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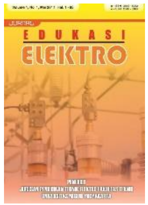

Immersive Technology-Based Adaptive Learning to Improve Academic Achievement and Interpersonal Skills in Electrical Engineering Education

Hanif Rifai Adha, Yuni Rahmawati, Danang Arengga Wibowo, Faiz Hilmawan Masyfa

Universitas Negeri Malang, Malang, Indonesia

Abstract— The Development of digital technology creates significant opportunities to improve the learning experience in the engineering education sector. This study investigates and analyses the impact of Augmented Reality as an immersive learning technology to improve academic achievement and interpersonal skills (collaboration and communication). A quasi-experimental design was used to compare the influence of AR-based learning with conventional learning systems in two classes of 60 students. Pre-test and post-test results showed significant improvement in the experimental class, with paired t-tests showing mean differences of -31.20 ($t = -20.75$, $p < 0.001$) and -18.76 ($t = -13.67$, $p < 0.001$) for the control class. A greater improvement in collaboration and communication skills was observed in the experimental class compared to the control class. The t-test independently revealed significant differences in collaboration skills ($t = 4.92$, $p < 0.000$) and communication skills ($t = 2.71$, $p < 0.000$). AR provides a more interactive learning experience, improving teamwork and effective communication. These results demonstrate that AR has significant potential in enhancing academic capabilities and 21st-century skills in engineering education.

Keywords: academic achievement, augmented reality, collaborative skills, communication, engineering education

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Corresponding Author:
Hanif Rifai Adha,
Universitas Negeri Malang,
Malang, Indonesia
Email: hanif.rifai.ft@um.ac.id

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1 Introduction

The development of digital technology, which is rapidly expanding across various sectors, has a profound impact on social, cultural, and educational life. Issues in the world of education, as reported in the 2023 Indonesian Education Report, explain that the literacy level of students remains at 40% to 70% [1], [2], [3]. Lifestyle factors, combined with advanced technology, make students choose paths that they feel can pamper themselves. This issue poses a challenge in 21st-century education, as it aims to prepare students with the necessary skills [4], [5]. Engineering education plays a vital role in equipping and preparing the younger generation to face the challenges of the modern industrial world and the evolving educational landscape [6], [7], [8], [9]. However, behind the technical skills possessed, interpersonal skills are an essential key in 21st-century skills. As technology advances at an increasingly rapid pace, the ability to work in a team and communicate effectively has become increasingly important, especially in the technology-based education sector. In the technical education sector, several challenges are faced, one of which is creating teaching methods that not only develop students' technical skills but also enable them to work collaboratively and communicate fluently.

One of the most documented pedagogical challenges in engineering education is the difficulty of teaching abstract and non-visible phenomena, such as electromagnetic fields, current flow, and force interaction, which cannot be directly observed in real-world settings. These invisible concepts are notoriously difficult to visualize and comprehend through static diagram or traditional lectures [10]. Many learners develop misconceptions or superficial understanding, especially in subject requiring spatial reasoning and three-dimensional conceptualization [11]. AR can directly address this issue by enabling interactive, immersive visualization that transform abstract phenomena into tangible experience. Through AR, can manipulated 3D simulations, observe dynamic field behavior, and explore invisible forces in real time, thereby narrowing the gap between theoretical models and perceptual understanding [12], [13].

Recent educational innovations indicate that integrating immersive technologies such as AR can enhance conceptual understanding and learning engagement [14], [15]. In engineering education, AR bridges the physical and digital worlds to help student visualize complex technical concepts more realistically and interactively [8], [16], [17]. This approach collaborates and communication by facilitating shared problem-solving in hybrid environment [14]. The implementation of AR in engineering education is in line with the development goals that refer to the SDGs, especially SDG 4, which emphasizes the importance of inclusive, equitable, and quality education in lifelong learning [18], [19]. Meanwhile, the AR technology applied has excellent potential for education by providing affordable and dynamic experience. In addition, SDG 17 highlights the importance of global partnerships in achieving sustainable development by creating innovative technology-based learning [20].

Several studies have explored the application of AR technology in education. This technology can increase concept understanding by up to 35% and motivation by 20% compared to conventional methods. Meanwhile, the application of AR to electromagnetism simulations increased collaborative skills by 40% although the impact on communication has not been explored [17], [21]. In addition, another study found a 25% increase in cognitive and motivational outcomes by 30% [22]. The use of AR can create up to 50% class participation, demonstrating the great potential of AR in creating an engaging and inspiring learning environment [23]. However, some research focuses on the technological aspects and has not thoroughly examined AR implementation strategies that support 21st-century skills, particularly collaboration and communication [24], [25], [26]. Therefore, this study proposes strategic AR-based learning to evaluate its impact on learning outcomes, including both academic and interpersonal skills in the 21st century, especially those related to collaboration and communication.

This study aims to examine the influence of applying AR technology in the engineering education sector, particularly in enhancing academic achievement, as well as collaborative and communication skills. This research focuses on analyzing the extent to which AR technology can optimize students' learning experiences, enhance team collaboration, and improve communication in the engineering education sector. These are two essential elements needed in the world of industry 4.0 for the quality of education to improve.

Considering this, the researcher formulated two research formulations:

1. How does Augmented Reality technology affect the student's learning outcomes int the electromagnetic field course?
2. How does Augmented Reality technology impact the improvement of collaborative and communication skills in engineering education?

2 Method

2.1 Research Activities

This study employs a quasi-experimental design to assess the impact of integrating AR in engineering education. It compares learning outcomes and interpersonal skills between a control class (conventional learning) and an experimental class (AR-supported learning). The research involves 60 participants, selected from two existing classes via convenience sampling due to scheduling constraints. The participants included 46 male and 14 female sophomore students, all of whom have been exposed to electromagnetic fields.

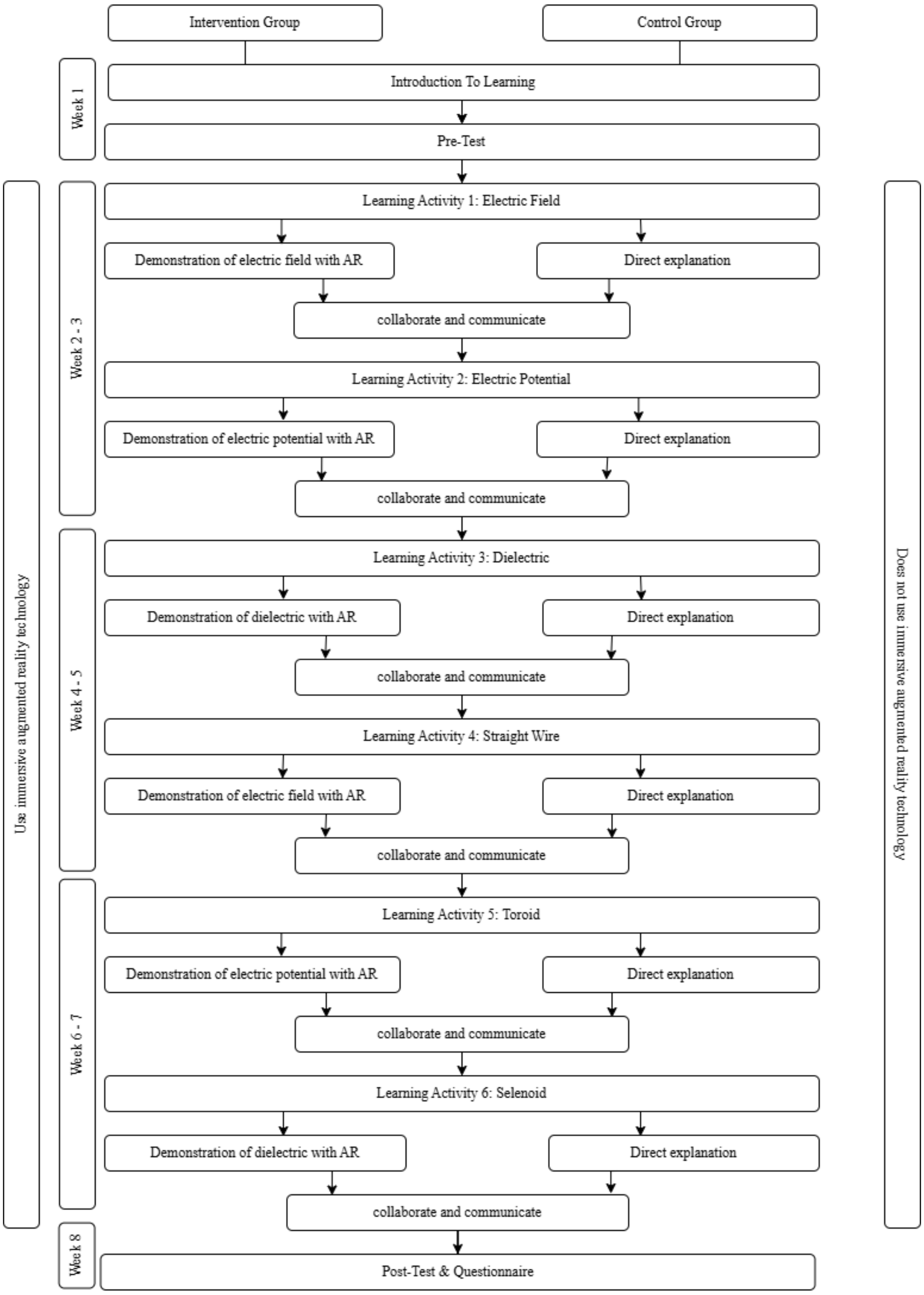

Figure 1. Research Activities

Figure 1 illustrates the sequence of activities implemented in this quasi-experimental study. Both classes participated in Electromagnetic Field learning session conducted face-to-face in the classroom, with primary distinction being instructional treatment applied. The experimental class engaged in learning integrated with immersive AR technology, while the control class received conventional instruction without AR integration. Although convenience sampling was employed due to scheduling constraints, both classes were confirmed to have comparable academic abilities prior to treatment. Pre-test analysis indicated no statistically significant difference between the experimental (M=50.266) and control groups (M=51.166), suggesting baseline equivalence before AR integration.

In the experimental class, AR based learning material were presented in 3D visualization, allowing students to observe the electric and magnetic field phenomena from multiple perspectives [27], [28]. This immersive approach enabled learners to visualize abstract and non-visible electromagnetic concepts more concretely. Through these activities, students were encouraged to collaborate and communicate during group discussions and problem-solving sessions with AR learning environment. Such engagements were expected to stimulate the development of interpersonal competencies, particularly collaboration and communication skills [29].

Meanwhile, in the control class, students followed learning activities using conventional module. The instruction was delivered through direct explanations by lecturer, followed by discussion based on the student's manual observation and problem-solving outcomes. Both classes covered identical topics. Such as Electric Field, Electric Potential, Dielectric, Straight Wire, Toroid, and Solenoid. Over eight weeks, ensuring content equivalents across treatments.

The research flow began with an introduction and pre-test to assess students' prior knowledge in week 1, followed by six structural learning activities across week 2-7, as shown in fig. 1. Each cycle consisted of concept introduction, demonstration (AR-based or conventional), and collaboration – communication phases. Finally, in week 8, both classes completed a post-test and questionnaire to evaluate learning outcomes and interpersonal skills. The structured flow ensured parity in learning content and timing while allowing a clear comparison of how immersive AR learning influences students' conceptual understanding, collaboration, and communication compared to traditional instruction.

2.2 AR integration in Learning Engineering Education

This study introduces an AR-based learning approach for engineering education, with a focus on electromagnetic field courses. As shown in Figure 2, the AR environment enables students to interact with learning elements and manipulate visual parameters, creating an immersive learning experience. Visual effects can be customized to highlight specific concepts, for example, adjusting field magnitude or voltage to scaffold deeper analytical thinking. The models are also rotatable through 360 degrees, allowing observation from multiple perspectives and supporting spatial reasoning on topics such as magnetic field lines and electric field distributions. These affordances grant learners greater control to personalize their learning pathways according to individual needs. In turn, the shared, manipulable visual workspace supports collaborative exploration and clearer communication among peers, strengthening interpersonal skills, as illustrated in Figure 3.

Figure 2. AR integration in Electromagnetic Course

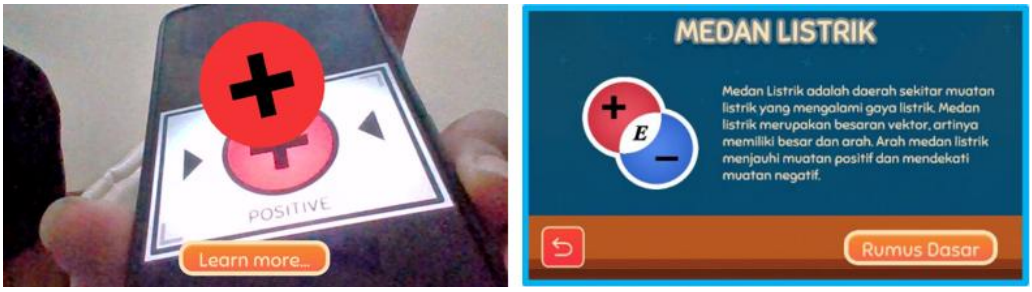

Figure 3. Illustrated Electric Field Course

2.3 Research Diagrams

The flow and structure of the research conducted are described in Figure 4, which outlines the process from problem identification to the presentation of research results.

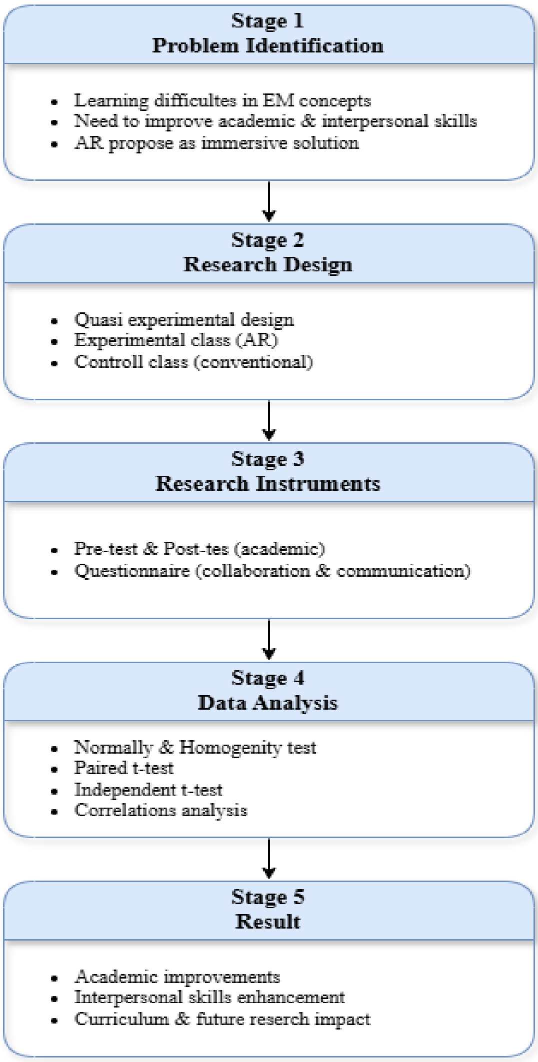

Figure 4. Research Stages

The first stage involved identifying problems that arise in the engineering education sector, particularly in the electrical engineering education program. The problem that occurs is in the form of a mind that is fixated on the difficulty of electromagnetic field courses, so that it is considered a scourge that will be difficult for the knowledge of reason to accept. In addition, the concept of terrain theory, which is only explained in a story, adds to the burden on this learning. The common thread in research is the improvement of collaborative skills and communication through augmented reality in engineering education, as well as the influence of augmented reality technology on academic achievement in engineering. The core of the problems that arise focuses on two main aspects: academic achievement and interpersonal skills. In this regard, the goal is to explore academic achievement and collaborative and communicative skills in engineering education students.

In the second stage, the research design was applied using a quasi-experimental design with two classes of participants: the experimental class and the control class. The experimental class received learning treatment using augmented reality, while the control class received direct learning treatment, also known as conventional learning. Each class underwent learning activities as outlined in Figure 1.

The third stage involves explaining the research and data collection instruments used. The data collected in this study are the values obtained from measuring students' knowledge levels through pre-test and post-test question instruments, which determine the level of knowledge before and after treatment. Additionally, it employs instruments, such as questionnaires, to measure the impact of augmented reality-based immersive technology on collaborative and communication skills. The interpersonal skills questionnaire underwent validity and reliability testing prior to its implementation. Content validity was reviewed by three experts in engineering education and educational psychology. Reliability analysis showed strong internal consistency, with Cronbach's Alpha coefficients of 0.89 for collaboration skills and 0.87 for communication skills, indicating that the instruments is highly reliable for measuring interpersonal competencies in engineering education contexts.

In the fourth stage, data is processed and analyzed based on appropriate data analysis techniques. The data collected from the pre-test and post-test results are tested for normality and homogeneity. The test is designed to ensure that the analyze data can be interpreted as valid and to determine the appropriate analysis method. Then it was further tested using parametric testing with a pair t-test to determine the improvement in learning outcomes for each class. Independent testing was used to compare interpersonal skills between the experimental class and the control class. Correlation testing was used to determine the strength of the relationship between the application of immersive technology and academic achievement and interpersonal skills.

The fifth stage involves outlining the research results and evaluating the application of augmented reality's significant impact on students' academic achievement and interpersonal skills. The research findings will later be used as a reference to contribute to the development of the electrical engineering education curriculum and as a follow-up study focusing on engineering education.

3 Results and Discussion

3.1 Increased Academic Achievement

In engineering education, certain subjects, such as electromagnetism, present significant challenges due to their abstract nature and difficulty in visualization using conventional teaching methods [30]. Unlike more tangible subjects, electromagnetism requires specialized teaching approaches to facilitate understanding, as students often struggle to grasp complex concepts without interactive and immersive tools. The absence of direct interaction with the content, compounded by heterogeneous student backgrounds, contributes to disengagement and low comprehension, particularly in analytical tasks [2], [31]. To address these challenges, integrating into Augmented Reality (AR) has emerged as a promising solution. AR allows students to engage with abstract concepts through 3D visualizations, fostering deeper cognitive engagement and enhancing their ability to independently conceptualize and analyze difficult topics.

This study aims to assess the impact of AR on academic achievement in the Electromagnetic Field course by comparing the performance of two groups, one utilizing AR-based learning and the other receiving conventional instruction. The academic achievement was evaluated through pre-test and post-test assessments administered to 60 students. Both groups showed significant improvements in their learning outcomes, with the experimental group demonstrating a more substantial increase in academic performance, suggesting that AR-based learning enhances students' understanding of complex concepts in electromagnetism.

Table 1. Analysis of Learning Outcomes with T-Test

Class		Mean	N	Correlation	Paired Differences					
					Mean	Std. Dev	Std. Err Mean	t	Df	Sig. (2-tailed)
Int	Pre	50.266	30	0.789	-31.20	8.235	1.50	-20.75	29	<0.001
	Post	81.466								
Con	Pre	51.166	30	0.884	-18.76	7.518	1.37	-13.67	29	<0.001
	Post	69.933								

Table 1 presents the results of the paired t-tests used to analyze changes in pre-test and post-test scores for both the experimental and control groups. Each group consisted of 30 students. In the experimental group, the average pre-test score was 50.266, which increased to 81.466 following the intervention. The mean difference was -31.20, which was statistically significant ($t = -20.75$; $df = 29$; $p < 0.001$) with standard deviation of 8.235. In comparison, the control group's pre-test score was 51.166, and the post-test score 69.93, reflecting a mean difference of -18.76 ($t = -13.67$; $df = 29$; $p < 0.001$) and standard deviation of 7,518.

These findings indicate a significant improvement in learning outcomes for both groups, with the experimental group showing a greater increase. Specifically, the experimental group demonstrated a more substantial improvement in academic achievement compared to the control group. The positive effect of AR-based learning on student outcomes is evident, as the immersive AR environment likely facilitated a deeper understanding of complex electromagnetic phenomena. By allowing students to interact with abstract concepts in a three-dimensional space, AR technology enhanced both conceptual understanding and material retention. The p-value of <0.001 further confirms the significant impact of AR-based learning compared to traditional instructional methods.

Although the control group also experienced an improvement in learning outcomes, other factors such as teaching methods and external motivational influences may have contributed to the observed engagement. While the AR intervention was beneficial, it is important to consider these additional factors, as they may have played a role in shaping the students' academic performance. Future studies should explore these variables to gain a more comprehensive understanding of the factors influencing learning outcomes.

3.2 Strengthening the perception of collaborative and communication skills

In the context of 21st-century education, collaboration and communication are recognized as core competencies essential for preparing students to navigate increasingly complex global and technological challenges [8], [32], [33], [34]. These skills enable learners to work effectively with others, exchange ideas, and develop logical, efficient solutions through teamwork and clear communication. Collaboration fosters the integration of diverse perspectives to achieve shared goals, while communication ensures that ideas are conveyed persuasively and meaningfully within group interactions.

This study examines the development of these interpersonal skills following the application of Augmented Reality (AR) in engineering education. Data on students' collaboration and communication skills were collected through a 5-point Likert-scale questionnaire administered after the learning intervention. The results revealed that the experimental group, which participated in AR-based learning, showed significantly greater improvement in both collaboration and communication skills compared to the control group. These findings suggest that immersive AR learning environments effectively enhance students' ability to collaborate and communicate, which are vital components of 21st-century competencies.

Table 2. Interpersonal Skills Test Results

Class		Mean	N	Std. Deviation	t-test			
					t	Sig. (2-tailed)	Mean difference	Std. Err Diff
Coll	**Int**	85.233	30	8.165	4.922	<0.000	11.600	2.356
	Cnt	73.633		9.998				
Comm	**Int**	82.166	30	8.107	2.707	<0.000	7.366	2.720
	Cnt	74.800		12.50				

Table 2 presents the results of the independent t-test used to compare interpersonal skills between the experimental and control classes, each consisting of 30 students. The findings show that the experimental class achieved higher mean scores in both collaborative and communication skills compared to the control class. Specifically, the mean score for collaborative skills was 85.233 (SD = 8,165) in the experiments class and 73.633 (SD = 9.998 in the control class. A t-value of 4.922 and a significance level of $p < 0.001$. Similarly, the mean score for communication skills was 82.166 (SD = 8.107) in the experimental class and 74.80 (SD = 12.50) in the control class. With a t-value of 2.71 and a significance level of $p < 0.001$.

These results indicate a statistically significant difference between the two groups, confirming that students exposed to AR-based immersive learning demonstrated stronger collaboration and communication abilities. The findings suggest that the use of immersive technology, particularly Augmented Reality, effectively enhances students' interpersonal skills, supporting the development of key 21st-century competencies in engineering education.

Table 3. Correlation of Learning Outcomes with Skills

Learning Outcomes \ **Interpersonal Skill**		**Collaborative**	**Communication**
Post-Test	Correlation	1.000	0.948
	Sig. (2-tailed)	-	<0.001
	df	0	57
	Correlation	0.948	1.000
	Sig. (2-tailed)	<0.000	-
	df	57	0

After conducting the t-tests to compare differences in learning outcomes between the experimental and control groups, a correlation analysis was performed to examine the interrelationship between the two interpersonal skill dimensions—collaboration and communication. This analysis aimed to determine whether improvements in one skill were accompanied by similar enhancements in the other. The results, as shown in Table 3, revealed a strong and statistically significant positive correlation ($r = 0.948$, $p < 0.001$), indicating that both collaboration and communication skills tend to develop concurrently. This finding suggests that the immersive AR-based learning environment not only improves each skill individually but also strengthens their mutual reinforcement as part of the overall interpersonal competence framework.

4 Conclusion

This study demonstrates that the application of Augmented Reality can significantly enhance academic achievement and interpersonal skills, particularly in areas such as skills and communication. The analysis of the pre-test and post-test results revealed a significant increase in both experiments following the integration of augmented reality technology. This technology enables the creation of immersive and efficient learning experience. The results of the t-test and correlation test reinforce the finding that collaborative and communication skills develop simultaneously, supporting better academic achievement. This study supports the concept of adaptive learning based on immersive technology as an effective method for improving the quality of education in the 21st century

5 Future Suggestion

Further research can explore and apply psychological aspects in the application of augmented reality to engineering education in a more in-depth way to understand psychological factors through interaction with learning technologies. Additionally, the levels of technological comfort, device accessibility, and individual differences in learning needs require further investigation. To develop the scope of the impact of technology on the interpersonal skills needed in the world of education and industry

6 Acknowledgment

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8 Authors Biography

Hanif Rifai Adha is a lecturer in the Electrical Engineering Education study program, specializing in Learning Technology of Engineering Education, Electrical Power System Engineering, and Industrial Automations at the Department of Electrical Engineering and Informatics, Faculty of Engineering, State University of Malang, Indonesia. He is active in the Electrical Distribution and Installation Laboratory, and Control Systems (email: hanif.rifai.ft@um.ac.id).

Yuni Rahmawati holds midwives in Planning, Data and Information, Ranking, Public Relations, and Cooperation. She is a lecturer at Electrical Engineering Education, Faculty of Engineering, State University of Malang, Indonesia (email: yuni.rahmawati.ft@um.ac.id).

Danang Arengga Wibowo is a lecturer in the Electrical Engineering Education program, specializing in Instrumentation Systems and Technology Engineering, at the Department of Electrical Engineering and Informatics, Faculty of Engineering, State University of Malang, Indonesia. Active as a member of the Indonesian Engineers Association (PII) since 2021. (email: danang.arengga.ft@um.ac.id)

Faiz Hilmawan Masyfa is a doctoral candidate in Computer Science and lecturer in the Informatics Engineering Program at Malang State University, active in the fields of knowledge engineering and data science, specializing in data science and gamification for education (email**:** faiz.hilmawan.ft@um.ac.id).