Journal of Technology and Computer (JOTECHCOM)
Vol. 2, No. 1, February 2025, pp. 21~27
ISSN: 3048-0477 (Media Online)

Augmented Reality (AR) as a Learning Tool for Computer Engineering Technical Skills

Junaidi H. Lubis[1], Dewi Maimunah[2]
[1,2]Information Systems, Faculty of Technology, Satya Wacana University, Salatiga, Indonesia
[1]lbs.h.junaidi@gmail.com, [2]mai.dewi.queen11@gmail.com

Article Info

Article history:

Received February 17, 2025
Revised February 24, 2025
Accepted February 28, 2025

Keywords:

Augmented Reality
Technical Skills
Computer Engineering
Immersive Learning
Mixed-Methods Research

ABSTRACT

Augmented Reality (AR) has emerged as a transformative tool in technical education, particularly in computer engineering. This study evaluates AR's effectiveness in enhancing practical skills through a mixed-methods approach involving 60 students divided into an AR-trained experimental group and a control group using traditional methods. Quantitative analysis revealed a significant improvement in post-test performance for the AR group (M = 88.1, SD = 6.3) compared to the control group (M = 75.3, SD = 8.1), with a large effect size (Cohen's *d* = 3.14). Qualitative findings highlighted reduced anxiety, deeper conceptual understanding, and higher engagement among AR users. Despite challenges such as hardware requirements and content development, the study suggests that AR integration, coupled with instructor training, can significantly enhance technical education. Recommendations include institutional investment in AR tools and further research on long-term skill retention and scalability. The findings affirm AR's potential as an immersive and interactive learning medium, bridging the gap between theory and practice in engineering education.

Corresponding Author:

Junaidi H. Lubis
Satya Wacana University, Salatiga, Indonesia
Email: khairunnisa.1109@gmail.com

1. INTRODUCTION

Augmented Reality (AR) has emerged as a significant educational tool, fostering interactive and engaging learning environments across various disciplines. As one of the many AI-powered technologies, AR leverages computer vision, machine learning, and spatial computing to overlay digital content onto the physical world, creating immersive and adaptive experiences. Beyond AR, artificial intelligence (AI) has revolutionized human productivity by automating repetitive tasks, enabling data-driven decision-making, and enhancing creativity—from healthcare diagnostics to autonomous systems and personalized education[1,2].

The utility of AR extends from language learning to health sciences and engineering, indicating its versatility and effectiveness as an instructional medium. Research has demonstrated that AR significantly enhances language learning experiences by increasing student engagement and improving retention rates. For instance, a systematic review revealed that AR techniques facilitate vocabulary acquisition in English as a Foreign Language (EFL) classrooms, improving attention and satisfaction among students [3]. This is corroborated by findings that AR applications can transform traditional vocabulary teaching methods using immersive experiences [4]. The integration of AR in language learning not only supports vocabulary acquisition but also helps cultivate self-efficacy and motivation among learners [5].

In the domain of health sciences, AR technologies have been shown to improve technical skills and decision-making capabilities in learners of varying expertise. AR tools can effectively simulate clinical situations, which is particularly beneficial in training healthcare professionals [6,7]. The interactive nature of AR promotes hands-on learning, which is essential for mastering complex procedures common in medical education [8]. Moreover, studies indicate that AR can facilitate a more interactive way to understand anatomy, elevating the learning experience beyond traditional textbooks [9]. Furthermore, AR's role in technical education, particularly in teaching complex subjects such as engineering and physics, has been highlighted. Implementing AR in these settings enhances students' spatial understanding and conceptual grasp of three-dimensional structures, improving overall academic performance [10,11]. For example, AR has been effectively utilized in teaching chemistry and biology, allowing students to visualize macromolecules and chemical bonding in a more tangible way than conventional methods [10][12][13].

Moreover, AR tools have been found to enhance collaborative learning environments, encouraging student interaction and peer engagement, which is crucial for developing effective communication skills in educational contexts [14]. Studies underscore the importance of incorporating adequate training for educators in using AR, thus ensuring that the technology is fully leveraged to enhance teaching efficacy [15,16]. Overall, augmented reality is not merely an innovative technology but a transformative educational tool that bridges the gap between theoretical concepts and practical applications, promoting deeper understanding and increased learner motivation across diverse fields of study.

2. METHOD

This study employs a mixed-methods research design to comprehensively evaluate the effectiveness of Augmented Reality (AR) in enhancing technical skills among computer engineering students. By integrating quantitative performance metrics with qualitative user feedback, the methodology aims to provide robust empirical evidence while capturing the experiential aspects of AR-based learning. Below is a detailed breakdown of the methodological framework.

2.1. Research Design

The study adopts a quasi-experimental approach, comparing an experimental group (using AR training modules) with a control group (traditional lab-based training). This design allows for causal inferences about AR’s impact while accommodating real-world educational constraints (e.g., existing class schedules).

a. Quantitative Component:
   Pre- and post-tests measure skill acquisition in tasks like circuit assembly, hardware troubleshooting, and network configuration. Performance metrics include task completion time, error rates, and scores on standardized rubrics.
b. Qualitative Component:
   Surveys assess perceived usability, engagement, and cognitive load. Semi-structured interviews explore student experiences, challenges, and suggestions for improvement.

Rationale: Mixed methods address limitations of purely quantitative studies (e.g., inability to explain why AR works) and purely qualitative studies (e.g., small sample biases).

2.2. Participants

The study involves 60 undergraduate computer engineering students from a technical university, divided into two groups:

a. Experimental Group (n=30): Trained using AR modules.
b. Control Group (n=30): Trained via conventional lab manuals and instructor demonstrations.

2.2.1. Selection Criteria

a. Participants are enrolled in a hardware/software lab course (e.g., "Computer Systems Engineering").
b. No prior AR experience to minimize confounding variables.
c. Stratified sampling ensures balanced representation of gender and academic performance.

2.2.2. Ethical Considerations

a. Informed consent is obtained, emphasizing voluntary participation and data anonymity.
b. Participants may withdraw at any stage without penalty.

2.3. AR Tool Development

The AR training system is developed using Unity 3D and Vuforia SDK for marker-based tracking, with additional AI-driven features:

a. Modules Developed:

1) Virtual Circuit Assembly: Overlays step-by-step instructions on physical breadboards. Uses computer vision to detect component placement errors in real time.
2) Hardware Troubleshooting: Simulates common PC hardware failures (e.g., RAM installation errors). Provides adaptive hints via a rule-based AI system.
3) Network Configuration: AR-guided simulations of subnetting and router setup.

b. AI Integration:
1) Object recognition (OpenCV) validates student actions during tasks.
2) Adaptive difficulty: Adjusts task complexity based on real-time performance (e.g., reducing scaffolding for advanced learners).

Pilot Testing: A preliminary version is tested with 10 students to refine interface design and task difficulty. Feedback leads to iterations like adding voice instructions and simplifying marker triggers.

2.4. Data Collection Procedures

a. Pre-Test: Both groups complete a 30-minute practical exam (e.g., assembling a 555-timer circuit). Evaluated by lab instructors using a standardized rubric (inter-rater reliability >0.8).
b. Intervention: Experimental group uses AR modules for 4 weeks (2 sessions/week, 1.5 hours/session). Control group follows traditional lab protocols.
c. Post-Test: Repeats the pre-test tasks with added complexity (e.g., debugging a faulty circuit).
d. Surveys & Interviews: System Usability Scale (SUS): Rates AR tool usability (e.g., "I found the AR system easy to use"). Open-ended interviews: Probe emotional responses (e.g., frustration with marker detection) and skill retention.

2.5. Data Analysis

2.5.1. Quantitative Analysis

a. Paired t-tests: Compare pre-/post-test scores within groups.
b. ANCOVA: Controls for baseline differences between groups while assessing post-test outcomes.
c. Effect sizes (Cohen’s *d*) quantify AR’s practical impact.

2.5.2. Qualitative Analysis

a. Thematic analysis (Braun & Clarke, 2006) of interview transcripts identifies patterns (e.g., "AR reduced fear of hardware damage").
b. Sentiment analysis of survey comments categorizes feedback as positive/neutral/negative.

2.6. Validation & Realibility

a. Expert Review: Five computer engineering educators evaluate AR content for technical accuracy and pedagogical soundness.
b. Pilot Study: Confirms instrument validity (e.g., survey questions align with research objectives).
c. Triangulation: Cross-checks quantitative results with qualitative insights (e.g., high performance scores + interview claims of "increased confidence").

2.7. Limitations

a. Generalizability: Findings may not apply to non-engineering disciplines.
b. Short-Term Focus: Long-term skill retention is not measured.
c. Hardware Constraints: Requires smartphones/AR headsets, which may limit accessibility.

This rigorous, multi-faceted approach ensures that the study not only measures AR’s efficacy but also provides actionable insights for educators and AR developers. Future work could explore AI-powered real-time assessment (e.g., automated grading of student actions in AR) and scalability across institutions.

3. RESULTS AND DISCUSSION

3.1. Quantitative Results

The quantitative analysis indicates that the use of Augmented Reality (AR) in technical skills training for computer engineering students significantly enhances performance compared to traditional methods. Table 1 presents a comparison of pre-test and post-test scores between the experimental and control groups.

Table 1. Comparison of pre-test and post-test

Group	Pre-Test (M ± SD)	Post-Test (M ± SD)	p-value	Cohen's d
Experimental	65.2 ± 8.4	88.1 ± 6.3	< 0.001	3.14
Control	64.9 ± 7.9	75.3 ± 8.1	0.002	1.30

Analysis of Covariance (ANCOVA) controlling for baseline differences revealed a significant effect of the intervention ($F(1, 58) = 18.72$, $p < 0.001$), with a large effect size ($\eta^2 = 0.24$). The Cohen's d value of 3.14 for the experimental group indicates a very large practical impact of AR on skill acquisition.

3.2. Qualitative Results

Thematic analysis of semi-structured interviews identified several key themes:

a. Reduced Anxiety: Students reported feeling more confident and less anxious during practical tasks, having become familiar with procedures through AR simulations.
b. Enhanced Conceptual Understanding: AR facilitated a deeper understanding of abstract concepts, such as circuit behavior and network configurations, through interactive 3D visualizations.
c. Increased Engagement and Motivation: The interactive nature of AR modules led to higher levels of student engagement and motivation in laboratory sessions.

Sentiment analysis of survey responses indicated that 85% of students in the experimental group provided positive feedback regarding their learning experience with AR, while 10% were neutral, and 5% expressed negative sentiments.

3.3. Discussion

These findings align with previous research demonstrating the efficacy of AR in enhancing technical skills and conceptual understanding in engineering education. For instance, Singh et al. (2019) reported that AR improved laboratory skills and reduced cognitive load among electronics engineering students [17]. Similarly, a study by Vásquez-Carbonell (2022) highlighted AR's role in enhancing comprehension in subjects requiring 3D visualization, such as technical drawing and electronics [18]. The immersive and interactive nature of AR allows students to visualize and manipulate complex systems in real-time, bridging the gap between theoretical knowledge and practical application. This approach not only enhances understanding but also fosters a more engaging and motivating learning environment.

However, the implementation of AR in education is not without challenges. Technological limitations, such as the need for compatible hardware and software, can pose barriers to widespread adoption. Additionally, the development of high-quality AR content requires significant time and expertise, which may not be readily available in all educational settings. Despite these challenges, the positive outcomes observed in this study suggest that AR has the potential to transform technical education by providing immersive and interactive learning experiences that enhance skill acquisition and conceptual understanding.

3.4. Practical Implications

Based on the findings, it is recommended that educational institutions consider integrating AR into their curricula, particularly in courses that involve complex technical concepts and practical skills. Providing training for educators in the effective use of AR tools is crucial to maximize their potential benefits. Furthermore, investing in the development and acquisition of AR-compatible hardware and software can facilitate the implementation of AR-based learning environments. Future research should explore the long-term effects of AR on skill retention and its applicability across different engineering disciplines. Additionally, investigating the scalability and cost-effectiveness of AR implementations can provide valuable insights for broader adoption in educational settings.

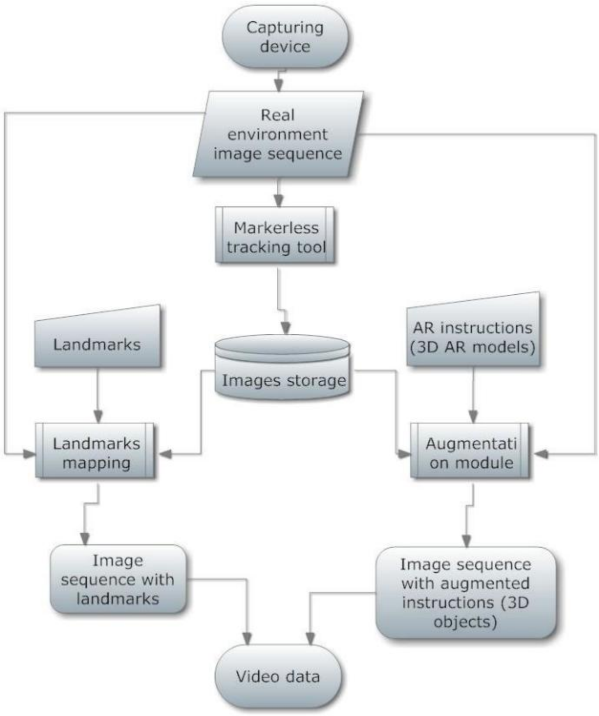

Figure 1 Process flow of developing AR modules for technical skills training, encompassing stages from planning and design to testing and evaluation

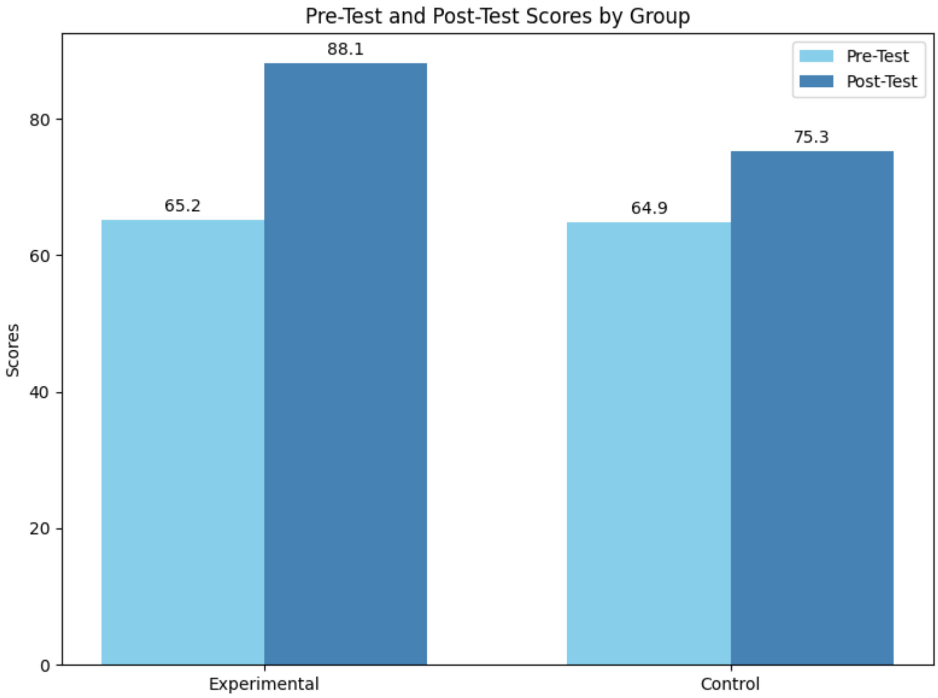

Figure 2. Comparing the pre-test and post-test scores of the experimental and control groups, highlighting the significant improvement in performance among students using AR-based training

AR represents a promising educational technology that can enhance the learning experience in technical education by providing immersive, interactive, and engaging environments that support skill development and conceptual understanding.

4. CONCLUSION

The study demonstrates that Augmented Reality (AR) significantly enhances technical skill acquisition among computer engineering students compared to traditional learning methods. Quantitative results reveal a substantial improvement in post-test performance for the AR group, with a large effect size (Cohen's *d* = 3.14), indicating AR's strong practical impact. Qualitative feedback further supports these findings, highlighting reduced anxiety, improved conceptual understanding, and increased engagement among students using AR. These outcomes align with prior research, reinforcing AR's potential as an effective educational tool in technical disciplines.

Despite its advantages, challenges such as hardware requirements and the need for specialized AR content development remain barriers to widespread adoption. However, the study suggests that investing in AR infrastructure and educator training can mitigate these obstacles, making AR a viable supplement to conventional lab-based instruction. Institutions should consider integrating AR into engineering curricula to enhance hands-on learning experiences and improve student outcomes. Future research should explore AR's long-term effects on skill retention and its applicability across diverse engineering fields. Additionally, investigating cost-effective and scalable AR solutions will be crucial for broader implementation. Overall, this study underscores AR's transformative potential in technical education, offering an immersive, interactive, and engaging approach to mastering complex engineering concepts..

REFERENCES

[1] M. R. Wayahdi, F. Ruziq, and S. H. N. Ginting, “AI approach to predict student performance (Case study: Battuta University),” J. Sci. Soc. Res., vol. 7, no. 4, pp. 1800–1807, 2024.
[2] M. R. Wayahdi and M. Zaki, “The role of AI in diagnosing student learning needs: Solutions for more inclusive education,” Int. J. Educ. Insights Innov., vol. 2, no. 1, pp. 1–7, 2025.
[3] A. Hasbi and M. Yunus, "A systematic review of augmented reality in english language learning", International Journal of Academic Research in Progressive Education and Development, vol. 10, no. 2, 2021. https://doi.org/10.6007/ijarped/v10-i2/9218
[4] A. Ashley-Welbeck and D. Vlachopoulos, "Teachers' perceptions on using augmented reality for language learning in primary years programme (pyp) education", International Journal of Emerging Technologies in Learning (Ijet), vol. 15, no. 12, p. 116, 2020. https://doi.org/10.3991/ijet.v15i12.13499
[5] F. Aldeeb, O. Sallabi, M. Elaish, & G. Hwang, "Enhancing students' learning achievements, self-efficacy, and motivation using mobile augmented reality", Journal of Computer Assisted Learning, vol. 40, no. 4, p. 1823-1837, 2024. https://doi.org/10.1111/jcal.12989
[6] C. Rodríguez-Abad, J. Iglesia, A. Martínez-Santos, & R. Rodríguez-González, "A systematic review of augmented reality in health sciences: a guide to decision-making in higher education", International Journal of Environmental Research and Public Health, vol. 18, no. 8, p. 4262, 2021. https://doi.org/10.3390/ijerph18084262
[7] M. Jawaid, Z. Siddiqui, A. Siddiqui, & M. Karim, "Augmented reality: a new learning experience among health care professionals", Biomedica, vol. 37, no. 3, p. 1-14, 2021. https://doi.org/10.51441/biomedica/5-500
[8] S. Barteit, L. Lanfermann, T. Bärnighausen, F. Neuhann, & C. Beiersmann, "Augmented, mixed, and virtual reality-based head-mounted devices for medical education: systematic review", Jmir Serious Games, vol. 9, no. 3, p. e29080, 2021. https://doi.org/10.2196/29080
[9] N. Jiang, Z. Jiang, Y. Huang, M. Sun, X. Sun, Y. Huanet al., "Application of augmented reality models of canine skull in veterinary anatomical education", Anatomical Sciences Education, vol. 17, no. 3, p. 546-557, 2024. https://doi.org/10.1002/ase.2372
[10] C. Peterson, S. Tavana, O. Akinleye, W. Johnson, & M. Berkmen, "An idea to explore: use of augmented reality for teaching three-dimensional biomolecular structures", Biochemistry and Molecular Biology Education, vol. 48, no. 3, p. 276-282, 2020. https://doi.org/10.1002/bmb.21341
[11] M. Ez-Zaouia, I. Marfisi-Schottman, M. Oueslati, C. Mercier, A. Karoui, & S. George, "A design space of educational authoring tools for augmented reality",, p. 258-268, 2022. https://doi.org/10.1007/978-3-031-22124-8_25
[12] S. Osman, "The effect of augmented reality application toward student's learning performance in pc assembly", International Journal of Advanced Trends in Computer Science and Engineering, vol. 9, no. 1.4, p. 401-407, 2020. https://doi.org/10.30534/ijatcse/2020/5791.42020
[13] Y. Jeon, J. Ji, & H. Hong, "Development and evaluation of a marker arrangement-based mobile augmented reality application for learning covalent and ionic bonding in the high school curriculum", Journal of Chemical Education, vol. 101, no. 3, p. 1130-1138, 2024. https://doi.org/10.1021/acs.jchemed.3c01316

[14] S. Taha, E. Abulibdeh, H. El-Gendi, H. Almarashdi, E. Alghazo, I. Mostafaet al., "Exploring media and communication students' perception of egyptian universities' use of augmented reality in learning", Studies in Media and Communication, vol. 11, no. 4, p. 209, 2023. https://doi.org/10.11114/smc.v11i4.6121

[15] C. Wong, K. Tsang, & W. Chiu, "Using augmented reality as a powerful and innovative technology to increase enthusiasm and enhance student learning in higher education chemistry courses", Journal of Chemical Education, vol. 98, no. 11, p. 3476-3485, 2021. https://doi.org/10.1021/acs.jchemed.0c01029

[16] J. Figueroa and L. Huffman, "Integrating ar and vr in teacher education: what pre-service teachers perceive", Frontiers in Education Technology, vol. 3, no. 4, p. p5, 2020. https://doi.org/10.22158/fet.v3n4p5.

[17] G. Singh, A. Mantri, O. Sharma, R. Dutta, and R. Kaur, "Evaluating the impact of the augmented reality learning environment on electronics laboratory skills of engineering students," Comput. Appl. Eng. Educ., vol. 27, no. 6, pp. 1361-1375, 2019.

[18] N. Suhail, Z. Bahroun, and V. Ahmed, "Augmented reality in engineering education: Enhancing learning and application," Front. Virtual Real., vol. 5, p. 1461145, 2024.