Innovative Laboratory Learning: A Study Evaluating the Practicality of Integrated E-Worksheets with Augmented Reality in Electrical Machines Course

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***Abstract*—The study aims to assess students' perceptions regarding the usability of the integrated e-worksheet with augmented reality technology (E-WAR) within the context of laboratory learning in the Electrical Machine Course (EMC). A quantitative survey method was employed using the Practical Response Instrument (PRI) for data collection. Students' perceptions of E-WAR were evaluated after they utilized this learning tool during the course. The research involved 97 second-year students enrolled in the Industrial Electrical Engineering Study Program at Universitas Negeri Padang, Indonesia. Data analysis reveals that students' perceptions indicate a notably high practicality level of E-WAR as a learning medium for laboratory learning. The evaluation of four practicality aspects (Ease of Use, Suitability of Learning Materials, Engagement and Interest, and AR Technology Performance) demonstrates a significantly high level of practicality, indicating it as 'very practical'. In conclusion, this study determines that, as per student perspectives, E-WAR exhibits a high degree of practicality. This signifies that integrating AR technology into E-Worksheets as a learning medium could offer an innovative alternative to laboratory learning methodologies, optimizing the learning process.**

***Keywords*—practicality, E-Worksheets, augmented reality technology, E-WAR, laboratory learning, electrical machine course**

I. Introduction

Laboratory learning within higher education, particularly in the context of the electrical engineering study program, holds a pivotal role in fostering comprehension of intricate technical concepts [1, 2]. Nevertheless, challenges emerge in delivering engaging and effective learning materials to students [2–4]. Innovations in educational technology have emerged as a primary focal point in enhancing the laboratory learning experience [3, 4]. One such promising technology is the integration of Augmented Reality (AR), offering the potential to transform the conventional learning paradigm into a more dynamic, interactive, and immersive one [2, 5, 6]. Prior studies have underscored the advantages of AR technology across diverse learning environments, such as enhancing students' understanding of concepts and practical skills in the learning processes of physics, chemistry, and mechanical engineering [2, 7–9], the integration of AR technology has also been shown to boost students' interest and engagement in the learning processes of geography, nursing, and electronic engineering [10–12]. However, there remains a relatively novel and intriguing domain to explore its application specifically within electrical engineering laboratories [2–4].

In the realm of laboratory learning innovation, the integration of AR technology has emerged as a central focal point for enhancing the educational experience [2, 8]. AR technology holds promise in rendering learning environments more dynamic and interactive, seamlessly integrating virtual elements into tangible, real-world settings [13, 14]. Nonetheless, to maximize the efficacy of AR application within laboratory learning settings, there is a requisite for tools that are both effective and tailored to the specific needs of the curriculum and the students. Among these tools, worksheets play a pivotal role in laboratory learning within the domain of electrical engineering [15–17]. These worksheets serve to aid students in comprehending practical material, conducting experiments, and engaging in holistic practical activities.

Worksheets serve as crucial learning aids within laboratory learning [15, 18]. In the context of laboratory learning, worksheets encompass tailored documents intended to bolster practical activities or experiments conducted by students in the laboratory [16, 18, 19]. These documents typically comprise instructions, guidance, queries, or assignments meant for completion during laboratory sessions [16, 20]. The primary objective of worksheets is to structure practical activities, steer students through requisite steps, and stimulate comprehensive comprehension of concepts learned through experimentation [15, 17, 18]. By transitioning worksheets into an electronic format (E-Worksheets) and integrating them with AR technology, a novel innovation emerges in laboratory learning. This amalgamation leverages the accessibility inherent in E-Worksheets while harnessing the augmentative capabilities of AR technology, introducing virtual elements such as animations, 3D objects, or supplementary information overlaid on physical objects within the students' observed real environment via AR-compatible devices.

The Electrical Machine Course (EMC) stands as a cornerstone within the Industrial Electrical Engineering curriculum, demanding a comprehensive grasp of fundamental principles governing electrical machines. Laboratory learning serves as a crucial platform for translating theory into practical applications [2, 3, 21]. Nevertheless, effectively delivering intricate material and enhancing the efficiency of laboratory learning remains a persistent challenge for educators and academic administrators. The constraints of traditional learning mediums, failing to captivate student attention and align content with learning requisites, prompt exploration into technological innovations within higher education [1, 3, 22]. The utilization of AR technology in education has garnered considerable interest owing to its capacity to offer immersive and interactive experiences [2, 23]. The fusion of E-Worksheets with AR technology holds promise in enhancing the presentation of educational material, elucidating complex concepts, and bolstering student engagement within laboratory learning.

In the realm of research concerning the integration of E-Worksheet technology with AR technology within laboratory learning, specifically in the EMC, there exists a need to bridge the gap in comprehending student responses to the feasibility of this innovation during the learning process [2, 3]. While earlier studies have explored the utilization of AR technology across diverse learning environments, there remains a scarcity of focused investigation into its application within laboratory learning in the realm of Electrical Engineering [2, 3]. This area encompasses a thorough assessment of student perceptions and reactions toward the practicality of E-Worksheets integrated with AR technology in comprehending EMC-related materials. An exploratory and comprehensive investigation into the reception and impact of these technologies on laboratory learning processes in this field is imperative. This necessity arises from the significance of pioneering and efficacious learning methodologies in fostering a profound comprehension of intricate technical concepts within the domain of EMC.

Laboratory learning within the EMC has witnessed a substantial surge in exploring and implementing AR technology as an innovative means to enhance the student learning experience [2, 6]. Several recent studies underscore the success of AR technology across various educational domains, emphasizing its role in delivering more engaging and interactive content, particularly within engineering learning contexts [4, 6, 23]. The integration of E-Worksheets with AR technology as a learning medium within EMC laboratories stands as a pivotal facet of the current trend of innovation in engineering education. Ongoing endeavors aim to elevate the quality, efficacy, and appeal of existing learning methodologies. While some research outcomes showcase a burgeoning interest in leveraging AR technology to enhance the comprehension of intricate technical concepts in EMC [3, 6, 23], there remains a necessity for further exploration that specifically evaluates students' perception toward the practicality of this innovation within laboratory learning in the EMC. Previous research findings indicate that the utilization of AR technology can aid students in understanding challenging concepts such as electromagnetic field interactions, power losses, and electromagnetic compatibility [5, 6, 24]. However, there has been limited in-depth research on how students perceive the practicality of the AR technology they use in the context of laboratory learning. This necessitates further investigation to fill this knowledge gap. Therefore, this study aims to address the research question: What is the practicality of E-WAR as an innovative laboratory learning medium at the EMC based on students' perceptions as users?

The primary aim of this research is to assess and analyze student perceptions regarding the practicality of employing E-WAR within the laboratory learning environment of EMC. This study innovatively explores the application of AR technology within a specific laboratory learning, emphasizing the integration of E-Worksheets. The significance of this research lies in the insights garnered from student reactions and perspectives on the practicality of employing E-WAR innovations within the laboratory learning framework. These insights serve as a foundation for refining and devising more innovative and efficient learning methodologies and platforms. The potential benefits encompass enriching students' learning experiences to comprehend intricate technical concepts in EMC, while also offering valuable insights for educators and academic institutions to optimize laboratory learning methodologies in alignment with the latest technological advancements.

II. Literature Review

A. E-Worksheets

E-worksheets represent electronic or digital renditions of traditional worksheets devised to bolster learning across diverse educational settings [15, 25]. Similar to their conventional counterparts, E-Worksheets serve the fundamental purpose of furnishing structure, guidance, and instructions to students during the learning or experimental processes [15, 16]. The distinguishing factor lies in their digital format, accessible through electronic devices such as laptops, tablets, or smartphones. These resources can assume various forms including PDF files, text documents, specialized applications, or online learning platforms disseminating information, directives, and assignments pertinent to specific lessons or practical sessions [20, 25, 26].

E-worksheets offer inherent advantages in flexibility and accessibility. They can be readily updated, enhanced, or tailored to accommodate evolving learning requirements [15, 25]. Moreover, their digital nature allows for heightened interactivity, encompassing embedded videos, dynamic images, hyperlinks, or other multimedia elements aimed at fostering a more engaging grasp of concepts [16, 20, 25]. Utilizing E-Worksheets also facilitates seamless collaboration between students and educators, thereby streamlining distance or blended learning methodologies more effectively. Their online accessibility further contributes to cost savings by minimizing printing expenses while ensuring easy access for students irrespective of their geographic location [15, 25, 27].

B. Augmented Reality Technology

AR technology integrates real-world surroundings with digital components, creating a combined experience that overlays the physical environment with digital information [6, 28, 29]. Within educational contexts, AR introduces an additional stratum of information, images, or virtual objects into the existing physical reality via devices such as smartphone cameras, tablets, or AR glasses [6, 13, 23].

The integration of AR in education fosters a more immersive and interactive learning milieu. Through specialized applications or devices, students can access supplementary information, 3D objects, animations, or visual explanations superimposed atop physical objects observed in the real world [22, 23]. This augmentation aids in elucidating intricate concepts, expanding comprehension, and cultivating a more immersive learning environment.

Furthermore, the efficacy of AR technology stems from its capacity to bolster student engagement and motivation in learning. By integrating captivating virtual elements within a tangible environment, AR has the potential to pique interest and encourage further exploration of the studied concepts, thus culminating in a more engaging and enjoyable learning experience [6, 23].

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

E-WAR constitutes the integration between E-Worksheets and AR technology within the realm of laboratory learning. This concept amalgamates the strengths of E-Worksheets in providing digitally structured guidance, instructions, and tasks with the potential of AR to add virtual elements to the real environment [6, 17, 23]. In E-WAR, electronic worksheets are presented through digital platforms or applications containing information, instructions, tasks, or guidelines pertinent to specific learning topics or practical exercises [6, 21]. Simultaneously, AR technology is employed to append virtual elements, such as animations, 3D objects, or supplementary information onto physical objects present in the observed real environment accessed by students through AR-compatible devices like smartphones or tablets.

Through E-WAR, students can digitally access worksheets encompassing experimental instructions or specific tasks. Additionally, they can view additional information, visual guidelines, or virtual objects overlaid on the physical objects they examine within laboratory or practical settings. This concept holds the potential to enhance interactivity, concept comprehension, and student engagement in learning. Utilizing E-WAR allows students to access supplementary information directly from the physical environment they observe, providing more interactive and in-depth guidance in conducting experiments or practical tasks [2, 6, 21].

III. Methods

A. Research Design

This study aims to elucidate students' responses and perceptions concerning the practicality of integrating E-WAR as a learning media innovation within laboratory learning focusing on EMC. To accomplish this objective, a quantitative research design based on surveys was employed [2, 6]. The methodology involved gathering data about students' reactions and evaluations of the practicality of E-WAR after its implementation as a learning medium during laboratory learning for EMC. Employing a survey-based quantitative approach is suitable for acquiring descriptive insights into the assessment of a specific variable. The structured nature of data collection ensures the accuracy and reliability of the obtained information [6, 17]. This research design facilitates comprehensive data acquisition concerning the practicality level of E-WAR as an innovative laboratory learning medium employed at EMC. The research design is presented in Fig. 1.

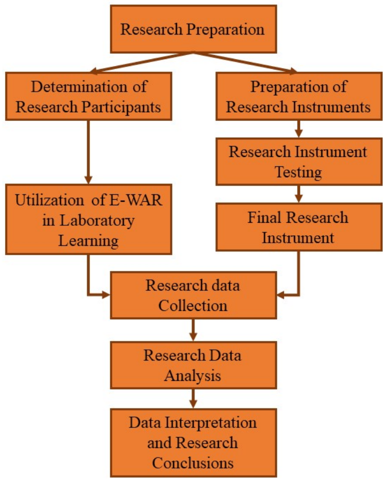

Fig. 1. Research design.

1) Research preparation

This stage marks the inception of the research activity. Its purpose is to ensure thorough preparation for the research, enabling its smooth execution and the attainment of predefined objectives. This stage encompasses two primary activities:

a) Determination of research participants

This phase involves identifying the participants for the research, including selecting test subjects for the research instruments utilized in data collection.

b) Preparation of research instruments

This step involves compiling and preparing the research instruments to be employed in the study. This process includes a literature analysis related to the variables and indicators of the research instruments, particularly in assessing the practicality of E-WAR based on student perceptions. The research instrument developed is termed the Practical Perception Instrument (PPI). Following the preparation of the PPI, trials are conducted on test subjects to ensure their adherence to research instrument criteria, such as validity and reliability. After validity and practicality analyses, a final PPI is established as a research data collection instrument.

2) Utilization of E-WAR in laboratory learning

During this phase, students participate in EMC laboratory learning sessions, utilizing E-WAR for one semester. At the semester's end, students complete the PPI to gather data on the practicality of the E-WAR utilized. Integrating E-WAR into laboratory learning is the foundation for students to complete the PPI based on their individual experiences.

3) Research data collection

In this stage, students who have utilized E-WAR in EMC laboratory learning are requested to complete the PPI, thereby collecting student perception data regarding the practicality of the E-WAR employed. The data gathered in this phase undergoes analysis to derive research outcomes.

4) Analysis of research data

This stage involves the analysis of research data collected during the preceding phase. Data, in the form of students' perceptions regarding the practicality of E-WAR, undergoes scrutiny utilizing established data analysis techniques. The outcomes of this analysis serve as the research findings, forming the basis for drawing research conclusions.

5) Data interpretation and research conclusions

Following the analysis of research data using established techniques, the findings are interpreted and translated into meaningful conclusions, aligned with the research objectives. Through a systematic approach to research design, it is anticipated that the study will accomplish its stated objectives.

B. Research Instrument

The Practical Perception Instrument (PPI) serves as the research tool for collecting data on students' perceptions regarding the practicality of using E-WAR in this study. This instrument comprises statements related to practical perceptions, accompanied by response choices on a Likert scale (1−5), ranging from a minimum score of '1' for 'Strongly Disagree' to a maximum score of '5' for 'Strongly Agree' [2, 17, 27]. The instrument is utilized to assess participants' perceptions of the practicality of implementing E-WAR, encompassing several variables or aspects, namely Ease of Use, Suitability of Learning Materials, Engagement and interest, as well as AR Technology Performance. Table 1 presents the variables and indicators incorporated within the PPI, complemented by a theoretical framework. These four variables or aspects determine the practicality level of E-WAR when employed by students in laboratory learning at EMC. Each variable, comprising several indicators, serves as a reference for analyzing and determining the practicality level of E-WAR based on students' perceptions as users, as depicted in the research conceptual framework in Fig. 2.

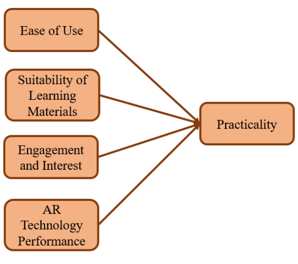

Fig. 2. Conceptual framework.

Before utilization, PPI was tested with 30 students who were not included in the main study. Following this, the instrument underwent an analysis to determine its validity and reliability. Validity was assessed using Pearson Product Moment Correlation analysis, while reliability was evaluated using Cronbach's Alpha reliability analysis [30−32]. The validity analysis results indicated that the r-count value for all indicators exceeded the r-table value (>0.361) at a Degree of Freedom (DF) of 28, with significance values below 0.05. This indicates that all indicators within the research instrument were considered valid. The Cronbach's alpha analysis produced a value of 0.907, exceeding the threshold of 0.60 (0.907 > 0.600), indicating that the research instrument can be deemed reliable. In addition, following data collection, the validity and reliability of the research data for each indicator are analyzed using analytical techniques outlined in the technique of data analysis section.

Table 1. Variables and Indicators of PPI

Variables	Indicators	
Ease of Use (EOU) [2, 33, 34]	EOU.1.	The E-WAR is comfortable to use
	EOU.2.	The E-WAR is equipped with easy-to-understand instructions
	EOU.3.	The E-WAR has an easy-to-use interface.
	EOU.4.	The E-WAR has information that is easy to find.
	EOU.5.	The E-WAR has features that can all be used easily.
Suitability of Learning Materials (SLM) [2, 6, 35, 36]	SLM.1.	The E-WAR delivers relevant content pertaining to laboratory learning in the EMC.
	SLM.2.	The E-WAR furnishes content aiding comprehension of the correlation between theory and practical application in laboratory learning within the EMC context.
	SLM.3.	The E-WAR offers information that fulfills the requirements for comprehending the material in laboratory learning within the EMC framework.
	SLM.4.	The E-WAR encompasses a comprehensive guide for implementing laboratory learning aligned with the learning topic.
	SLM.5.	The E-WAR presents coherent and easily comprehensible experimental procedures for laboratory learning.
	SLM.6.	The E-WAR provides content tailored to meet my learning requirements.
	SLM.7.	The E-WAR employs AR technology to visually elucidate the concepts of electrical machines' material.
Engagement and Interest (EI) [6, 23, 31]	EI.1.	The E-WAR heightened my interest in laboratory learning within the EMC.
	EI.2.	The E-WAR enhances my learning motivation in laboratory learning within the EMC context.
	EI.3.	The E-WAR renders laboratory learning in the EMC more engaging and interactive.
	EI.4.	The E-WAR intensifies my concentration on laboratory learning within the EMC.
	EI.5.	The E-WAR boosted my enthusiasm for participating in laboratory learning within the EMC.
AR Technology Performance (TP) [2, 33, 37, 38]	TP.1.	The AR technology within E-WAR exhibits rapid interaction response.
	TP.2.	The AR technology embedded in E-WAR effectively delivers essential information.
	TP.3.	The AR technology employed in E-WAR demonstrates high-performance content delivery.
	TP.4.	The AR technology integrated into E-WAR offers clear and valuable feedback.

C. Research Participants

This research engaged 97 second-year students enrolled in the Industrial Electrical Engineering Study Program at the Faculty of Engineering, Universitas Negeri Padang, Indonesia. These students have utilized E-WAR as an innovative learning medium in laboratory learning for EMC. They will offer feedback regarding the practicality of E-WAR by completing the Practicality Perception Instrument (PPI). The recorded responses will serve as reference data to ascertain the practicality level of E-WAR as one of the learning media implemented in laboratory learning. Participant selection was conducted through a simple random sampling technique.

D. Technique of Data Analysis

Partial Least Squares (PLS) analysis was conducted on the research data to ascertain the validity and reliability of all research variables' indicators [21, 39]. Upon confirming the validity and reliability of these indicators, descriptive analysis was employed by computing the percentage for each practical aspect [39, 40]. Subsequently, the outcomes from this analysis were interpreted using the practicality criteria table to determine the practicality level of E-WAR, one of the innovative learning media examined in this research. This sequential data analysis process yields comprehensive and precise insights into the practicality of using E-WAR as a learning medium in laboratory learning, relying on students' responses and perceptions as the primary users in the learning process [34, 35, 41].

IV. Result and Discussion

A. Results

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

E-worksheets are digital learning resources accessible to students through laptops or smartphones, containing instructional materials and practice sheets tailored for laboratory learning [15−17]. They function as comprehensive guides for students during their laboratory activities. In the context of EMC, E-WAR denotes an innovative learning tool that merges AR technology with electronic worksheets specifically crafted for laboratory learning in EMC. This technology amalgamates digital information and virtual elements into the real-world setting, enhancing the learning process by providing interactive and immersive experiences [5, 33, 42]. Through E-WAR, EMC students gain access to a digital platform showcasing virtual content integrated with physical worksheets. Leveraging AR, students can visualize and engage with three-dimensional models of electrical machinery, explore their components, simulate operational scenarios, and conduct virtual experiments before hands-on laboratory practice.

The framework of E-WAR, tailored specifically for laboratory learning within the EMC context, encompasses various elements: course identity, learning topics, educational objectives, concise theory integrated with AR technology, tools and materials integrated with AR technology, illustrations of experiments integrated with ar technology, occupational safety and health guidelines, experimental procedures, observation tables, and assignments. AR technology is integrated into segments necessitating visualization and simulation before students proceed with direct hands-on laboratory work. The E-WAR interface examined in this study is illustrated in Fig. 3.

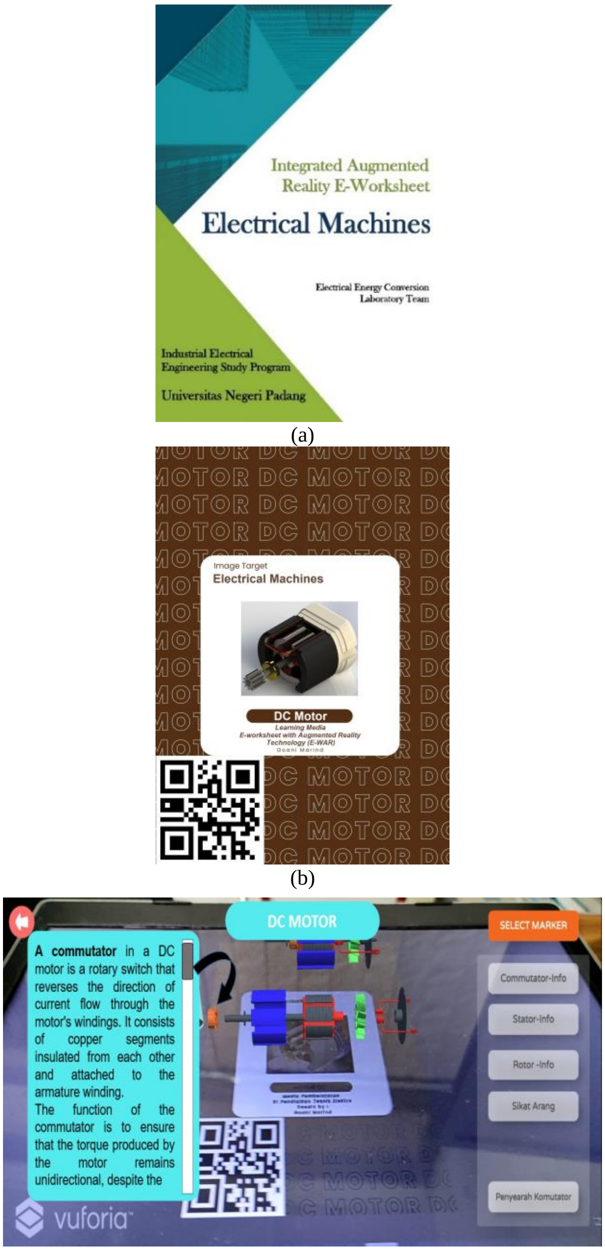

Fig. 3. The view of E-WAR: (a) E-WAR cover; (b) AR target image in E-WAR and (c) AR display in E-WAR.

2) Validity and reliability

After collecting the research data, an initial analysis was conducted using PLS analysis. This analysis aimed to assess the validity, reliability, and accuracy of each indicator in representing the respective variable [21, 39]. This process ensured that the data obtained from the instruments accurately portrayed each variable or aspect under assessment to determine the practicality level of E-WAR based on student responses or perceptions [21, 39]. However, before conducting such an analysis, the data needed to fulfill specific assumptions and criteria. One crucial aspect to consider was the issue of multicollinearity. It was essential to confirm the absence of multicollinearity issues among the indicators and variables. The Variance Inflation Factor (VIF) values served as a reference to identify multicollinearity [21, 39]. The analysis results of the VIF values for each indicator presented in Table 2 revealed that all VIF values were below 5 (VIF < 5), signifying the absence of multicollinearity issues [21, 39]. Consequently, the data for each indicator met the necessary assumptions and analysis criteria.

Table 2. The indicator VIF values analysis

Variables	Indicators	VIF
EOU	EOU.1	1.011
	EOU.2	2.090
	EOU.3	1.001
	EOU.4	1.098
	EOU.5	2.093
SLM	SLM.1	1.009
	SLM.2	2.967
	SLM.3	2.331
	SLM.4	2.112
	SLM.5	1.901
	SLM.6	1.007
	SLM.7	1.091
EI	EI.1	2.113
	EI.2	1.990
	EI.3	1.442
	EI.4	1.332
	EI.5	1.110
TP	TP.1	2.110
	TP.2	2.987
	TP.3	2.003
	TP.4	3.114

Following the confirmation of the absence of multicollinearity issues among the indicators, the subsequent step involves analyzing these indicators. In PLS analysis, this analysis is referred to as Outer Model Analysis, focusing on item validity, convergent validity, discriminant validity, construct reliability, and unidimensional models [21, 39]. Item validity is evaluated based on the outer-loading values outlined in Table 3. All indicators exhibit outer-loading values surpassing 0.7 for each variable. Consequently, all indicators are deemed valid concerning item validity [21, 39].

Table 3. The outer loading analysis

	EOU	SLM	EI	TP
EOU.1	0.811			
EOU.2	0.912			
EOU.3	0.781			
EOU.4	0.890			
EOU.5	0.896			
SLM.1		0.867		
SLM.2		0.841		
SLM.3		0.899		
SLM.4		0.795		
SLM.5		0.960		
SLM.6		0.912		
SLM.7		0.874		
EI.1			0.901	
EI.2			0.814	
EI.3			0.846	
EI.4			0.810	
EI.5			0.923	
TP.1				0.845
TP.2				0.891
TP.3				0.811
TP.4				0.797

The measurement capacity of each variable is evaluated using Internal Consistency Reliability (ICR), determined by Cronbach's Alpha (CA) value [21, 39]. Table 4 illustrates CA values for each tested variable, all of which exceed 0.6, signifying the reliability of all variables [21, 39]. The Unidimensional Model (UM) assessment was conducted to ensure no measurement issues for each variable. As demonstrated in Table 4, all variables fulfill UM requirements as the Composite Reliability (CR) value surpasses 0.7. Additionally, with an Average Variance Extracted (AVE) value exceeding 0.50 across all variables, they meet the Convergent Validity (CV) criteria, indicating their validity [21, 39].

Table 4. The results of indicator analysis

	CA	rho_A	CR	AVE	ICR	CV
EOU	0.910	0.874	0.877	0.611	R	V
SLM	0.791	0.841	0.890	0.709	R	V
EI	0.887	0.830	0.791	0.699	R	V
TP	0.895	0.811	0.813	0.684	R	V

Note: R = Reliable
V = Valid

Discriminant Validity (DV) can be evaluated using the Fornell-Larcker Criterion, comparing the square root of the AVE of each variable with the correlation between other variables in the tested path. As displayed in Table 5, all AVE root values for each variable exceed the correlation between variables. Hence, it can be concluded that all tested variables meet the DV criteria [21, 39, 40].

Table 5. Results of the discriminant validity analysis

	EOU	SLM	EI	TP	DV
EOU	0.782				Valid
SLM	0.690	0.842			Valid
EI	0.587	0.567	0.818		Valid
TP	0.559	0.698	0.513	0.827	Valid

3) Student's perception of the practicality of E-WAR in laboratory learning

The analysis of data obtained through the Practical Perception Instrument (PPI) from students regarding E-WAR in laboratory learning within the EMC context reveals that students were awarded an average score of 93.09% for the Ease of Use aspect. Interpreted using the practicality interpretation table, this figure indicates a very high level of practicality. A detailed analysis of the indicators within this aspect demonstrates strong consistency in the assessment, with the highest score of 94.5% achieved in the EOU.4 indicator. This indicates that students found information easily within E-WAR while using it in the laboratory learning process. This high score underscores E-WAR's success in delivering an intuitive and user-friendly experience, meeting students' needs and expectations in the laboratory learning process within the context of EMC.

Furthermore, the analysis indicates that E-WAR is highly compatible with the learning material in the laboratory learning. Scoring an average of 90.91% for the aspect of content suitability, which also reflects a very high level of practicality, the indicators demonstrate a close correlation between the content integrated into E-WAR and the materials covered in the electrical engineering course. Specifically, indicators SLM.5 and SLM.6 scored above 93, highlighting a robust association between the content within E-WAR and the learning objectives of the EMC within the laboratory learning context.

However, there was a slight decline in the Engagement and

Interest aspect, averaging 87.84%. Nevertheless, this figure still falls within the category of a very high level of practicality. Most indicators in this aspect scored above 85, indicating that E-WAR maintains a satisfactory level of student engagement in the Electrical Machines laboratory learning. Conversely, the AR Technology Performance aspect received an average score of 91.37%, indicating that the AR technology integrated into E-WAR demonstrates good performance and responsiveness as perceived by students. Particularly, the TP.1 indicator illustrates the exceptional performance of AR technology in presenting Electrical Machine learning material, scoring the highest among other indicators. The analysis results of student responses regarding the practicality of E-WAR as an innovative learning medium for laboratory learning in the EMC context are presented in Table 6.

Table 6. The results of the practicality analysis of E-WAR

Variables	Indicators	Practicality Score (%)	Average (%)	Level of Practicality
EOU	EOU.1	91.75	93.09	Highly Practical
	EOU.2	92.55		Highly Practical
	EOU.3	93.55		Highly Practical
	EOU.4	94.50		Highly Practical
	EOU.5	93.12		Highly Practical
SLM	SLM.1	91.34	90.91	Highly Practical
	SLM.2	90.40		Highly Practical
	SLM.3	87.98		Highly Practical
	SLM.4	89.05		Highly Practical
	SLM.5	93.44		Highly Practical
	SLM.6	94.03		Highly Practical
	SLM.7	90.11		Highly Practical
EI	EI.1	85.50	87.84	Highly Practical
	EI.2	90.75		Highly Practical
	EI.3	85.95		Highly Practical
	EI.4	87.33		Highly Practical
	EI.5	89.65		Highly Practical
TP	TP.1	92.71	91.37	Highly Practical
	TP.2	90.95		Highly Practical
	TP.3	91.75		Highly Practical
	TP.4	90.05		Highly Practical

In interpreting the practicality data, the research reveals that E-WAR exhibits a remarkably high level of practicality. Based on the classification used (81−100 = Highly Practical) [30, 33, 34], E-WAR falls within the Highly Practical category in the context of laboratory learning for the EMC. This classification is substantiated by consistently high scores, ranging from above 80% to 100% across almost all assessed aspects. This implies that E-WAR stands as a promising alternative, facilitating innovative and practical laboratory learning for student engagement within the context of the EMC.

B. *Discussion*

The research findings indicate that students perceive the utilization of E-WAR in laboratory learning at EMC as highly practical and beneficial. Regarding the Ease of Use aspect, students acknowledge a significant level of convenience while using this technology. They found the user interface of E-WAR to be highly intuitive, signifying that the design facilitates a seamless user experience and is easy to grasp.

The research outcomes underscore the alignment of content with learning materials. Students' responses indicated that the content furnished through E-WAR was highly pertinent to the material covered in EMC. Moreover, students expressed that E-WAR assisted them in comprehending the correlation between theory and practical application in the course. This demonstrates that E-WAR effectively presents relevant information and reinforces the theoretical learning necessary within the laboratory learning.

The engagement and interest of students in utilizing E-WAR technology are crucial aspects of this evaluation. Students expressed that the use of AR technology heightened their interest in laboratory learning within the context of EMC. Moreover, they felt more focused and enthusiastic while using E-WAR, signifying that this technology could provide an additional boost to motivation and student involvement throughout the learning process. This illustrates that the use of E-WAR can create a more dynamic and engaging learning environment for students. Although this aspect obtained slightly lower scores compared to others, attributed to various factors such as the type of device used by each student and higher expectations from some students, it is crucial to note that the score still falls within the "highly practical" level. Thus, it does not diminish the overall practicality of using E-WAR technology in laboratory learning at EMC.

In assessing the performance aspect of the AR technology integrated into E-WAR, students as users expressed that the response of the AR technology to their interactions was highly responsive and effectively provided necessary information during use. Students were content with the performance of the AR technology in delivering the learning content. These findings indicate that the integrated AR technology within the E-Worksheet offers a responsive and satisfactory interactive experience for students during laboratory learning in the EMC context.

Past studies investigating AR technology's implementation in educational settings have underscored its merits in augmenting student engagement and comprehension of concepts [6, 23, 43, 44]. Similar outcomes are evidenced in research within engineering education, mirroring this study's findings concerning AR technology's practicality in enhancing students' grasp of intricate subject matter. However, a distinct aspect lies in this research's emphasis on evaluating the acceptance and applicability of AR technology within the EMC laboratory setting, setting it apart as a focal point in this study.

Other studies have delved into integrating AR technology into engineering education, particularly in courses demanding comprehension of intricate concepts [6, 23, 33, 35]. These studies align with student responses, indicating that employing E-WAR augmented interest, motivation, and active engagement in the learning process. Nevertheless, notable distinctions emerge in the detailed assessments of specific practical aspects, such as Ease of Use and Responsiveness of AR Technology, which constitute the primary focus of this ongoing research. Additionally, prior studies highlight the positive impact of AR technology on enhancing student involvement in grasping technical concepts [14, 45−47]. However, differences are evident in the design of the practicality assessment instrument utilized, with this study centering on an exhaustive evaluation of four practicality aspects in implementing E-WAR within the EMC laboratory context.

Overall, comparing these findings with previous research emphasizes the consistent positive impact of AR technology in enhancing students' understanding and engagement within engineering learning contexts. Additionally, students responded favorably to the practicality of integrating AR technology with learning materials. However, this research's primary contribution lies in its focused evaluation of AR technology's practicality within laboratory learning in EMC, specifically addressing four key indicators: (1) ease of use; (2) suitability of learning material; (3) engagement and interest; and (4) AR technology performance. This detailed examination provides deeper insights into the effectiveness of AR technology in these specific contexts.

A careful comparison with previous research reveals both similarities and significant differences in the obtained results. These findings consistently underscore the advantages of AR technology as an innovative learning tool and its relevance in technological education environments. However, this study makes a distinctive contribution by specifically focusing on evaluating the practicality of integrating AR technology with E-Worksheets in an EMC laboratory setting. The study's strength lies in its comprehensive examination of practical aspects such as Ease of Use, Learning Effectiveness, Suitability of Learning Materials, AR Technology Performance, and Student Engagement within a concentrated context. These results not only reinforce prior findings regarding the benefits of AR technology in engineering education but also provide a deeper understanding of the acceptability and practical application of E-WAR technology in supporting learning within this specific course.

V. Conclusion

In conclusion, this research underscores the innovative application of E-WAR technology in laboratory learning at EMC. The findings affirm that students perceive E-WAR as a highly practical learning medium, aiding in comprehending intricate technical concepts, with marked practicality in ease of use, suitability of learning material, engagement and interest, and AR technology performance. Comparative analysis with related research consistently highlights the advantages of AR technology in enhancing student motivation and engagement in engineering education. However, the primary contribution of this study lies in its detailed assessment of the practical aspects of E-WAR technology in laboratory learning within the EMC context, an area with limited prior exploration. This implies that integrating AR technology into E-Worksheets not only enriches existing laboratory learning tools but also lays the groundwork for further advancements in engineering education, particularly in augmenting the efficacy of laboratory learning within the EMC context.

Limitations in this study stem from the restricted sample size, encompassing solely the student body of one educational institution, potentially limiting the broad applicability of the results. Moreover, the evaluation of E-WAR technology's practicality relies on student responses, susceptible to individual preferences and unmeasured factors. Future research ought to expand the sample size and include students from diverse educational institutions to enhance the study's generalizability. Employing mixed methods, combining quantitative and qualitative approaches, would offer a more comprehensive understanding of E-WAR technology's impact on laboratory learning in EMC courses. Further investigations could explore additional practicality facets, such as the technology's influence on student's academic performance or its long-term implications for grasping technical concepts relevant to industry work. The ongoing evolution of AR technology invites extensive research into refining and adapting E-WAR within the dynamic landscape of engineering education.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

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

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