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Enhancing learning activity and learning outcomes in the electrical installation course using augmented reality

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ABSTRACT

Student engagement and learning outcomes are two interrelated aspects that determine the effectiveness of the teaching and learning process. This study aimed to analyse the impact of Augmented Reality (AR)-based learning on student engagement and academic achievement compared to conventional instruction. The research employed a quasi-experimental design with an experimental and a control class. Student engagement was assessed through cognitive, affective, and psychomotor dimensions, while learning outcomes were measured using a post-test. The findings revealed that AR-based learning significantly improved student engagement across all domains, with average scores of 91.35% in the cognitive domain, 87.54% in the affective domain, and 90.04% in the psychomotor domain, all surpassing the success threshold of >75%. Conversely, the control class achieved only 79.67% in the cognitive domain, while the affective (66.62%) and psychomotor (69.34%) domains fell short of the expected standard. Similarly, the experimental group demonstrated higher academic performance, with a mean post-test score of 91.21, compared to 66.46 in the control group. These results indicate that AR-based learning not only fosters active student participation but also enhances academic achievement. The study implies that integrating innovative, technology-enhanced strategies in higher education is essential for promoting holistic learning that prepares graduates for professional and digital-era challenges.

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INTRODUCTION

Student activeness is one of the key indicators of successful learning in higher education (Li & Xue, 2023). Active students tend to demonstrate higher cognitive, affective, and psychomotor engagement, enabling them to internalise concepts more effectively (Liu, 2024; Pratomo et al., 2025). In the context of technical education, particularly in the Electrical Installation course, student engagement is crucial because the subject matter is not only conceptual but also demands practical skills that require spatial and procedural understanding (Ariza, 2023). Without active participation, students risk experiencing a gap between theoretical mastery and the practical skills needed in the workplace (Porat & Ceobanu, 2024). Sustained engagement in such courses also fosters problem-solving skills, critical thinking, and adaptability, which are essential competencies in the rapidly evolving technical industry (Tsai et al., 2024). Furthermore, active involvement enhances collaborative learning experiences, allowing students to develop teamwork and communication skills that are vital for professional success (Ruiz-Rojas et al., 2024).

Unfortunately, conventional teaching methods still primarily focus on one-way delivery of material through lectures and limited demonstrations (Özden et al., 2024). This often results in students becoming passive recipients of information, with little involvement in the learning process. In fact, research has shown that active student engagement can enhance motivation to learn, knowledge retention, and problem-solving skills (Castillo et al., 2023). In vocational and technical education, active participation also affects students' work-readiness and adaptability to technological developments in industry (Alhawiti, 2023). Moreover, insufficient opportunities for hands-on learning may hinder the development of practical competencies critical to professional performance (DelaTorre-Díaz et al., 2025). Consequently, there is a growing need to adopt innovative pedagogical approaches that promote deeper involvement and interaction throughout the learning process (Chao & Li, 2025).

AR has emerged as an innovative technology that can facilitate increased student engagement (Zhang et al., 2024). AR enables the integration of three-dimensional virtual objects into the real world, allowing students to directly interact with simulations of electrical equipment and circuits visually and interactively (Mukhlisin et al., 2025). Studies developing the AR Laboratory Environment (ARLE) have shown that students become more active in exploring concepts, independently experimenting with electrical installation configurations, and demonstrating improved technical skills (Kovalev et al., 2025; Palada et al., 2024).

However, the effectiveness of AR in enhancing student activeness has not been entirely consistent (Kim & Choi, 2025). A study used the application as a laboratory preparation tool and found that although students reported high engagement, there was not always a significant improvement in learning outcomes or long-term motivation compared to traditional methods (Goh, 2025). Several studies have also indicated that the novelty effect of technology may boost activeness only at the initial stage, but this tends to decline over time if not supported by appropriate instructional design (Cicconi, 2024; Rayan & Watted, 2024).

Furthermore, previous research has tended to focus more on measuring students' perceptions of AR than on objectively assessing activity through indicators such as participation analysis, interaction frequency, or initiative in completing tasks (Mohamad & Husnin, 2023). The scarcity of studies linking AR use to objectively measured student activity creates a clear research gap (Kim & Choi, 2025). Moreover, very few studies have combined AR with a robust experimental design, such as the Solomon Four-Group Design, which can isolate the effect of technology on student activity from other factors, such as pretest effects or initial motivation (Mukhlisin et al., 2025).

In response to these conditions, the present study is designed to examine the effectiveness of AR in improving student engagement in the Electrical Installation course at the higher education level. By employing the Solomon Four-Group experimental design, this research aims to provide stronger empirical evidence on the impact of AR on student engagement, while offering an innovative instructional strategy relevant to technical and vocational education in the digital era. Furthermore, the study investigates how increased student engagement contributes to improved learning outcomes, thereby providing a more comprehensive understanding of the pedagogical value of AR in technical education.

METHOD

This study employed an experimental method using the Solomon Four-Group Design. This design was selected because it allows for the examination of the effects of AR technology on enhancing students' learning activity in the electrical installation course, while simultaneously controlling for potential pretest effects that may influence the results (Jdaitawi et al., 2022). In this design, students were divided into four groups: an experimental group with a pretest, a control group with a pretest, an experimental group without a pretest, and a control group without a pretest (Ssemugenyi, 2023). The experimental groups received instruction using AR-based learning, whereas the control groups participated in conventional learning without AR. The study was conducted across four universities offering electrical engineering programs during the 2024/2025 academic year. The population consisted of all students enrolled in the electrical installation course, and the sample was selected via cluster random sampling based on available class sections, totalling 139 students, as shown in Table 1.

Table 1. The Solomon Fourth Group Design Experimental

No.	Group	Pretest	Treatment	Posttest
1	Experiment 1	O_1	X_1	O_2
2	Control 1	O_3		O_4
3	Experiment 2		X_2	O_5
4	Control 2			O_6

The study was conducted across four universities offering electrical engineering programs during the 2024/2025 academic year. The population consisted of all students enrolled in the electrical installation course. Experiment 1 was conducted at University A with 34 students, Control 1 at University B with 35 students, Experiment 2 at University C with 35 students, and Control 2 at University D with 35 students. The experimental groups received AR-based learning interventions, whereas the control groups participated in conventional instruction without AR.

Data collection techniques use observation and tests in the form of descriptions. The research instruments comprised two main components: a student learning activity observation and a cognitive test. The learning activity observation was designed to assess student engagement during the learning process. To ensure the accuracy and objectivity of the collected data, the observation process was conducted by three independent observers who had been trained to use the observation instrument consistently. In contrast, the cognitive test was used to assess students' learning outcomes and examine the relationship between engagement levels and academic achievement. The data from observations of student activities were analysed by describing the stages of learning using Formula 1 (Purwanto, 2013).

$$NP = \frac{R}{SM} x\ 100 \quad (1)$$

Information:
NP: Per cent Value
R: Score Acquisition
SM: Ideal Maximum Score of Test Points
100: Fixed Number

Student learning engagement is considered successful when it meets the criterion of achieving a score of 75% or higher. This benchmark serves as a standard to evaluate the extent to which students are actively involved in the learning process. In this context, learning can be regarded as both effective and of high quality if all, or at least the majority (75%), of students demonstrate active participation across the three dimensions of engagement: cognitive, affective, and psychomotor. These dimensions reflect not only students' intellectual involvement but also their emotional commitment and practical participation during the learning process. To systematically assess this engagement, an observation instrument was employed, as presented in Table 2, which provides detailed indicators for measuring student activity throughout the learning sessions.

Table 2. Student Activity Observation Instrument

Aspects	Description of Observable Behaviour	Indicator
Cognitive	1. The student prepares for class by bringing learning resources and opening relevant materials before the session begins.	1. Bringing learning materials and preparing notes.
	2. The student remains attentive throughout the class, avoids distractions, and follows the lecturer's instructions.	2. Maintaining focus on the lecturer's explanation.

Aspects	Description of Observable Behaviour	Indicator
Affective	3. The student actively seeks or proposes solutions when facing challenges in understanding the lesson content.	3. Attempting to find solutions when encountering difficulties.
	4. The student connects the concepts learned to practical experiences or workplace situations.	4. Relating lesson content to real-life applications.
	5. The student shows enthusiasm in participating in class and responds positively to the lecturer's questions.	5. Demonstrating interest and motivation in learning.
	6. The student participates actively in group discussions or collaborative tasks.	6. Actively engaging in group work.
	7. The student completes assigned tasks within the given deadlines.	7. Completing assignments on time.
	8. The student demonstrates interest in further exploring the lesson content outside of class sessions.	8. Showing willingness to learn beyond class hours.
	9. The student actively asks questions or shares opinions during class discussions.	9. Asking questions or expressing opinions.
Psychomotor	10. The student can demonstrate skills or procedures in accordance with the lecturer's instructions.	10. Performing learned skills during class activities.
	11. The student proactively engages in learning activities without waiting for the lecturer's instructions.	11. Voluntarily engaging without prompts.
	12. The student directly and actively participates in practical or laboratory-based learning activities.	12. Actively participating in hands-on activities.

Learning outcome data were first subjected to preliminary assumption testing, including the Kolmogorov–Smirnov test for normality and Levene's test for homogeneity of variance. Once the statistical assumptions were met, further analysis was conducted using Analysis of Covariance (ANCOVA) and Independent Samples t-test to determine the effect of AR on student engagement and its relationship with improved learning outcomes. If the results of the ANCOVA show a significance value (p) < 0.05, this can be interpreted as indicating a statistically significant difference between the experimental group and the control group after accounting for the influence of initial ability (Wu et al., 2025). Meanwhile, for the Independent Sample t-Test, if the significance value (p) < 0.05, it can be concluded that the two groups exhibit a statistically significant difference in learning achievement (Bagheri et al., 2025). The test instrument for the electrical installation course's learning outcomes is shown in Table 3.

Table 3. Electrical Installation Course Learning Outcome Test Instrument

No.	Question
Q1	Explain the definition of a simple household electrical installation and identify its main components.
Q2	Draw a single-line diagram representing the electrical installation of a house with two bedrooms, one living room, and one kitchen.
Q3	State and explain the function of an MCB (Miniature Circuit Breaker) in a simple household electrical installation.
Q4	Describe the procedure for installing a single-pole switch to control the lighting in the living room.
Q5	Explain the differences in application between NYA, NYM, and NYY cables in a simple household electrical installation.
Q6	List the safety inspection steps that must be taken before starting work on a simple household electrical installation.
Q7	Calculate the total electrical power consumption (in watts) for a house equipped with six 15-watt LED lamps, two 60-watt electric fans, and one 150-watt refrigerator. Also, determine the total current required if the supply voltage is 220 V.
Q8	Explain the concept of grounding in a simple household electrical installation and its function.
Q9	Identify common causes of electrical faults in a simple household electrical installation and describe appropriate troubleshooting measures.

No.	Question
Q10	Provide the routine maintenance steps necessary to ensure that a simple household electrical installation remains safe and efficient.

RESULTS AND DISCUSSION

Results

The results of this study focus on two main aspects: the analysis of students' activity levels during the learning process and the analysis of improvements in students' learning outcomes following the intervention. The analysis of student activeness was conducted to determine the extent to which the implementation of AR-based learning could foster students' cognitive, affective, and psychomotor engagement during the Electrical Installation course. Student engagement is recognised as a critical indicator of successful learning, as active participation in the learning process is believed to strengthen conceptual understanding.

Implementation of AR in the Electrical Installation Course

The implementation of AR in the Electrical Installation course was carried out through a series of structured stages designed to maximise students' interaction with the learning materials and instructional objects. In the initial stage, the instructor introduced the AR application and provided a brief demonstration on how to scan markers, manipulate three-dimensional objects, and access simulation features. This approach ensured that all students possessed a basic understanding of how to operate the application before engaging in the core learning activities.

During the learning process, AR was used as the primary medium to help students understand electrical concepts that are often difficult to grasp when delivered solely through two-dimensional images on the whiteboard or in textbooks. By utilising AR, students were able to visualise electrical circuits in three dimensions, zoom in on and rotate components, and observe the interrelationships between the installation's elements more clearly. The AR visual representation enabled students to independently explore circuit structures and gain a comprehensive understanding of each component's function, as shown in Figure 1 below.

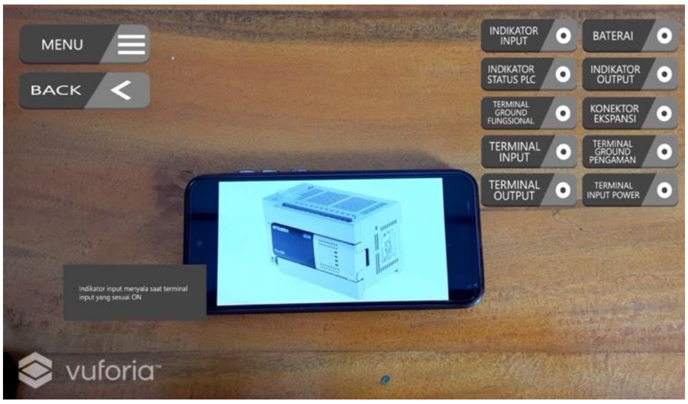

Figure 1. Student Activity Data in Experiment 1 and Control 1

Student Activeness Analysis

The data on student activity were collected through direct observation during the Electrical Installation course sessions. Three trained observers carried out the observations to ensure consistency in the assessment process. The observation instrument was developed based on three main dimensions of student activeness: cognitive, affective, and psychomotor. The observations were conducted continuously during each learning session, both for the experimental group, which utilised AR, and for the control group, which employed conventional teaching methods. All observation data were compiled, analysed, and presented as bar charts to facilitate comparison between groups. The presentation of data in Figure 2 aims to provide a visual representation of the differences in student activeness levels across the three measured dimensions for each group.

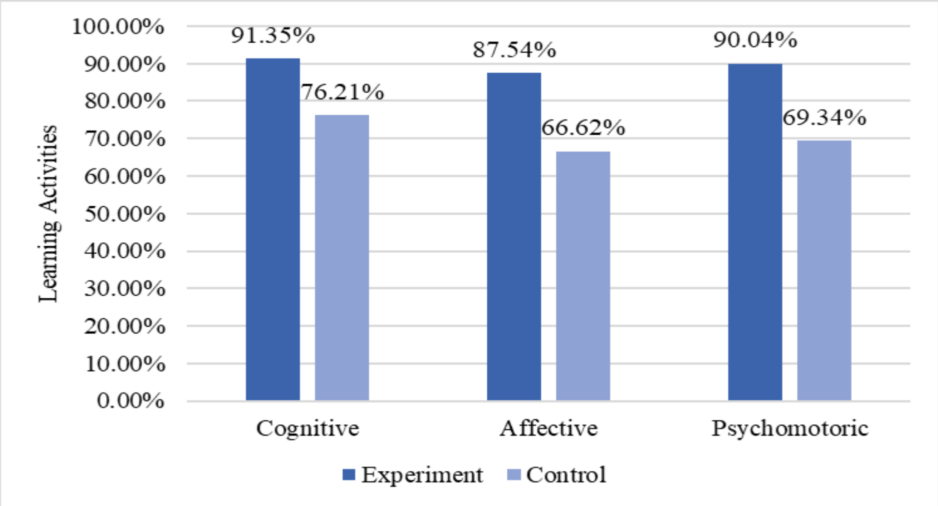

Figure 2. Student Activity Data in Experiment 1 and Control 1

Based on the graph, there is a noticeable difference in student learning activities between the experimental and control classes across the three dimensions: cognitive, affective, and psychomotor. In the cognitive dimension, students in the experimental class achieved a learning activity level of 91.35%, which was higher than that of the control class (76.21%). This finding indicates that the instructional approach implemented in the experimental class was more effective in encouraging critical thinking, conceptual understanding, and problem-solving skills. In the affective dimension, the experimental class reached 87.54%, while the control class achieved only 66.62%. This suggests that students in the experimental class demonstrated greater motivation, enthusiasm, and positive attitudes toward the learning process compared to their counterparts. In the psychomotor dimension, the experimental class again showed superior outcomes, with 90.04% compared to 69.34% in the control class. This result reflects the effectiveness of the experimental learning model in fostering practical skills, active participation, and hands-on engagement.

Overall, the findings reveal that the experimental class demonstrated a consistently high level of learning engagement, with scores exceeding 85% across all measured dimensions. This performance not only surpassed the minimum benchmark of >75% but also indicates that the instructional approach in this class fostered optimal levels of student activity. In contrast, the control class showed relatively weaker results, particularly in the affective and psychomotor dimensions, with scores remaining below the success threshold. These results show that the learning method implemented in the experimental class was more effective at promoting comprehensive student engagement across cognitive, affective, and psychomotor domains than the conventional instructional approach.

Analysis of Improving Student Learning Outcomes

Before examining differences in students' learning outcomes between the experimental and control groups, preliminary assumption tests were carried out to ensure that the data met the required statistical assumptions. These preliminary tests included a normality test to determine whether the learning outcome data were normally distributed and a homogeneity-of-variance test to verify the equality of variances across groups. The normality test was performed using the Kolmogorov–Smirnov method, while the homogeneity of variance was assessed using Levene's Test, which can be seen in Table 4.

Table 4. Normality Test Results for Experimental 1 and Control 1

Group		Kolmogorov-Smirnov[a]		
		Statistic	**df**	**Sig.**
Learning Outcomes	Pretest Experiment$_1$	.137	34	.108

Group	Kolmogorov-Smirnov[a]		
	Statistic	**df**	**Sig.**
Posttest Experiment$_1$	.128	34	.174
Pretest Control$_1$	.143	35	.068
PosttestControl$_1$	.140	35	.079

The results of the Kolmogorov–Smirnov normality test presented in Table 4 indicate that all significance (Sig.) values for both the pretest and posttest data in the experimental and control groups are above 0.05. This finding suggests that the distribution of learning Outcome data across all groups meets the assumption of normality. With this assumption fulfilled, the learning outcome data are deemed appropriate for further analysis using parametric statistical tests to more accurately examine differences in learning achievement between the experimental and control groups. Subsequently, the same normality test was conducted on the learning outcome data for Experimental Class 2 and Control Class 2. The testing procedure used the Kolmogorov–Smirnov method on the first set of groups.

Table 5. Normality Test Results for Experimental 2 and Control 2

Group		Kolmogorov-Smirnov[a]		
		Statistic	**df**	**Sig.**
Learning Outcomes	Posttest Experiment$_2$	.135	35	.108
	Posttest Control$_2$	.131	35	.138

The results of the Kolmogorov-Smirnov normality test presented in Table 5 indicate that the significance (Sig.) value for the Posttest Experimental 2 group is 0.108, and for the Posttest Control 2 group is 0.138, both of which exceed the threshold of 0.05. These findings suggest that the distribution of learning outcome data for both groups meets the assumption of normality. With this assumption satisfied, the learning outcome data from the Experimental 2 and Control 2 groups are deemed suitable for further analysis using parametric statistical tests, thereby allowing a valid and reliable examination of differences in learning achievement between the groups.

After the normality test was conducted and the data were confirmed to follow a normal distribution, the next step prior to performing parametric statistical analysis was to examine the homogeneity of variances. The purpose of this test is to determine whether the variances or the spread of data across the groups being compared are statistically equivalent. The homogeneity of variance was assessed using Levene's Test, which tests whether the variances differ significantly across groups. If the significance value (Sig.) exceeds 0.05, the variances are considered homogeneous, and the assumption of homogeneity is deemed to be met. The results of the homogeneity test are presented in Table 6.

Table 6. Results of the Homogeneity Test

Levene Statistic	df1	df2	Sig.
.27	3	139	.839

Based on the results of the homogeneity of variance test using Levene's Test, as presented in the table, a significance value (Sig.) of 0.839 was obtained. This value is substantially higher than the critical threshold of 0.05, indicating that there is no significant difference in variance among the groups compared in this study. Therefore, it can be concluded that the learning outcome data across the four groups exhibit homogeneous or equal variances. Homogeneity of variance is a fundamental assumption that must be met before performing parametric statistical analyses such as ANCOVA or the Independent Samples t-test. When this assumption is satisfied, the results of inferential analyses are considered more valid and unbiased, as equal group distributions ensure the integrity of statistical comparisons.

Subsequently, after confirming that the learning outcome data for the Experimental 1 and Control 1 classes met the assumptions of normality and homogeneity of variance, an ANCOVA was conducted. This analysis aimed to examine differences in learning outcomes between the two groups while controlling for prior ability (pretest) as a covariate. By employing ANCOVA, the analysis was expected to provide a more accurate depiction of the effect of the Augmented Reality-based instructional intervention on students' learning outcomes, controlling for variations in their initial abilities.

Table 7. ANCOVA Analysis Results for Experimental 1 and Control 1

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	11227.184[a]	3	3742.395	344.327	.000
Intercept	270.389	1	270.389	24.878	.000
Pretest	594.593	1	594.593	54.707	.000
Group	9795.852	2	4897.926	450.644	.000
Error	706.468	65	10.869		
Total	438779.000	69			
Corrected Total	11933.652	68			

Based on the analysis presented in Table 7, the significance value for the Group factor is 0.000 (< 0.05), indicating a significant difference in learning outcomes between Experimental Group 1 and Control Group 1 after controlling for prior ability (pretest). The Pretest covariate also shows a significance value of 0.000 (< 0.05), suggesting that students' initial abilities significantly influence their learning achievements. The exceptionally high F-value for the Group factor (450.644) indicates a strong effect of the Augmented Reality-based instructional intervention on improving learning outcomes. These findings confirm that integrating Augmented Reality into the Electrical Installation course substantially enhances students' academic performance compared to conventional teaching methods, even after accounting for differences in initial ability.

Following the ANCOVA analysis for Experimental Group 1 and Control Group 1, the next step was to conduct an Independent Samples t-test for Experimental Group 2 and Control Group 2. This test was employed to compare the learning outcomes between the two groups that did not receive a pretest, thereby determining whether there were significant differences in achievement after participating in instruction using different methods. Experimental Group 2 received instruction based on AR, whereas Control Group 2 followed conventional teaching methods. Through this analysis, it is expected that a more precise understanding of AR's effectiveness in enhancing student learning outcomes can be obtained in a context where no initial measure of academic ability is available.

Table 8. Independent T-test Analysis Results for Experimental 2 and Control 2

T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
27.67	69	.000	28.09	1.015	26.06	30.11
27.60	66.43	.000	28.09	1.017	26.06	30.12

Based on the analysis presented in Table 8, the significance value (Sig. 2-tailed) was 0.000 (< 0.05), indicating a statistically significant difference in learning outcomes between Experimental Class 2 and Control Class 2. The mean difference of 28.09 indicates that students in Experimental Class 2 had substantially higher learning outcomes than those in Control Class 2. The 95% confidence interval for the mean difference ranged from 26.06 to 30.12, entirely above zero, thereby reinforcing the evidence of a genuine treatment effect. The remarkably high t-value (27.67) indicates that the observed difference is not only statistically significant but also demonstrates a strong effect size. These findings suggest that Augmented Reality–based learning makes a significant contribution to improving students' academic performance compared to conventional teaching methods in contexts where no pretest is administered.

Based on the results of data analysis, both through ANCOVA conducted on Experimental Class 1 and Control Class 1, as well as the Independent Sample t-Test performed on Experimental Class 2 and Control Class 2, the findings indicate a significant difference in learning outcomes between the group that received Augmented Reality-based instruction and the group that engaged in conventional learning. This difference demonstrates that integrating Augmented Reality provides a substantial, tangible contribution to enhancing students' academic achievement. The improvement in learning outcomes is illustrated in the following graph, which presents the differences in mean final scores between the two groups for each test. This is shown in Figure 3.

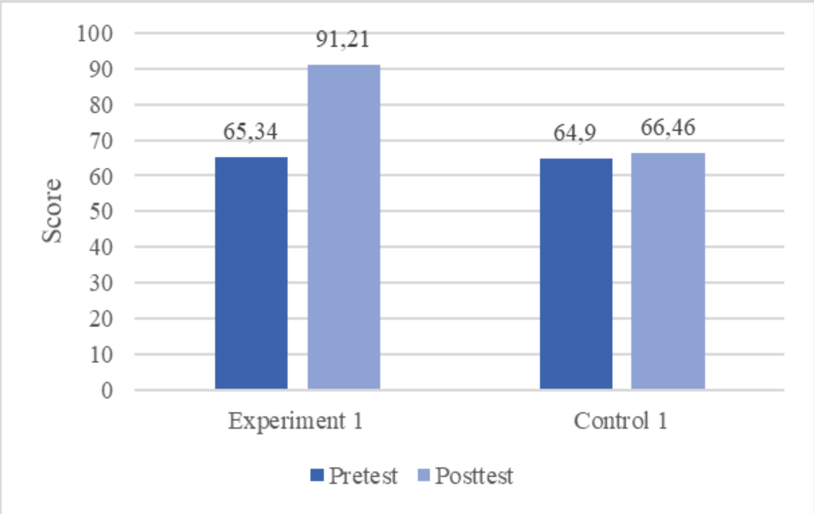

Figure 3. Comparison of Learning Outcomes between Experiment 1 and Control 1

Discussion

The findings of this study indicate that integrating AR into the learning process can effectively address the limitations of conventional teaching methods, which often rely on one-way delivery of material. By presenting content in an interactive and immersive format, AR transforms students from passive recipients into active participants in their own learning. This transformation is crucial in vocational and technical education, where the ability to apply knowledge in real-world contexts is as important as mastering theoretical concepts (Moukhliss et al., 2024; Su et al., 2025). The interactive nature of AR allows students to manipulate virtual objects, explore simulated environments, and receive immediate feedback, thereby fostering a more dynamic and engaging learning atmosphere (Rodríguez-Saavedra et al., 2025).

Moreover, the active engagement facilitated by AR aligns with research suggesting that such involvement enhances learning motivation, knowledge retention, and problem-solving abilities (Neale et al., 2025). In this study, students who received AR-based instruction demonstrated not only higher test scores but also greater enthusiasm for the learning process (Kim & Choi, 2025). The visual and experiential elements of AR appear to stimulate curiosity and sustain attention, enabling learners to process and retain information more effectively (Palada et al., 2024). These findings corroborate earlier work in educational technology that highlights the cognitive benefits of interactive and multimodal learning environments.

From a skills development perspective, AR provides an avenue for bridging the gap between theory and practice (Mansour et al., 2024). The hands-on learning opportunities offered through AR simulations allow students to practice technical procedures in a risk-free environment before applying them in real-world situations (Suhail et al., 2024). This is particularly relevant in vocational and technical education, where practical competence is a core requirement for professional readiness. Through repeated and self-paced practice in an AR environment, students can refine their skills, correct errors, and build confidence, all of which are essential for successful workplace performance (Rodríguez-Abad et al., 2023).

The adaptability fostered by AR-enhanced learning also addresses the industry's demand for graduates who are comfortable with emerging technologies. Exposure to AR tools in an educational context helps students develop not only content-specific skills but also broader technological literacy (Crogman et al., 2025; Mukhlisin et al., 2023; Mukhlisin, Gani, Purnamawati, et al., 2022). As industries continue to evolve toward automation and digital integration, familiarity with advanced tools becomes an asset that enhances employability (Nurhayati et al., 2025; Tzirides et al., 2024). The ability to quickly adapt to new technologies, learned through experiences such as AR-based learning, supports long-term career growth and resilience in rapidly changing work environments (Poláková et al., 2023).

Additionally, the collaborative potential of AR can be leveraged to promote peer learning and teamwork, both of which are critical in professional settings (Alkhabra et al., 2023). Instructors can design AR activities that require students to work together to solve problems, analyse scenarios, or complete projects, thereby fostering communication, coordination, and shared responsibility (Lorenzis et al., 2024). Such experiences not only reinforce academic content but also build interpersonal skills that are highly valued in the workforce. By embedding collaboration into the AR learning experience, educators can cultivate a more holistic set of competencies in their students (Y. Wu et al., 2023). Then, AR merges theoretical knowledge with practical applications, making it an essential tool for educational advancement (Mukhlisin, Gani, & Purnamawati, 2022).

In summary, integrating AR into teaching and learning directly addresses the shortcomings of traditional lecture-based methods by fostering active participation, enhancing motivation and retention, providing practical skill development, supporting technological adaptability, and encouraging collaborative learning (Egunjobi & Adeyeye, 2024). The results of this study demonstrate that AR can serve as a powerful pedagogical tool in vocational and technical education, offering measurable improvements in learning outcomes and better preparing students for professional success (González et al., 2025). These findings underscore the importance of continued innovation in educational practice, particularly in contexts where hands-on competencies and technological readiness are critical for graduate employability.

CONCLUSION

Based on the findings, it can be concluded that the implementation of AR-based learning significantly enhanced both student engagement and learning outcomes compared to conventional instruction. Student engagement in the experimental class achieved excellent results, with average scores of 91.35% in the cognitive domain, 87.54% in the affective domain, and 90.04% in the psychomotor domain, all exceeding the success threshold of >75%. In contrast, the control class only reached 79.67% in the cognitive domain, while the affective (66.62%) and psychomotor (69.34%) domains remained below the expected standard. This increased engagement was reflected in student achievement, where the experimental group obtained a mean post-test score of 91.21, considerably higher than the control group's mean score of 66.46. These findings demonstrate that technology-enhanced learning not only fosters active participation but also contributes to higher academic achievement. The implications of this study suggest that lecturers and higher education institutions should consider adopting innovative instructional strategies that address not only the cognitive dimension but also foster affective and psychomotor engagement. Such an approach would lead to more meaningful and holistic learning, aligned with the demands of the professional world that emphasise critical thinking, collaboration, and mastery of practical skills. Furthermore, the results of this study may serve as a foundation for developing technology-integrated curricula in higher education, particularly in vocational and technical fields, to produce graduates who excel academically and are well-prepared to face the challenges of the digital era.

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