Augmented reality learning media for electrical motor: case study in electrical engineering education

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ABSTRACT

The impact of augmented reality (AR) learning tools and students' critical thinking abilities on learning outcomes in electrical engineering education is the focus of this study. The study explores the ways in which these factors, both independently and in combination, influence student performance. Findings reveal that AR-based learning materials significantly enhance understanding and retention across self-directed and guided learning models. Critical thinking skills emerge as a key determinant of success, with students exhibiting strong critical thinking consistently outperforming peers with lower-level skills, regardless of the instructional model. The study also highlights variations in AR tools' effectiveness depending on the learning model and students' critical thinking abilities. Guided learning with AR tools benefits all students, while self-directed AR tools prove most effective for those with advanced critical thinking skills. Students with lower critical thinking abilities face challenges in navigating less structured AR environments. These results underscore the importance of fostering critical thinking and adopting tailored strategies when integrating AR technology into engineering education. By considering both the learning model and critical thinking levels, educators can optimize AR's potential to enhance student learning outcomes in technical fields.

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1. INTRODUCTION

The goal of technical and vocational education (TVE) is to prepare graduates for employment or advanced studies at higher educational levels [1], [2]. The swift advancement of science and technology has compelled educational institutions to adapt effectively, ensuring the quality of their graduates [3], [4]. Low graduate quality makes it challenging for them to secure employment, and many TVE graduates who have been employed for a while face layoffs due to their inability to adapt to technological advancements [5], [6]. As a result, technical and vocational education must produce graduates with exceptional skills and adaptable capabilities, enabling them to keep pace with and actively contribute to the fast-evolving technological landscape [7], [8].

Indonesia has focused significantly on TVE as a strategy to enhance the skills and capabilities of its workforce [9]. The Indonesian government's engagement with TVE is demonstrated through strategic enhancements in curriculum design, learning infrastructure, and teaching personnel quality [10]. Despite efforts to improve TVE, numerous complex factors can potentially impede the successful development of high-quality graduates [2]. North Sumatra Province in Indonesia has been grappling with the persistent issue of producing graduates with substandard qualifications from its technical and vocational education programs [11]. Despite implementing various improvement strategies, the learning outcomes have yet to meet the predetermined performance targets [12]. In the electrical engineering program, students' poor academic performance stems primarily from insufficient foundational competencies in engineering and physics, which are critical for developing professional skills [13]. This issue is not only faced by TVE graduates in North Sumatra, Indonesia, but also in other regions, as shown by the research findings. It is crucial to address this problem promptly to halt the declining quality of TVE graduates, which has contributed to rising unemployment [4].

The issue of students' low skills in electrical engineering education must be addressed without delay, as these skills are key to achieving professional competence for TVE graduates. The lack of effective teaching and learning tools, due to the absence of learning media, must be properly remedied [14]. Electrical engineering education requires media that can transform abstract concepts into more concrete visualizations, making it easier for students to understand [15]. The delivery of theoretical and conceptual content in electrical engineering education will be ineffective without the proper use of appropriate learning materials and media [16]. One of the courses in the electrical engineering education study program is electrical motor installation. This course discusses the use of electric motors (alternating current (AC) and direct current (DC)), types of motors, motor installations, and calculations of force, torque, and power (HP) in accordance with the characteristics of mechanical loads. In addition, this course provides knowledge about the concept of motor speed control, motor torque, braking, and its application in industry. Given the characteristics of the electrical motor installation course, it is clear that this course is abstract and requires learning media that can display parts of an electric motor clearly [17].

Learning can be divided into three main phases: input, process, and output. The input phase involves acquiring necessary resources and knowledge, the process phase focuses on engaging with and applying that knowledge through activities, and the output phase assesses the outcomes by measuring students' ability to demonstrate the skills and knowledge they have gained [18], [19]. The process stage emphasizes student learning activities, where the teaching materials, methods, media, and learning resources are crucial in shaping the effectiveness of the learning experience [20]. As crucial components of education, media must be created with the lesson's context, the characteristics of the students, and multimedia design principles in mind [21]. With connections to Paivio's dual-coding theory and Baddeley's working memory model, the low category is associated with the theory of memory systems and cognitive processes [22]. In addition, the high category is linked to the multimedia design principle, which draws on key concepts and theories, such as Sweller's cognitive load theory and the cognitive theory of multimedia learning by Clark and Sweller [23].

The creation of effective multimedia that enhances learning outcomes must align with the essential design principles, particularly coherence, time-space organization, redundancy, modality, and segmentation [24], [25]. The appropriate model for preparing learning media can be selected based on the lessons and the characteristics of the students [26]. In this study, the structure for preparing electrical engineering education learning media was developed using two models: the self-directed learning model and the guided learning model. Self-directed learning is an approach in which students actively take responsibility for their own learning process. In self-directed learning, students are given the freedom to organize the time, place, and method of learning that best suits their needs and interests. This approach encourages students to become independent and proactive lifelong learners [27]. Guided learning is an approach in which teachers or educators play an active role in directing, assisting, and facilitating students' learning process. In guided learning, teachers provide clear directions, provide learning materials, and help students understand difficult concepts [28]. In these two models, augmented reality is used to build media content that brings objects and events to life through animations and virtual simulations, closely resembling their real-world counterparts [29].

To address the issue of low learning outcomes in electrical engineering education, media based on augmented reality (AR) were chosen and developed as a solution [29]–[31]. If the amount of information to be processed at once is too overwhelming, it can impair students' critical thinking abilities and hinder their capacity to absorb the material, a phenomenon known as cognitive load [32]. The use of suitable instructional media can help minimize intrinsic, extrinsic, and germane cognitive load during the learning process [33], [34]. Multimedia in learning can be employed to deliver instructional content through visuals, audio, videos, and animations, making it easier for students to comprehend the material and improving their cognitive engagement [35]. Numerous published studies have demonstrated the effectiveness of learning that incorporates augmented reality-based multimedia [36].

As technology continues to advance, various augmented reality-based learning tools have been created. The choice of media for teaching electrical engineering education should align with the concepts and characteristics of the media to match the learning content effectively [36], [37]. A number of relevant studies have demonstrated the effectiveness of augmented reality-based media in teaching areas like electrical motor installation, basic electronics, fundamental electrical engineering, and electrical circuits [30]. The advancement of augmented reality-based learning media has kept pace with technological progress, providing innovative and effective solutions for teaching electrical engineering concepts. Research demonstrates their applicability in areas such as electrical motor installation, basic electronics, and electrical circuits, underscoring the need to ensure that the media's features align with the specific requirements of the learning content.

Besides learning media, critical thinking plays a crucial role in determining student learning outcomes. Research has shown that critical thinking has a significant impact on student performance, especially in TVE disciplines, with findings indicating its strong influence on students' success in mathematical competencies [31]. Critical thinking is the ability to analyze, evaluate, and interpret a situation or information objectively and rationally, without being influenced by bias or untested assumptions [38]. This is important so that the current situation can be understood as a whole and evaluated holistically to produce the most optimal decision. This skill is essential for problem-solving in science, encompassing abilities such as arithmetic calculations, verbal reasoning, reading comprehension, sequence analysis, and spatial reasoning, which involve visualizing objects in three dimensions [39]. Additionally, this skill can be utilized to address problems using 3D animation visualization, supported by critical thinking for accurate data analysis [40]. Critical thinking abilities vary from person to person, influenced by factors such as age, gender, and intelligence [41]. This skill can be cultivated to enhance higher-order thinking abilities, contributing to the achievement of optimal performance in areas like machine learning and artificial intelligence [42]. Based on both theoretical and empirical evidence, it is evident that success in electrical engineering education is influenced by the effectiveness of learning multimedia and the development of students' critical thinking skills.

Student learning outcomes in electrical engineering education play a crucial role in determining the professional competence of TVE graduates, especially within the electrical engineering education program. This field requires a solid understanding of fundamental concepts and theories essential for mastering professional skills, including basic electricity, static and dynamic electricity, power generation, semiconductors, electronic circuits, energy, and electrical power [15]. Electrical engineering education, covering a wide range of topics, serves as a foundational requirement for various skill-based subjects that are crucial to students' success in attaining TVE professional competence.

Numerous studies have examined the teaching and learning of basic electrical engineering and its relationship to students' academic competencies. Learning media utilizing AR and virtual reality (VR) have been shown to significantly enhance student outcomes in various fields, particularly in electrical engineering and geo-education [37]. Research has consistently demonstrated that the integration of learning media greatly enhances the quality and efficiency of education in science, technology, engineering, arts, mathematics, and imagineering [43]. Research on learning electrical motor installation has also highlighted the significant impact of critical thinking skills on improving student learning outcomes, alongside the use of effective learning media [31]. Critical thinking skills, encompassing arithmetic proficiency, verbal analogies, and 3D object visualization, have been shown to influence student learning outcomes in social, technology, engineering, arts, and mathematics (STEAM) education [44], [45]. The findings of these studies highlight the significant impact of multimedia learning and critical thinking on student outcomes in STEAM education.

This research takes a focused approach to exploring the effects of augmented reality-based learning media, differences in critical thinking skills, and their combined influence on student achievement within the context of electrical engineering education. By examining these factors, the study aims to provide insights into how advanced technologies and cognitive abilities intersect to enhance learning outcomes. The lessons derived from this research serve as a critical foundation for fostering professional competencies essential to TVE. Furthermore, the anticipated outcomes are poised to offer groundbreaking learning strategies and actionable solutions for improving both the technical skills and academic performance of students. This aligns with the broader goal of preparing a highly skilled and adaptable workforce capable of meeting the demands of modern industry and technology-driven environments.

This research aimed to explore the influence of augmented reality-based learning media and critical thinking skills on student performance in electrical engineering education. The study focused on three primary questions: i) how augmented reality-based learning media (self-directed and guided learning models) affect learning outcomes; ii) the role of critical thinking levels (high and low) in shaping learning outcomes; and iii) the interaction between augmented reality-based media and critical thinking in determining learning outcomes. The findings identified the most effective combination of media and critical thinking levels for improving student performance. This research provided actionable solutions to address low learning outcomes in electrical engineering education and laid the groundwork for enhancing professional competencies, contributing to the overall quality of TVE graduates.

2. METHOD

This study was carried out at the Faculty of Engineering, State University of Medan, Indonesia, using a quasi-experimental design [46]. The learning model incorporated augmented reality-based media as the independent variable, which was divided into two groups: self-directed learning augmented reality (AR.SD) and guided learning augmented reality (AR.GL), with learning outcomes serving as the dependent variable. Critical thinking was used as a moderator variable, categorized into two groups: high cognitive ability (CT.H) and low cognitive ability (CT.L). The details of the methodology employed in this study are presented in Table 1, which outlines the research design.

The research utilized a 2×2 factorial design, involving 138 participants, with 61 in the CT.H group and 77 in the CT.L group. The evaluation of media feasibility followed the multimedia design standards established by Alessi and Trollip [47]. The critical thinking measurement tool was adapted from the Watson-Glaser critical thinking appraisal, while the learning outcomes assessment was created based on the curriculum. Both tools underwent extensive evaluation, including tests for validity, difficulty index, discriminating power, and reliability. The study tested three hypotheses: i) the impact of different types of augmented reality-based learning media on student learning outcomes, ii) the effect of critical thinking levels on student learning outcomes, and iii) the interaction between augmented reality media types and critical thinking levels on student performance. Data were analyzed using descriptive and inferential methods, with a two-way social, technology, engineering, arts, and mathematics (ANOVA) applied after meeting the necessary assumptions [48].

Table 1. Research design

Critical thinking		Augmented reality self-directed learning (A_1)	Augmented reality guided learning (A_2)
	High (B_1)	A_1B_1	A_2B_1
	Low (B_2)	A_1B_2	A_2B_2

3. RESULTS AND DISCUSSION

This study was carried out in the context of electrical motor installation subjects, covering three main topics: i) characteristics of 3 phase induction motors, ii) electromechanical control systems and iii) starting a 3-phase industrial motor. The instructional content was organized using AR media, specifically categorized into two types: AR self-directed learning (AR_{SD}) and AR guided learning (AR_{GL}). The AR_{SD} learning media emphasized creating teaching materials that prioritized students' self-directed learning, while the entire AR_{GL} approach focused on ensuring that students receive the direction and support needed to achieve their learning goals. The illustrations provided include Figure 1, which showcases augmented reality media for 3-phase induction motors, Figure 2, highlighting AR media for components of electromechanical control systems, and Figure 3, featuring media for starting a 3-phase industrial motor.

The data was analyzed using statistical package for social sciences (SPSS) 25.0 software. The statistical analysis results, which were validated through normality and homogeneity tests using the one-sample Kolmogorov-Smirnov test and Levene's test of equality of error variances, are shown in Table 2. As indicated in Table 2, the research data exhibited a normal distribution, and all variables demonstrated homogeneity ($p > 0.05$). This ensures that the statistical assumptions required for further analysis are met, allowing for valid comparisons across the models. Table 3 provides a descriptive summary of the scores in the models, highlighting variations in mean values and standard deviations among the different groups.

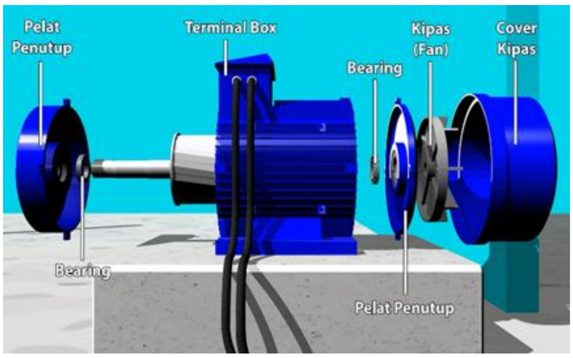

Figure 1. Augmented-reality media for 3-phase induction motors

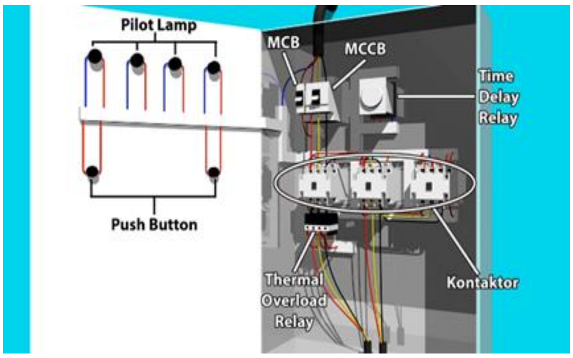

Figure 2. AR media of component electromechanical control systems

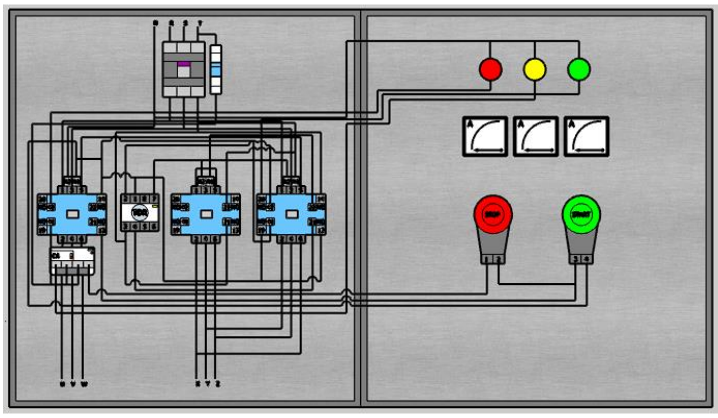

Figure 3. Media of starting a 3-phase industrial motor

Table 2. Statistics prerequisite analysis

Data	Normality test		Homogeneity tests	
Learning outcomes	N	Asymp. Sig	Levene statistic	Sig.
	138	0.365	1.176	0.964

Table 3. Descriptive statistics of learning outcomes

Group	Critical thinking	Mean	Std. Dev	N
AR_{SD}	Low	83.91	0.793	38
	High	87.94	2.265	35
	Total	85.43	1.529	73
AR_{GL}	Low	80.29	1.001	34
	High	86.55	1.542	31
	Total	83.92	1.272	65
Total	Low	82.10	0.897	73
	High	87.25	1.904	65
	Total	82.59	3.207	138

Table 3 shows that student learning outcomes vary according to the type of AR learning medium used. Specifically, students using the AR Self-directed learning (AR_{SD}) media performed better than those using the AR guided learning (AR_{GL}) media. The AR_{SD} group had a higher average test score of 85.43 compared to 83.92 for the AR_{GL} group. This suggests the AR learning materials designed with a self-directing focus were more effective for student learning versus those focused solely on guided learning. Additionally, the analysis shows critical thinking had a significant influence on student outcomes. The group of students with lower baseline critical skills attained a lower average score of 82.10 across both media types compared to their higher ability peers. This implies that student critical factors also impacted the efficacy of the AR learning media.

In summary, the type of AR media used as well as the inherent critical thinking of students were differentiating factors in student performance. The AR_{SD} media designed around self-directing appeared to promote greater learning, while students with higher critical thinking skills overall achieved higher outcomes. Further statistical examination using a two-way ANOVA test was conducted to analyze interaction effects between the variables, with these results reported in Table 4.

Table 4. Results of the two-way ANOVA analysis

Tests of between-subjects effects					
Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	1123.454[a]	3	374.485	159.549	0.000
Intercept	984409.482	1	984409.48	419408.16	0.000
Group	79.691	1	79.691	33.953	0.000
Critical thinking	902.928	1	902.928	384.693	0.000
Group*CT	154.949	1	154.949	66.016	0.008
Error	314.517	134	2.347		
Total	991022.000	138			
Corrected total	1437.971	137			

a. R Squared=.781 (Adjusted R squared=0.776)

The data in Table 4 indicates that the F value exceeded the critical threshold across all tested criteria. This suggests that the independent variables under examination, specifically the AR media formats and critical thinking aptitude levels, exerted a positive influence on the dependent variable of learning outcomes. The robust F statistic of 159.549 for the corrected model and a significant value of $p < 0.05$ confirms the validity of the postulated model. Furthermore, the results of the analysis can be interpreted as follows:

a. The analytical findings demonstrate that the AR media interventions had a statistically significant positive impact on student achievement in electrical motor installation courses. The addition of AR multimedia for self-directing learning in instruction resulted in enhanced academic performance, reflected in a mean score of 85.43 with a standard deviation of 1,529. Similarly, the AR guided learning media enhanced outcomes with mean and standard deviation values of 83.92 and 1,272, respectively. In brief, the incorporation of AR media resulted in superior learning outcomes across various measures, as indicated by the overall mean of 82.59 and a standard deviation of 1,904.
b. Students' critical thinking aptitude levels demonstrated a statistically significant positive link with their academic achievement in the electrical motor installation course. Students with inferior critical thinking capacities had a lower mean score of 82.10 and a standard deviation of 0.897 on examinations measuring learning outcomes. In contrast, students categorized as having higher critical thinking competencies scored markedly better, with a mean of 87.25 and a standard deviation of 1,904 on the same evaluative instruments. This divergence indicates that students' foundational critical thinking abilities are an important predictive factor for their educational achievement in this subject area. Students with greater critical thinking aptitude are likely to absorb and apply the electrical motor concepts more effectively. Meanwhile, students with lower critical thinking skills may struggle to grasp the technical knowledge without additional support. These results highlight the need to account for students' cognitive levels when designing instruction in this course. Additional scaffolding and alternative teaching methods may be necessary to ensure students with lower critical thinking abilities can sufficiently comprehend the material and achieve the desired learning outcomes.
c. Analysis indicates the presence of a significant interactive effect between AR media-supplemented pedagogy and baseline student critical thinking competencies on measured learning outcomes. Overall, students classified as high critical thinking performers displayed superior mean assessment scores 87.25 relative to their low critical thinking counterparts 82.10. Further stratified analysis reveals that for high critical thinking students, both the AR_{SD} and AR_{GL} interventions manifested analogous efficacy, yielding mean scores of 87.94 and 86.55 respectively. However, low critical thinking students demonstrated asymmetry in outcomes, wherein AR_{GL} assisted learning produced a higher mean score 83.91 compared to AR_{SD} assisted learning 80.29. This divergence suggests students' underlying critical thinking faculties may moderate the marginal effectiveness of particular AR multimedia approaches. Additional controlled trials appear merited to further probe this potential aptitude-treatment interaction.
d. The study findings showed that learning aided by AR guided learning media was beneficial for students of all critical thinking ability levels. Nevertheless, the efficacy of AR self-directing learning media exhibited greater variance based on students' ex ante capacities-proving more effective for students with high critical thinking abilities, yet less impactful for those with low critical thinking competencies. In summary, while AR_{GL} multimedia conferred universal benefits, the advantages conferred by AR_{SD} visual aids appeared contingent on students pre-established skill levels. These findings illuminate a potential aptitude-treatment interaction between critical thinking abilities and specific AR media types. Further controlled experiments directly investigating this relationship may be merited.

This study's findings reveal that AR multimedia confers significant benefits for student learning outcomes within science and technology coursework. Many abstract concepts must be taught to students, but conventional pedagogical approaches often prove ineffective for conveying complex, mechanistic phenomena. Our results demonstrate a positive influence of visually-enriched media on retention and hands-on performance in electrical motor installation training [49]. These conclusions align with and expand upon past studies documenting the utility of multimedia supplements for enhancing conceptual understanding in technical domains [21], [50]. The present research also mirrors investigations spotlighting the superiority of animated and simulation-based content for apprehending the dynamics of science, technology, engineering, and mathematics (STEM) systems [51]. Ultimately, the degree of advantage imparted by multimedia aids depends substantially on deliberate, theory-grounded design considerations that align with learner cognition. Looking ahead, instructors must leverage structurally-sound and empirically-validated multimedia tools to maximize scholastic achievement for the intricacies that define modern science and technology curricula [23].

The integration of AR technology plays a crucial role in education, particularly in multimedia learning. The results of this study showed an improvement in student learning outcomes during electrical motor installation sessions, with an average score of 85.29. These outcomes align with previous studies that employed AR learning media, demonstrating its efficacy in enhancing learning outcomes in the electronic and electrical domains [20], [52]. The results of this study supported previous research, highlighting how AR media can enhance learning outcomes in science and technology, aligning with the requirements of the fourth industrial revolution [53].

For every set of responders, a comprehensive analysis was carried out, taking into account the interaction between critical thinking capacities and learning models. Based on varying levels of critical thinking capacity, the investigation showed differences in learning outcomes. In general, media that uses augmented reality, such as AR_{SD} and AR_{GL}, when compared to other multimedia models, it had a considerable favorable influence on student learning results. Additionally, individuals with high critical thinking skills showed better learning results than those with poor critical thinking abilities when degrees of critical thinking ability were taken into account. When examining the interaction between learning models and critical thinking ability, the AR_{GL} model proved effective for both high and low critical thinking ability student groups. However, it was more effective for high critical thinking ability students than for those with low critical thinking ability. These findings underscore the dominant role of critical thinking ability in determining student learning outcomes in AR media. The study's findings support past studies that have suggested the influence of critical thinking capacity on scholastic performance in the areas of physics and basic electronics instruction [54]. The positive impact of critical thinking ability on intricate critical thinking skills has been demonstrated, and it also makes a substantial positive contribution to success across diverse fields [36], [55]. Based on the findings of this study, critical thinking ability emerged as a significant variable influencing students' success, impacting not only in physics but also in STEM disciplines [56].

The method of preparing multimedia learning materials also influenced the extent of students' comprehension of the studied material. The AR_{SD} learning media, characterized by task block design, facilitated independent learning by requiring students to employ higher-order thinking skills and perseverance. Consequently, the study results fundamentally demonstrated that students with high critical thinking abilities achieved superior learning outcomes, whereas those with low critical thinking abilities did not attain optimal results. This contrasted with the guided learning approach, which offered lesson materials concurrently and with unrestricted access. Students in both high and low critical thinking ability groups may attain ideal results, according to the AR self-directing learning, which featured a parallel and open structure of teaching resources. Based on the findings of this study, it is recommended that students with low critical thinking skills use AR_{GL} media, while those with high critical thinking abilities can benefit from both AR_{GL} and AR_{SD}, as both are equally effective for these students.

4. CONCLUSION

Augmented reality greatly improves the role of learning media in teaching abstract and conceptual subjects by using artificial intelligence to turn abstract ideas into tangible visuals. In electrical engineering education, where learning difficulties are still present, especially for students who perform poorly, augmented reality-based learning materials show promise as a way to enhance learning results. In electrical engineering education, critical thinking abilities are a major factor in determining academic success, hence the efficacy of such media depends on matching learning resources with students' cognitive structures. The results of this research led to the following conclusions: augmented reality-based learning media, both AR.SD and AR.GL, were found to be effective in enhancing learning outcomes. Critical thinking ability had a positive and significant impact on learning outcomes in electrical engineering education, with students possessing high critical thinking abilities (CT.H) achieving better results than those with low critical thinking abilities (CT.L), regardless of whether they used AR.SD or AR.GL. Additionally, a significant interaction was observed between the learning model using augmented reality media and students' critical thinking levels. The CT.H group showed positive results with both AR.SD and AR.GL, while the CT.L group was only effective with AR.GL, and AR.SD did not yield significant results for them.

Based on the findings of this study, it is recommended that lecturers teaching electrical engineering education courses utilize the guided learning augmented reality (AR.GL) media. This model was effective in significantly improving student learning outcomes. Moreover, AR.GL media proved to be effective for all student groups, regardless of their critical thinking abilities, whether high or low. With the positive impact on learning outcomes in electrical engineering education, it is anticipated that students' competence and expertise in the field of electrical engineering will also improve, ultimately enhancing the quality of graduates and preparing them to meet the expectations of stakeholders.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study were collected through field research and are available from the first author, BM, and corresponding author, AMS, upon reasonable request. Due to privacy and ethical considerations, some data may be subject to access restrictions.

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