Jupiter: Jurnal Pendidikan Terapan
Homepage : https://journal.diginus.id/jupiter/index
Email: jurnalpendidikanterapan@gmail.com.

p-ISSN : 2985-3214; e-ISSN : 2964-3171
Jupiter, Vol. 4, No. 5, November 2026
Page 79-89

Three-Dimensional Augmented Reality for Electrical Installation Learning: A Quasi-Experimental Study in Vocational Education

Ardian Isma[1*], Muhammad Riska[2], Muhammad Yusuf Mappeasse[3]
[1,2,3]Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Makassar, Makassar, Indonesia

ARTICLE INFO

Article history:
Submitted: August 02, 2026
Final Revised: October 05, 2026
Accepted: October 28, 2026
Published: November 03, 2026

Keywords:
Academic achievement; Augmented reality; Electrical Installation; Student acceptance; Vocational education.

ABSTRACT

Purpose: This study evaluates whether three-dimensional augmented reality (AR) is associated with better cognitive learning outcomes in vocational electrical installation instruction and describes learners' responses to the technology.

Methods: A quasi-experimental pretest–posttest control-group study involved 44 Grade XI electrical installation students at SMK Negeri 10 Makassar, Indonesia (22 AR; 22 conventional instruction). Both classes completed 35-item achievement tests before and after four lessons. The AR group additionally completed a 20-item, five-dimension response questionnaire. Shapiro–Wilk, Levene, Mann–Whitney U, and normalized-gain analyses were reported.

Findings: Student-level calculations from the corrected workbook yielded mean posttest scores of 87.40 (AR) and 70.78 (control), with a two-sided Mann–Whitney comparison ($U = 383.0$, $p = .001$). Mean individual normalized gain was 0.593 versus 0.237 ($U = 421.0$, $p < .001$). The pretest comparison did not detect a difference ($U = 257.0$, $p = .733$). The AR group's overall questionnaire response was 90.51%, with descriptive dimension scores ranging from 87.73% to 96.59%.

Research implications: Structured 3D visualization may complement explanations of components, wiring routes, and safe procedural sequences before workshop practice; practical skill gains were not tested.

Originality: The study links achievement comparisons with five dimensions of student-reported experience in a specific electrical-installation vocational context.

Doi: https://doi.org/10.61255/jupiter.v4i5.2194

INTRODUCTION

Electrical installation education in vocational high schools requires learners to connect symbols in wiring diagrams with the physical appearance, spatial arrangement, and safe use of electrical components. Learning to identify circuit breakers, switches, conductors, protective connections, and installation sequences cannot be reduced to memorizing definitions; learners must develop coherent mental representations of how electrical systems are structured, interconnected, and operated. In classrooms where practical training time, equipment availability, and opportunities for repeated demonstrations are constrained, conventional instructional approaches may create a substantial gap between conceptual understanding and the visualization of technical procedures. Akçayır and Akçayır (2017) demonstrated the educational potential of augmented reality (AR), while Ibáñez and Delgado-Kloos (2018) highlighted its relevance to science, technology, engineering, and mathematics education. Similarly, Chiang et al. (2022) identified opportunities for integrating AR into vocational training environments. These developments suggest that AR offers possibilities for addressing the representational limitations of conventional instruction through the integration of interactive digital objects into physical learning environments. However, the educational significance of this technology should not be determined by its visual sophistication alone, but by its capacity to support the specific cognitive processes required for understanding electrical installation systems.

Existing empirical evidence increasingly supports the integration of augmented reality into educational environments, although its effectiveness varies across instructional settings and learning objectives. Garzón and Acevedo (2019) synthesized quantitative evidence concerning the influence of AR on learning achievement, whereas Chang et al.

(2022) examined its implications for learner responses, knowledge acquisition, skills development, and educational performance. Furthermore, Garzón et al. (2020) emphasized the importance of pedagogical approaches, including instructional guidance, collaborative activities, and task organization, in determining the educational effectiveness of AR applications. These findings indicate that the relationship between AR implementation and learning improvement is neither automatic nor independent of instructional conditions. The availability of three-dimensional visualization does not necessarily guarantee meaningful knowledge acquisition when the presented information is poorly aligned with learning objectives or students' cognitive capacities. Accordingly, the central educational question extends beyond whether AR can improve academic achievement to understanding how its representational characteristics can be integrated into instructional activities that require students to interpret complex technical information.

Within technical and vocational education, the effectiveness of immersive technologies deserves particular attention because learning outcomes frequently depend on the integration of theoretical knowledge, spatial understanding, and procedural reasoning. Chiang et al. (2022) identified the relevance of AR for procedural training, assembly activities, maintenance, and technical skill acquisition. More recent investigations have broadened this perspective by distinguishing behavioral, cognitive, and affective outcomes in mixed-reality vocational interventions (Bödding et al., 2025) and identifying challenges associated with teacher preparation, technological infrastructure, and institutional integration (Boel et al., 2024). Empirical applications in engineering drawing (Tiwari et al., 2024), electronic laboratory learning (Tuli et al., 2022), and structural systems visualization (Hu et al., 2021) further illustrate the potential contribution of interactive representations to technical education. Meanwhile, investigations concerning electrical vocational learning materials have highlighted the importance of instructional resources that correspond to the conceptual and procedural characteristics of technical subjects (Ramdani et al., 2021; Dani et al., 2022). Nevertheless, evidence derived from general engineering or STEM environments cannot automatically be generalized to electrical installation instruction at the secondary vocational level. Electrical installation competence involves distinctive relationships among circuit representations, physical components, installation sequences, and safety-related procedures. Consequently, further empirical investigation is needed to establish how AR-assisted instruction relates to measurable learning outcomes within this specific educational context.

The theoretical justification for integrating AR into electrical installation education can be developed through multimedia learning and cognitive-load perspectives. Paas and van Merriënboer (2020) explained the importance of managing cognitive demands when individuals process complex instructional information, whereas Elford et al. (2022) contributed to discussions concerning the cognitive implications of technology-supported learning environments. Research examining AR-supported instructional activities has also considered learning achievement in relation to cognitive load, indicating the importance of evaluating educational performance alongside the demands imposed by digital learning environments (Mokmin et al., 2024). In electrical installation instruction, three-dimensional representations may help students associate abstract wiring symbols with the physical characteristics and spatial relationships of installation components. However, the simultaneous presentation of digital objects, instructional explanations, and interactive features may introduce additional cognitive demands when technological information is inadequately organized. The potential contribution of AR therefore depends on the relationship between the complexity of the learning material and the clarity of its instructional representation. From this perspective, interactive visualization should be understood as a pedagogical resource whose effectiveness is contingent upon its ability to facilitate meaningful information processing rather than simply increase the amount of information presented to learners.

Beyond cognitive achievement, the implementation of AR in vocational classrooms requires consideration of students' perceptions and experiences when interacting with instructional technologies. Jeffri and Rambli (2021) discussed the implications of AR for mental workload and task performance, while Koumpouros (2024) examined broader developments and challenges associated with educational AR applications. Research addressing technology acceptance has also emphasized perceived usefulness and ease of use as relevant considerations in educational technology adoption (Koutromanos et al., 2024; Nikou, 2024). Furthermore, investigations across other educational disciplines have explored relationships among AR-supported instruction, learning achievement, and students' perceptions of technology-based learning experiences (Chen, 2020a, 2020b; Silva et al., 2023). Although these findings provide a foundation for examining learners' responses, positive perceptions should not be interpreted as direct evidence of improvements in technical proficiency or electrical safety performance. Students may consider an application useful, engaging, or visually appealing without necessarily demonstrating corresponding improvements in every dimension of vocational competence. Therefore, evaluations of AR-assisted instruction should distinguish between measurable learning achievement and subjective learning experiences, allowing both dimensions to provide complementary rather than interchangeable evidence of instructional effectiveness.

Beyond the general effectiveness of augmented reality, a more fundamental research problem concerns the extent to which its instructional advantages can be translated into measurable learning outcomes within competency-based

vocational education. Existing systematic reviews and meta-analyses have established a substantial evidence base for AR-supported learning; however, differences in educational contexts, intervention designs, assessment instruments, and instructional objectives complicate the generalization of findings across specific technical disciplines (Garzón & Acevedo, 2019; Chang et al., 2022; Chiang et al., 2022). This distinction is particularly important in electrical installation education, where students must develop an integrated understanding of symbolic representations, physical components, spatial configurations, and sequential installation procedures. Unlike learning activities primarily concerned with conceptual recognition, electrical installation instruction requires learners to mentally translate schematic information into interconnected physical systems. Three-dimensional augmented reality may support this representational process by enabling students to inspect electrical components and their spatial relationships through interactive visualization. Nevertheless, its educational value depends on whether these technological affordances facilitate meaningful cognitive integration rather than merely increase visual stimulation. Drawing on cognitive-load and multimedia learning perspectives, instructional effectiveness may be influenced by how digital representations organize information, direct learners' attention, and support the construction of coherent mental models (Paas & van Merriënboer, 2020; Elford et al., 2022). Although these theoretical perspectives provide plausible explanations for the potential benefits of AR, they do not independently establish its effectiveness in electrical installation classrooms. An important empirical gap therefore remains concerning whether AR-assisted instruction is associated with measurable differences in students' cognitive achievement when implemented under authentic vocational classroom conditions. Addressing this gap requires a context-sensitive evaluation that connects technological affordances with explicitly defined educational outcomes rather than relying exclusively on generalized assumptions about the benefits of immersive learning technologies.

A further consideration concerns the methodological distinction between identifying differences in learning achievement and establishing the conditions under which an educational technology can be meaningfully implemented. Previous research has highlighted the importance of examining educational outcomes alongside the instructional and institutional conditions influencing AR implementation (Chang et al., 2022; Boel et al., 2024; Bödding et al., 2025). Although comparative investigations provide useful evidence of differences in achievement, findings obtained from intact classroom groups must be interpreted with careful consideration of initial learning conditions, possible instructional differences, and the limitations of non-randomized educational settings. Pre-intervention assessments can characterize students' initial achievement, whereas post-intervention comparisons and normalized learning gains provide complementary information concerning learning performance following instruction. Nevertheless, the absence of statistically significant differences in baseline scores should not be interpreted as definitive evidence that experimental and comparison groups are equivalent. Equally important, improvements in cognitive achievement cannot automatically be generalized to practical installation proficiency, long-term knowledge retention, or compliance with electrical safety procedures when these dimensions have not been directly measured. Incorporating students' perceptions offers an additional evaluative perspective by examining the perceived usefulness, ease of use, clarity of visualization, learning engagement, and comfort associated with AR-assisted instruction. However, these perceptions should be distinguished from direct evidence concerning the cognitive mechanisms responsible for learning improvement. Accordingly, combining comparative achievement assessment with descriptive learner feedback provides a broader interpretation of instructional outcomes while maintaining clear boundaries between educational performance and technology acceptance. Such an approach contributes to a more methodologically transparent evaluation of AR implementation by identifying both the measurable outcomes of the intervention and the limitations within which those outcomes can reasonably be interpreted.

At SMK Negeri 10 Makassar, preliminary classroom observations indicated that electrical installation instruction was predominantly delivered through teacher-led explanations supported by printed learning materials, projected presentations, and limited opportunities for hands-on activities. These instructional conditions provide a relevant setting for examining whether interactive three-dimensional visualization can support students' understanding of electrical installation concepts and procedures. Previous investigations have demonstrated the applicability of AR across vocational and technical learning environments (Supriyanto et al., 2023; Mukhlisin et al., 2025; Sakr & Abdullah, 2024). However, the relevance of these findings to a particular vocational classroom requires direct examination because differences in educational facilities, instructional organization, and student characteristics may influence the outcomes associated with technology-assisted learning. Against this background, the present study employed a quasi-experimental design involving two existing Grade XI classes, with one receiving AR-assisted instruction and the other receiving conventional instruction. The study specifically aimed to examine differences in cognitive learning achievement and normalized learning gains between the two instructional groups while describing students' responses to AR in terms of perceived usefulness, ease of use, visualization clarity, engagement, and comfort. By integrating comparative learning assessments with evidence of students' experiences, this study seeks to provide context-specific empirical insights into the application of three-dimensional AR in electrical installation education. Its

contribution lies not in claiming that AR constitutes an entirely new instructional approach, but in examining its association with cognitive learning outcomes within a technical subject where the integration of symbolic, spatial, and procedural knowledge is particularly important. The resulting evidence is intended to inform a more grounded understanding of how immersive instructional technologies can be evaluated and incorporated into vocational education while recognizing the methodological and practical boundaries of their implementation.

METHOD

Study Design and Participants

The study used a quantitative, quasi-experimental pretest–posttest control-group design. Two existing Grade XI Electrical Power Installation (TITL) classes at SMK Negeri 10 Makassar were compared: XI TITL 2 received AR-assisted instruction (initial class size 26), whereas XI TITL 1 received conventional instruction (initial class size 30), as confirmed by the author. After the attendance and complete-testing inclusion criteria described in the thesis were applied, 22 students remained in each group (N = 44); four members of the AR class and eight members of the comparison class were not represented in the analytic dataset. The workbook does not independently document each student's exclusion reason. Assignment occurred at the intact-class level rather than by individual randomization, and no independent random-allocation record was provided. The thesis places the study in the first semester of the 2026/2027 school year, with four treatment lessons within a longer preparation and assessment period.

Intervention and Outcome Measures

Both groups studied the same subject matter, instructional objectives, and nominal teaching time. In the intervention group, the instructor combined introductory explanation with exploration of 3D component and circuit representations, guided discussion, exercises on wiring paths and installation sequences, and brief reflection. The comparison group used lecture, slides, teaching modules, and teacher demonstration without 3D AR. The intervention was conceived as preparation for reasoning about installations rather than a substitute for supervised workshop practice (Chiang et al., 2022; Singh & Ahmad, 2024). The original report does not document sufficient application-specific information to verify the precise software version, hardware configuration, or whether marker-based and markerless modes were used consistently; these details should be confirmed by the author before submission.

Cognitive achievement was assessed using pretest and posttest forms, each containing 35 multiple-choice questions scored as correct/incorrect and converted to a 0–100 scale. The blueprint covered component identification, interpretation of diagrams, wiring connections, installation sequences, occupational safety, protection principles, and simple fault identification. The thesis describes validation and reliability procedures, but this article does not insert instrument coefficients not independently verified against the original test report. After posttesting, AR students completed a 20-item questionnaire on a four-point response scale, including eight reverse-keyed items. Five descriptive dimensions were analyzed: perceived usefulness, ease of use, clarity of 3D visualization, engagement, and comfort/usability. The questionnaire was not administered to controls; its percentages therefore describe AR users only (Khairi & Mu'minin, 2025; Koutromanos et al., 2024).

Statistical Analysis and Interpretive Scope

Raw correct-answer scores were converted to a 0–100 scale using (correct answers/35) × 100, then analyzed for the 22 complete cases in each class. Descriptive statistics included means, medians, sample standard deviations, and score categories. Shapiro–Wilk and Levene tests were recomputed from the author's corrected student-level workbook, followed by two-sided, asymptotic Mann–Whitney U comparisons of pretest, posttest, and individual normalized gain, with ties handled in the asymptotic approximation ($\alpha = .05$). For pretest scores below 100, individual normalized gain was calculated as (posttest − pretest)/(100 − pretest), and the individual values were averaged within each class. The absolute rank-biserial magnitude was calculated as $|2U/(n_1n_2) - 1|$, with the U statistic referring to the AR group. Because the intervention was assigned to only one class per condition, student-level statistical comparisons do not isolate the treatment effect from class-level contextual factors. As distributions differ in shape, the Mann–Whitney findings are treated as rank-based comparisons rather than direct inferential tests of mean differences.

RESULTS

Participants and Descriptive Achievement Outcomes

Forty-four students were included in the final analysis, consisting of 22 students who received three-dimensional augmented reality (AR)-assisted instruction and 22 students who received conventional instruction. The descriptive statistics of pretest and posttest scores are presented in Table 1. Before the intervention, both groups demonstrated comparable initial achievement levels, with mean pretest scores of 63.64 for the AR group and 62.08 for the control group. Following the instructional intervention, the AR group achieved a higher mean posttest score (87.40) compared with the conventional group (70.78).

Table 1. Pretest and Posttest Statistics

Group (n = 22)	Assessment	Mean	Median	SD	Minimum	Maximum
AR 3D	Pretest	63.64	65.71	22.57	25.71	94.29
AR 3D	Posttest	87.40	88.57	6.21	77.14	100.00
Control	Pretest	62.08	67.14	22.33	20.00	91.43
Control	Posttest	70.78	77.14	21.01	17.14	94.29

The descriptive pattern indicates that both groups experienced improvement after instruction; however, the magnitude of improvement differed substantially. The AR group showed not only a higher average posttest achievement but also a considerably lower score dispersion compared with the control group. The smaller standard deviation in the AR group suggests that post-intervention scores were more concentrated among higher achievement levels, whereas the wider distribution in the control group indicates greater variation in student outcomes. Nevertheless, these descriptive differences represent observed achievement patterns and require inferential testing to determine whether the differences are statistically meaningful.

Assumptions and Inferential Comparisons

Before conducting comparative analysis, distributional and variance assumptions were examined using Shapiro–Wilk and Levene tests. The results are summarized in Table 2.

Table 2. Distributional and variance Checks Recalculated

Assessment	AR Shapiro–Wilk p	Control Shapiro–Wilk p	Levene F	Levene p
Pretest	.076	.042	0.040	.843
Posttest	.343	.007	8.483	.006

The assumption tests indicate that not all achievement variables satisfied parametric assumptions. Specifically, the control-group scores for both pretest and posttest deviated from normality, and posttest variance between groups was significantly different based on Levene's test. Therefore, non-parametric analysis using the Mann–Whitney U test was employed to compare achievement distributions between groups.

The pretest comparison resulted in $U = 257.0$ with $p = .733$, indicating that no statistically significant difference was detected between groups before the intervention. This finding suggests that the two intact classes started with statistically comparable observed achievement levels. However, the absence of a significant difference should not be interpreted as complete equivalence between groups because other unobserved classroom characteristics may still exist.

Achievement Comparison and Normalized Learning Gain

The Mann–Whitney U test was subsequently applied to compare posttest achievement and normalized learning gains between groups. The results are displayed in Table 3.

Table 3. Achievement Comparisons and Individual Normalized Gains

Outcome	AR 3D	Conventional	Mann–Whitney U	p
Pretest mean	63.64	62.08	257.0	.733
Posttest mean	87.40	70.78	383.0	.001
Normalized gain mean (SD)	0.593 (0.202)	0.237 (0.236)	421.0	< .001

The inferential analysis demonstrates statistically significant differences in posttest achievement between students receiving AR-assisted instruction and those receiving conventional instruction. The AR group achieved a mean posttest score that was 16.62 points higher than the control group, accompanied by a statistically significant Mann–Whitney comparison ($U = 383.0$, $p = .001$). This pattern indicates that students exposed to three-dimensional AR visualization achieved higher cognitive test outcomes within the observed classroom context.

A similar pattern was identified in the normalized learning gain analysis. The AR group obtained a higher average gain score (0.593) compared with the conventional group (0.237), with a significant difference based on the Mann–Whitney test ($U = 421.0$, $p < .001$). These results indicate that the improvement trajectory following instruction was greater among AR participants. However, because the intervention was implemented in only one class per condition, these findings should be interpreted as an association between the implemented instructional approach and observed learning outcomes rather than definitive evidence of a universal causal effect.

To provide additional descriptive interpretation, student achievement categories and normalized gain classifications were examined after the intervention. At the posttest stage, 15 students in the AR group (68.2%) achieved the very-high category, while the remaining seven students (31.8%) were classified as high. No AR students were categorized into moderate, low, or very-low achievement levels. In contrast, the control group showed greater variation, with seven

students (31.8%) classified as very high, eight students (36.4%) as high, four students (18.2%) as moderate, one student (4.5%) as low, and two students (9.1%) as very low.

The normalized gain classification showed a similar tendency. Six AR students (27.3%) achieved high gain, fourteen students (63.6%) achieved moderate gain, and only two students (9.1%) showed low gain. Meanwhile, the control group consisted of nine students (40.9%) with moderate gain and thirteen students (59.1%) with low or negative gain. These distributions provide contextual support for the statistical comparisons by illustrating that the AR group generally demonstrated more consistent improvement patterns. Nevertheless, categorical classifications are interpreted descriptively and do not replace the inferential rank-based analyses.

Student Responses to Augmented Reality

Following the intervention, students in the AR group completed a questionnaire evaluating their experiences with the technology. The results are summarized in Table 4.

Table 4. AR students' response ratings by dimension (n = 22)

Questionnaire dimension	Reported score (%)	Interpretive category
Perceived usefulness	87.73	Very positive
Ease of use	89.20	Very positive
3D visualization clarity	90.06	Very positive
Engagement	91.19	Very positive
Comfort and usability	96.59	Very positive
Overall	90.51	Very positive

The questionnaire results indicate that students reported highly favorable perceptions toward the implementation of three-dimensional AR in electrical installation learning. Among the evaluated dimensions, comfort and usability received the highest score (96.59%), followed by engagement (91.19%) and visualization clarity (90.06%). These results suggest that students generally perceived the AR environment as accessible, visually supportive, and engaging during learning activities.

Although the overall response was strongly positive, these findings represent students' subjective experiences rather than direct evidence of improved practical competence or long-term adoption. The questionnaire complements the achievement analysis by providing insight into learner acceptance and perceived instructional value, but it should not be interpreted as a substitute for objective measurement of installation skills, safety behavior, or knowledge retention.

DISCUSSION

Learning Outcomes and Technical Visualization

The observed score pattern is consistent with a potentially valuable role for structured 3D AR in electrical installation instruction. The higher posttest outcome in the intervention class and its larger normalized gain are compatible with the proposition that manipulable models can help learners connect schematic symbols with physical components. Electrical installation tasks often require simultaneous attention to component functions, wiring routes, basic protection, and ordered work steps. In that setting, visualizing a switch, circuit breaker, or conductor connection from several perspectives may reduce the translation students must perform between flat representations and three-dimensional assembly. This mechanism is plausible in light of the wider AR literature but was not directly measured in this dataset (Hu et al., 2021; Tiwari et al., 2024; Tuli et al., 2022).

Comparative synthesis provides an appropriate frame without permitting direct extrapolation. Garzón and Acevedo (2019) reported generally favorable learning gains from AR across diverse settings, while Chang et al. (2022) emphasized the need to distinguish types of outcomes. Bödding et al. (2025) similarly showed that cognitive, behavioral, and affective performance in vocational mixed-reality interventions can differ. For the current study, the outcome is specifically a written cognitive test, not observed quality of actual wiring, fault isolation, or electrical safety compliance. A large rank-biserial magnitude derived from these test scores should therefore not be translated into an equally large improvement in hands-on installation competency. Empirical work on AR-assisted electronics laboratories (Tuli et al., 2022), AR visualization in other engineering programs (Hajirasouli & Banihashemi, 2022), and chemical engineering processes (Zhou et al., 2024) provides useful analogies but cannot independently substantiate that unmeasured transfer.

Another interpretive consideration is the contrast between two intact classes. Nonsignificance in a pretest comparison does not show that classes are exchangeable or that all contextual influences have been eliminated. Instructor behavior, group dynamics, prior device familiarity, treatment novelty, and differential attention can remain relevant. With only one class assigned to each condition, classroom membership and the intervention are confounded at the cluster level; student-level p values do not address that design limitation. This result is best described as an association between the implemented AR instructional package and superior short-term test scores in the observed classes, not proof of a

universally causal effect. Research on comparative designs in engineering education reinforces the need for longer follow-up, richer process measures, and clearer descriptions of instructional components (Karcher et al., 2025; Keller et al., 2025).

Pedagogical Mediation and Cognitive Demand

The potential benefit of AR is conditional on instructional design. The intervention integrated teacher guidance, exploration, tasks, and reflection rather than leaving students to manipulate 3D models without direction. This accords with the finding by Garzón et al. (2020) that pedagogical approaches matter when AR is implemented. Literature on generative learning strategies also suggests that prompts can be integrated without necessarily reducing favorable learner attitudes (Buchner, 2022). From a cognitive perspective, an overlaid model may simplify visual-spatial coordination, but its interactive features can impose additional processing demands (Paas & van Merriënboer, 2020; Elford et al., 2022). Because objective cognitive load and gaze behavior were not measured here, statements that AR definitely "reduced cognitive load" would be stronger than the evidence warrants. Future trials should directly observe students' task sequences, annotation use, and workload to test the proposed mechanism.

Variation in how learners engage with complex content may also determine whether technology makes classroom work more efficient. Mokmin et al. (2024) linked achievement, motivation, and load in an AR design-course intervention, whereas Laumann et al. (2024) examined real equipment supported by AR glasses in laboratory teaching. These studies concern different learners and hardware, but together they suggest that AR should be considered a pedagogical configuration rather than a homogeneous treatment. In electrical installation teaching, a practical next step is to isolate the contribution of object rotation, highlighted wiring pathways, visual step sequencing, and teacher prompts. The results would then allow educators to identify which component provides instructional value instead of assuming all three-dimensional interfaces are equally helpful (Conley et al., 2020; Chen, 2020b; Singh & Ahmad, 2024).

Student Acceptance and Feasibility in Vocational Classrooms

The generally positive questionnaire profile adds a distinct implementation perspective to the achievement evidence. Usefulness and ease-of-use ratings suggest that most participating students regarded the technology as manageable and relevant, while the particularly high comfort/usability percentage offers a favorable indication for adoption in this particular class. In technology-acceptance research, these perceptions are meaningful but do not establish actual long-term use or improved practical skill. Koutromanos et al. (2024) and Nikou (2024) have demonstrated the relevance of acceptance constructs in educational AR, while Silva et al. (2023) illustrates their examination alongside learning outcomes. As the present instrument was used only with intervention students, its score should not be construed as evidence that AR was preferred to the comparison method across both groups.

Moreover, strongly positive overall ratings can conceal actionable variation at item level. The comparatively modest peer-discussion item suggests that interacting with a digital object does not automatically create collaborative discourse. Peer explanation, cooperative fault diagnosis, or group-based interpretation of a wiring diagram could be intentionally added. The relatively lower item on technical errors points to a need for predictable application performance, access to compatible devices, and teacher troubleshooting procedures. Such barriers are also reported in broader syntheses and technology-implementation research (Akçayır & Akçayır, 2017; Jeffri & Rambli, 2021; Koumpouros, 2024; Sakr & Abdullah, 2024). These questions become particularly important if the intervention moves from a brief pilot to routine deployment at scale (Boel et al., 2024; Koutromanos et al., 2024).

Novelty, limitations, and Implications for Future Research

The study's contribution is an applied comparison situated in Indonesian secondary vocational education, with outcome data and structured response evidence for a safety-relevant technical topic. It does not introduce a newly validated theory of AR acceptance or establish a new AR hardware architecture. Its substantive value lies in examining an instructional design that links abstract installation representations with teacher-guided exercises. Studies of augmented reality in vocational learning (Chiang et al., 2022; Supriyanto et al., 2023; Dani et al., 2022; Mukhlisin et al., 2025) justify further testing of this application-specific question. Adjacent research on curriculum design and immersive technology in STEM schools highlights the need for suitable content and equitable device access rather than blanket technological substitution (Jiang et al., 2025; Ibáñez & Delgado-Kloos, 2018).

Several constraints limit the strength and transferability of the findings. The corrected workbook supplies 44 complete individual achievement records from an initial two-class population of 56; four students from the 26-student AR class and eight from the 30-student control class are absent from the analyzed files. Their individual exclusion reasons are not documented in the workbook, limiting the assessment of selection bias. The treatment lasted four lessons, with no delayed test or independent objective measurement of hands-on electrical-installation competence. The corrected data permit independent replication of descriptive, Shapiro–Wilk, Levene, Mann–Whitney, and normalized-gain results; however, the two intact classes remain an important limitation for causal claims. Questionnaire dimensions follow the

thesis's item allocations rather than independently established latent factors, so category-level ratings should be treated as descriptive summaries (Khairi & Mu'minin, 2025; Koutromanos et al., 2024).

To extend the evidence, future investigations should involve multiple classes per intervention arm and more than one school, incorporate reproducible descriptions of device and application characteristics, report instrument validity and reliability transparently, and include task-based assessments of actual installation assembly and electrical safety procedures. Delayed posttesting would distinguish short-term learning from retention, while structured observation and cognitive-load measurement could help explain the observed achievement pattern. Multilevel or cluster-aware analyses would be appropriate when entire classes are assigned to conditions. Finally, comparative usability data collected in both groups could clarify whether positive student ratings reflect the AR medium specifically or more general satisfaction with the learning experience (Bödding et al., 2025; Elford et al., 2022; Keller et al., 2025; Karcher et al., 2025).

Beyond the present school, evidence from other professional learning settings can help formulate testable hypotheses without being treated as direct confirmation: Asoodar et al. (2024) discuss how immersive learning designs relate to educational theory, while Kurniawan and Masugino (2020) examined AR multimedia in a vocational subject. Teacher-side attitudes and enabling conditions may also determine whether positive short-term student responses translate into sustained use; Ateş and Gündüzalp (2025) offer a related technology-adoption perspective, although their population differs from the students investigated here. Riska et al. (2026) likewise reported that marker-based 3D AR improved conceptual understanding and engagement in Indonesian junior-high computer-network learning.

CONCLUSION

In the two Grade XI electrical installation classes studied, AR-assisted instruction was associated with higher short-term cognitive achievement than the comparison condition. Recalculation from the corrected workbook produced posttest means of 87.40 versus 70.78, mean individual normalized gains of 0.593 versus 0.237, and two-sided Mann–Whitney results of $U = 383.0$ ($p = .001$) for posttest and $U = 421.0$ ($p < .001$) for gain. Students receiving AR also reported a favorable overall experience (90.51%). These results support further assessment of AR as a supplement to teacher-guided visualization of components, diagrams, and installation procedures. They do not demonstrate improved hands-on electrical safety, long-term retention, or an effect independent of the two classroom contexts. Multi-school replication with class-level allocation, verified instrument properties, hands-on outcomes, and delayed assessment is needed.

REFERENCES

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. Educational Research Review, 20, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Asoodar, M., Janesarvatan, F., Yu, H., & de Jong, N. (2024). Theoretical foundations and implications of augmented reality, virtual reality, and mixed reality for immersive learning in health professions education. Advances in Simulation, 9, Article 36. https://doi.org/10.1186/s41077-024-00311-5

Ateş, H., & Gündüzalp, C. (2025). The convergence of GETAMEL and protection motivation theory: A study on augmented reality-based gamification adoption among science teachers. Education and Information Technologies, 30, 17361–17403. https://doi.org/10.1007/s10639-025-13480-1

Boel, C., Dekeyser, K., Lemal, M., Rotsaert, T., Valcke, M., Schellens, T., & Struyf, D. (2024). Towards a framework for a nation-wide implementation of augmented, virtual and mixed reality in K-12 technical and vocational education. TechTrends, 68, 295–306. https://doi.org/10.1007/s11528-023-00925-y

Buchner, J. (2022). Generative learning strategies do not diminish primary students' attitudes towards augmented reality. Education and Information Technologies, 27, 701–717. https://doi.org/10.1007/s10639-021-10445-y

Bödding, R., Schriek, S. A., & Maier, G. W. (2025). A systematic review and meta-analysis of mixed reality in vocational education and training: Examining behavioral, cognitive, and affective training outcomes and possible moderators. Virtual Reality, 29, Article 44. https://doi.org/10.1007/s10055-025-01118-z

Chang, H. Y., Binali, T., Liang, J. C., Chiou, G. L., Cheng, K. H., Lee, S. W. Y., & Tsai, C. C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-)experimental studies to investigate the impact. Computers & Education, 191, Article 104641. https://doi.org/10.1016/j.compedu.2022.104641

Chen, C. H. (2020a). AR videos as scaffolding to foster students' learning achievements and motivation in EFL learning. British Journal of Educational Technology, 51(3), 657–672. https://doi.org/10.1111/bjet.12902

Chen, C. H. (2020b). Impacts of augmented reality and a digital game on students' science learning with reflection prompts in multimedia learning. Educational Technology Research and Development, 68(6), 3057–3076. https://doi.org/10.1007/s11423-020-09834-w

Chiang, F. K., Shang, X., & Qiao, L. (2022). Augmented reality in vocational training: A systematic review of research and applications. Computers in Human Behavior, 129, Article 107125. https://doi.org/10.1016/j.chb.2021.107125

Conley, Q., Atkinson, R. K., Nguyen, F., & Nelson, B. C. (2020). MantarayAR: Leveraging augmented reality to teach probability and sampling. Computers & Education, 153, Article 103895. https://doi.org/10.1016/j.compedu.2020.103895

Dani, D. F., Ramdani, S. D., & Supriyatna, D. (2022). Developing augmented reality on differential system, competency system, and power transfer in vocational education. Jurnal Pendidikan Vokasi, 12(2), 152–167. https://doi.org/10.21831/jpv.v12i2.48804

Elford, D., Lancaster, S. J., & Jones, G. A. (2022). Exploring the effect of augmented reality on cognitive load, attitude, spatial ability, and stereochemical perception. Journal of Science Education and Technology, 31, 322–339. https://doi.org/10.1007/s10956-022-09957-0

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of augmented reality on students' learning gains. Educational Research Review, 27, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Garzón, J., Kinshuk, Baldiris, S., Gutiérrez, J., & Pavón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. Educational Research Review, 31, Article 100334. https://doi.org/10.1016/j.edurev.2020.100334

Hajirasouli, A., & Banihashemi, S. (2022). Augmented reality in architecture and construction education: State of the field and opportunities. International Journal of Educational Technology in Higher Education, 19, Article 39. https://doi.org/10.1186/s41239-022-00343-9

Hu, X., Goh, Y. M., & Lin, A. (2021). Educational impact of an augmented reality (AR) application for teaching structural systems to non-engineering students. Advanced Engineering Informatics, 50, Article 101436. https://doi.org/10.1016/j.aei.2021.101436

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education, 123, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Jeffri, N. F. S., & Rambli, D. R. A. (2021). A review of augmented reality systems and their effects on mental workload and task performance. Heliyon, 7(3), Article e06277. https://doi.org/10.1016/j.heliyon.2021.e06277

Jiang, H., Zhu, D., Chugh, R., Turnbull, D., & Jin, W. (2025). Virtual reality and augmented reality-supported K-12 STEM learning: Trends, advantages and challenges. Education and Information Technologies, 30, 12827–12863. https://doi.org/10.1007/s10639-024-13210-z

Karcher, A., Arnold, D., & Kuhlenkötter, B. (2025). Quality methods in virtual and augmented reality with a focus on education: A systematic literature review. Management Review Quarterly, 75, 1111–1142. https://doi.org/10.1007/s11301-023-00403-y

Keller, C., Walker, G., Amenduni, F., Tela, A., & Cattaneo, A. (2025). Find the apartment's flaws! The impact of virtual reality on vocational students' performance in general education classes and the roles of flow experience, motivation, and sense of presence. Education and Information Technologies, 30, 12709–12734. https://doi.org/10.1007/s10639-025-13320-2

Khairi, M. I., & Mu'minin, A. (2025). Usability evaluation of an augmented reality application for ship design learning: Evidence from Nielsen's attributes of usability. Jurnal Pendidikan Vokasi, 15(2). https://doi.org/10.21831/jpv.v15i2.77223

Koumpouros, Y. (2024). Revealing the true potential and prospects of augmented reality in education. Smart Learning Environments, 11(1), Article 2. https://doi.org/10.1186/s40561-023-00288-0

Koutromanos, G., Mikropoulos, A. T., Mavridis, D., & Christogiannis, C. (2024). The mobile augmented reality acceptance model for teachers and future teachers. Education and Information Technologies, 29, 7855–7893. https://doi.org/10.1007/s10639-023-12116-6

Kurniawan, D., & Masugino, M. (2020). Pengembangan multimedia pembelajaran differential berbasis augmented reality untuk siswa kelas XI SMK. Jurnal Pendidikan Teknik Mesin, 20(2), 66–69. https://doi.org/10.15294/jptm.v20i2.27935

Laumann, D., Schlummer, P., Abazi, A., Borkamp, R., Laaströer, J., Pernice, W., Schuck, C., Schulz-Schaeffer, R., & Heusler, S. (2024). Analyzing the effective use of augmented reality glasses in university physics laboratory courses for the example topic of optical polarization. Journal of Science Education and Technology, 33(5), 668–685. https://doi.org/10.1007/s10956-024-10112-0

Mokmin, N. A. M., Hanjun, S., Jing, C., & Qi, S. (2024). Impact of an AR-based learning approach on the learning achievement, motivation, and cognitive load of students on a design course. Journal of Computers in Education, 11(2), 557–574. https://doi.org/10.1007/s40692-023-00270-2

Mukhlisin, M., Asrifan, A., & de Barros Cardoso, L. M. O. (2025). The effectiveness of augmented reality in enhancing learning outcomes in a microcontroller course. Jurnal Inovasi Teknologi Pendidikan, 12(2), 179–191. https://doi.org/10.21831/jitp.v12i2.86903

Nikou, S. A. (2024). Factors influencing student teachers' intention to use mobile augmented reality in primary science teaching. Education and Information Technologies, 29, 15353–15374. https://doi.org/10.1007/s10639-024-12481-w

Paas, F., & van Merriënboer, J. J. G. (2020). Cognitive-load theory: Methods to manage working memory load in the learning of complex tasks. Current Directions in Psychological Science, 29(4), 394–398. https://doi.org/10.1177/0963721420922183

Ramdani, S. D., Islami, R., Pratiwi, H., Fawaid, M., Abizar, H., & Maulani, I. (2021). Developing digital teaching material on basic electricity based on problem-based learning in vocational education. Jurnal Pendidikan Vokasi, 11(1), 78–91. https://doi.org/10.21831/jpv.v11i1.38894

Riska, M., Mappalotteng, A. M., & Mutmainna. (2026). Development of augmented reality learning media for computer network topics in junior high school. *IJORER: International Journal of Recent Educational Research, 7*(3), 1211–1221. https://doi.org/10.46245/ijorer.v7i3.1408

Sakr, A., & Abdullah, T. (2024). Virtual, augmented reality and learning analytics impact on learners, and educators: A systematic review. Education and Information Technologies, 29, 19913–19962. https://doi.org/10.1007/s10639-024-12602-5

Silva, M., Bermúdez, K., & Caro, K. (2023). Effect of an augmented reality app on academic achievement, motivation, and technology acceptance of university students of a chemistry course. Computers & Education: X Reality, 2, Article 100022. https://doi.org/10.1016/j.cexr.2023.100022

Singh, G., & Ahmad, F. (2024). An interactive augmented reality framework to enhance the user experience and operational skills in electronics laboratories. Smart Learning Environments, 11(1), Article 5. https://doi.org/10.1186/s40561-023-00287-1

Supriyanto, S., Joshua, Q., Abdullah, A. G., Tettehfio, E. O., & Ramdani, S. D. (2023). Application of augmented reality (AR) in vocational education: A systematic literature review. Jurnal Pendidikan Vokasi, 13(2), 205–213. https://doi.org/10.21831/jpv.v13i2.54280

Tiwari, A. S., Bhagat, K. K., & Lampropoulos, G. (2024). Designing and evaluating an augmented reality system for an engineering drawing course. Smart Learning Environments, 11(1), Article 1. https://doi.org/10.1186/s40561-023-00289-z

Tuli, N., Singh, G., Mantri, A., & Sharma, S. (2022). Augmented reality learning environment to aid engineering students in performing practical laboratory experiments in electronics engineering. Smart Learning Environments, 9, Article 26. https://doi.org/10.1186/s40561-022-00207-9

Zhou, Z., Oveissi, F., & Langrish, T. (2024). Applications of augmented reality (AR) in chemical engineering education: Virtual laboratory work demonstration to digital twin development. Computers & Chemical Engineering, 188, Article 108784. https://doi.org/10.1016/j.compchemeng.2024.108784

ACKNOWLEDGEMENT

The author acknowledges the participating students, vocational-subject teachers, and school personnel who facilitated the data collection at SMK Negeri 10 Makassar.

AUTHOR CONTRIBUTION STATEMENT

AI: Conceptualization, methodology design, investigation, data collection, formal analysis, interpretation of results, and manuscript preparation.
MR: Supervision, validation, critical review of the manuscript, and refinement of the theoretical and methodological framework.
MYM: Academic guidance, validation of research procedures, manuscript review, and final approval of the submitted version.

AI DISCLOSURE STATEMENT

The authors used AI as a supportive tool during the preparation of this manuscript, primarily for strengthening research ideas, refining conceptual development, improving the organization of academic arguments, and assisting with

language clarity. The use of this tool was limited to conceptual and editorial support. The authors independently conducted the research design, data collection, statistical analysis, interpretation of findings, and scientific decision-making processes. After using the tool, the authors thoroughly reviewed, revised, and verified all content, references, analyses, and conclusions. The authors take full responsibility for the accuracy, originality, and integrity of the published work.

***Ardian Isma (Corresponding Author)**
Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Makassar,
Jl. A. P. Pettarani, Makassar, South Sulawesi, 90222, Indonesia
Email: ardianisma05@gmail.com

Muhammad Riska
Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Makassar,
Jl. A. P. Pettarani, Makassar, South Sulawesi, 90222, Indonesia
Email: muhammadrbabo@unm.ac.id

Muhammad Yusuf Mappeasse
Department of Electrical Engineering Education, Faculty of Engineering, Universitas Negeri Makassar,
Jl. A. P. Pettarani, Makassar, South Sulawesi, 90222, Indonesia
Email: muh.yusuf.mappeasse@unm.ac.id