approach, combining the advantages of AR visualization and the organized structure of e-worksheets, which can be widely adopted in engineering education and other fields. Thus, this research not only contributes to the development of learning technology but also provides practical guidance for the implementation of E-WAR in higher education.

V. Conclusion

This research reveals that using E-WAR is effective for implementing the laboratory learning process in the EMC. The data analysis shows that students who use E-WAR demonstrate a greater improvement in learning performance compared to students who use conventional worksheets. So, this research confirms that E-WAR not only effectively improves students' conceptual understanding but also effectively increases their learning performance during the learning process. E-WAR provides richer and more interactive visualizations, making it easier to understand complex technical concepts. These results align with previous research findings that emphasize the effectiveness of AR in education, while also highlighting that successful implementation of E-WAR requires technological readiness and adequate training. Therefore, E-WAR can be considered an effective and adaptive innovation in laboratory learning, offering a more dynamic and contextual learning approach for electrical engineering education, with the potential to be applied to other disciplines with an adequate development process.

This study has several limitations that need to be noted. First, the sample size used is relatively small, so further testing with a larger participant pool is needed to generalize the findings. Second, this research was only conducted at one higher education institution, so variations in institutional and geographic contexts have not been considered. Third, this research focuses on one specific course, namely EMC, which may have different characteristics from other courses. Thus, future research could expand this study by involving a larger and more diverse sample, covering various higher education institutions and different subjects to get a more comprehensive picture of the effectiveness of E-WAR. Longitudinal research can also be conducted to observe the long-term impact of using E-WAR on student learning performance. Additionally, further exploration of the adaptation of AR technology for various types of practical and laboratory learning in various disciplines can provide deeper insights.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: O.C., D.T.P.Y., H., J.S., and M.Y.; Methodology: O.C., D.T.P.Y., J.P.Y., H., and M.K.; Validation: M.Y., J.P.Y., J.S., and M.K.; Formal Analysis: O.C., D.T.P.Y., H., H.Z., and M.K.; Original Draft Preparation: D.T.P.Y, H., M.Y., and M.K.; Writing Review and Editing: O.C., H., H.Z., and J.P.Y. All authors had approved the final version.

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