Design and Evaluation of an Android-Based Augmented Reality Learning Application for Computer Hardware Education in Vocational High Schools

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Abstract

Augmented Reality (AR) has emerged as a transformative tool in educational technology, particularly for visualizing abstract or complex physical systems. This study presents the design, development, and empirical evaluation of an Android-based AR application for teaching computer hardware concepts to tenth-grade students in a vocational high school in Indonesia. Guided by Mayer's Cognitive Theory of Multimedia Learning and the Technology Acceptance Model (TAM), the application was developed using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) framework. The AR system enables students to interact with 3D models of hardware components (e.g., CPU, RAM, motherboard) via marker-based recognition on printed cards, supported by audio explanations and embedded quizzes. The application was validated by two media experts (94.5% "very feasible"), two design experts (92.5%), and one subject-matter expert (80% "feasible"). A field trial involving 30 students yielded a 90% positive response rate, with high ratings for usability (87.3%), visual clarity (92%), aesthetic appeal (91%), and instructional design (90%). Qualitative feedback indicated enhanced motivation, spatial understanding, and autonomous learning. Findings suggest that marker-based AR on widely available Android devices can effectively support computer hardware education in resource-constrained settings. This study contributes to the growing body of evidence on low-cost, scalable AR solutions in technical and vocational education.

Keywords: Augmented Reality; Android; Computer Hardware Education; Vocational Education; Educational Technology; ADDIE; Multimedia Learning

1. Introduction

In the rapidly evolving landscape of digital education, technical and vocational education and training (TVET) faces both unprecedented opportunities and persistent challenges. As industries increasingly demand digitally competent graduates, vocational schools particularly those offering Information and Communication Technology (ICT) tracks must equip students with not only theoretical knowledge but also practical, hands-on understanding of core computing concepts. Among these, computer hardware literacy remains foundational. Mastery of hardware components such as the central processing unit (CPU), random-access memory (RAM), motherboard, and storage devices is essential for students pursuing careers in computer assembly, maintenance, and network infrastructure. Yet, despite its importance, this domain is frequently perceived as abstract and difficult by learners, especially in under-resourced educational settings where access to physical hardware is limited or inconsistent.

Traditional instructional approaches—relying heavily on static textbooks, two-dimensional diagrams, and teacher-led lectures often fail to convey the spatial relationships, functional interdependencies, and physical characteristics of hardware components. This limitation is particularly acute in rural or low-income schools, where laboratory facilities are shared across multiple classes or lack sufficient equipment for individual exploration. In such contexts, students may memorize component names without truly understanding their roles, leading to superficial learning and diminished motivation. The need for more immersive, accessible, and interactive pedagogical tools has thus become increasingly urgent.

Augmented Reality (AR) has emerged as a promising solution to bridge this experiential gap. By overlaying three-dimensional digital models onto real-world objects through mobile devices, AR enables learners to visualize, manipulate, and interrogate complex systems in ways that static media cannot support. Unlike virtual reality, which requires specialized headsets, marker-based AR can operate on widely available smartphones and tablets—making it a scalable and cost-effective intervention for schools with constrained budgets. Recent studies have demonstrated AR's potential in STEM education, from anatomy visualization to engineering simulations (Akçayır & Akçayır, 2017; Wu et al., 2022). However, its application in vocational computer hardware education—particularly in Global South contexts remains underexplored.

Existing AR implementations in computer science education often focus on high-fidelity simulations or require stable internet connectivity, limiting their applicability in offline or low-infrastructure environments. Moreover, many studies prioritize technical feasibility over pedagogical alignment, neglecting integration with established learning theories or curriculum standards. This gap is critical: for AR to be more than a novelty, it must be grounded in cognitive principles that explain how and why it enhances learning. Mayer's Cognitive Theory of Multimedia Learning (CTML) offers such a foundation, positing that learners process information through dual channels (visual and verbal) and benefit from coherent, segmented, and interactive representations that reduce extraneous cognitive load. Complementarily, the Technology Acceptance Model (TAM) helps explain user adoption by emphasizing perceived usefulness and ease of use factors especially relevant in student populations with varying levels of digital literacy.

This study addresses these theoretical and practical gaps by presenting the design, development, and empirical evaluation of an offline, Android-based AR application for teaching computer hardware concepts to tenth-grade students in a vocational high school in West Kalimantan, Indonesia. Developed using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) framework, the application leverages marker-based recognition to project interactive 3D models of hardware components such as keyboards, CPUs, RAM modules, and SSDs onto printed cards. Each model is accompanied by concise audio narration and embedded quizzes, aligning with CTML's principles of modality and segmentation. The system operates entirely offline, requiring only a mid-range Android device (Android 11+, 4GB RAM, 8MP camera), thus ensuring accessibility in resource-constrained classrooms.

The research was conducted at SMKN 1 Bengkayang, a public vocational school where only one computer laboratory serves multiple classes, severely limiting hands-on access. Prior to this intervention, instruction relied primarily on PowerPoint slides and verbal explanations, resulting in student disengagement and poor conceptual retention. In response, we developed an AR media that students could use individually on their personal smartphones transforming passive learning into an active, self-paced exploration.

To assess the viability and impact of this intervention, we posed three research questions:

(1) How can an Android-based AR application be effectively designed to support computer hardware education in a vocational school context?

(2) To what extent is the application deemed feasible by domain experts in media, instructional design, and subject matter?

(3) How do students perceive the usability, engagement, and instructional value of the AR application?

This study contributes to the growing body of evidence on low-cost, theory-informed AR solutions in technical education. Unlike prior work that often targets university or well-resourced settings, our approach demonstrates how marker-based AR can be pragmatically integrated into real-world vocational classrooms with minimal infrastructure. By combining rigorous R&D methodology, multi-stakeholder validation, and learner-cantered design, we offer a replicable model for scalable digital innovation in TVET across similar contexts worldwide.

2. Theoretical Framework

The design and evaluation of educational technologies, particularly those leveraging immersive media such as Augmented Reality (AR), must be grounded in established learning theories to ensure pedagogical validity and cognitive effectiveness. In this study, the development of an Android-based AR application for computer hardware education is informed by two complementary theoretical frameworks: Mayer's Cognitive Theory of Multimedia Learning (CTML) and the Technology Acceptance Model (TAM). Together, these theories provide a robust foundation for understanding how learners process information through multimodal representations and how they adopt and engage with digital learning tools.

Mayer's Cognitive Theory of Multimedia Learning (2021) posits that human cognition operates through dual channels visual and verbal and that meaningful learning occurs when learners actively select, organize, and integrate information from both channels. According to CTML, effective instructional design should align with three core principles: (1) the multimedia principle, which asserts that people learn better from words and pictures than from words alone; (2) the *modality principle, which suggests that presenting information through visual and auditory channels reduces cognitive overload compared to text-only or static visual formats; and (3) the coherence principle, which emphasizes the removal of extraneous elements that do not support the learning objective. In the context of this study, the AR application embodies these principles by overlaying interactive 3D models of computer hardware components such as CPUs, RAM modules, and motherboards onto physical markers, while simultaneously delivering concise audio explanations. This dual-channel presentation allows learners to visually inspect spatial relationships and functional structures while receiving verbal elaboration, thereby supporting deeper conceptual integration and reducing the cognitive burden associated with abstract technical content.

Complementing CTML, the Technology Acceptance Model (Davis, 1989) offers a behavioural lens through which to understand user engagement with digital tools. TAM proposes that an individual's intention to use a technology is primarily determined by two perceived constructs: perceived usefulness (the degree to which a person believes the technology will enhance their performance) and perceived ease of use (the degree to which a person believes using the technology will be free of effort). In resource-constrained educational settings—such as vocational high schools in rural Indonesia—where access to physical hardware is limited and digital literacy varies among students; perceived ease of use becomes especially critical. To align with TAM, the AR application was designed to operate offline on widely available mid-range Android devices (Android 11+, 4GB RAM), requiring only a printed marker and a smartphone camera. The interface features intuitive navigation, minimal textual input, and immediate visual feedback, all of which lower the threshold for adoption. Furthermore, by enabling students to explore hardware components independently without reliance on shared laboratory equipment the application enhances perceived usefulness, positioning AR not as a novelty but as a practical solution to a real pedagogical challenge.

The synergy between CTML and TAM is evident in the application's architecture: CTML guides what is presented (multimodal, coherent, and segmented content), while TAM informs how it is delivered (accessible, intuitive, and contextually relevant). This dual-theoretical grounding ensures that the AR media is not only cognitively supportive but also behaviourally sustainable in authentic classroom environments. Moreover, this integration responds to recent calls in the literature for theory-driven design in AR-based educational interventions (Wu et al., 2022; Akçayır & Akçayır, 2017), moving beyond technical feasibility toward pedagogical intentionality.By anchoring the development process in these well-validated frameworks, this study contributes to a growing body of research that seeks to bridge the gap between immersive technology and evidence-based instructional design—particularly in technical and vocational education contexts where experiential learning is essential but often constrained by infrastructure limitations.

3. Methodology

This study employed a mixed-methods Research and Development (R&D) design grounded in the ADDIE (Analysis, Design, Development, Implementation, Evaluation) instructional systems development model. While R&D is often perceived as less rigorous than experimental designs, this study strengthened methodological credibility through systematic validation procedures, triangulation of expert and user feedback, and adherence to established quality criteria for educational media. The ADDIE framework provided a structured, iterative pathway from needs identification to product evaluation, ensuring alignment between pedagogical goals, technical implementation, and user experience.

The research was conducted at SMKN 1 Bengkayang, a public vocational high school in West Kalimantan, Indonesia, during the 2025 academic year. The target population comprised tenth-grade students enrolled in the Computer and Network Engineering (TKJ) program, a curriculum track focused on hardware, networking, and system maintenance. Given the exploratory and developmental nature of the study, purposive sampling was used to select participants who represented typical users of the intended product—namely, students with basic digital literacy but limited prior exposure to immersive learning technologies.

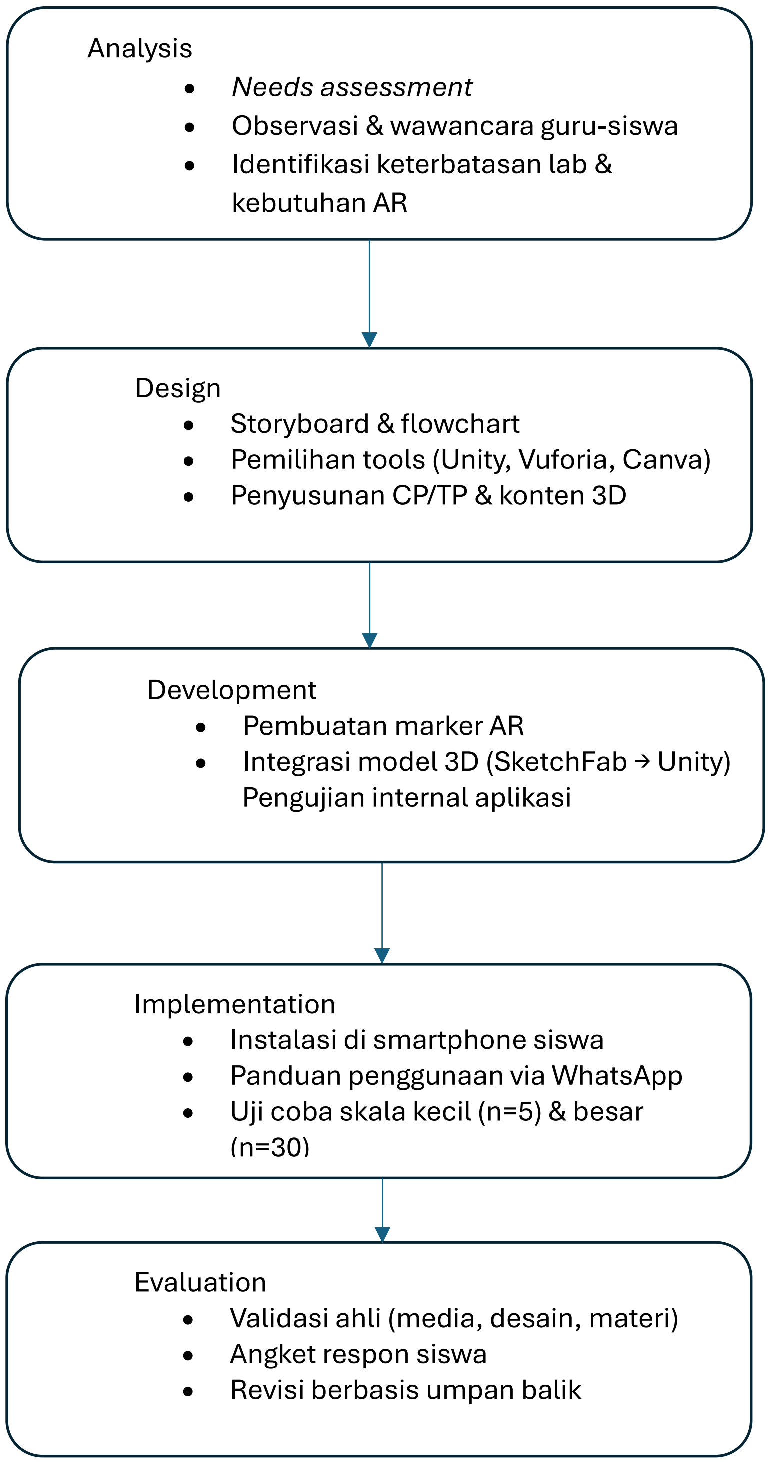

Figure 1. The ADDIE instructional design model adapted for this study.

The methodology unfolded across five sequential phases, consistent with the ADDIE model. In the Analysis phase, a needs assessment was conducted through classroom observations, semi-structured interviews with one ICT teacher, and informal discussions with students. The goal was to identify instructional challenges in teaching computer hardware concepts, particularly regarding spatial understanding, component recognition, and engagement. Findings revealed that students struggled to visualize internal hardware structures due to reliance on static PowerPoint slides and limited access to physical lab equipment—only one computer laboratory served multiple classes, constraining hands-on exploration.

In the Design phase, a conceptual blueprint for the AR application was developed. This included defining learning objectives aligned with the national vocational curriculum, selecting core hardware components (e.g., CPU, RAM, motherboard, SSD, keyboard, mouse), and designing user interaction flows. A storyboard and system flowchart were created to map the application's interface, navigation logic, and content sequencing. The design prioritized simplicity, offline functionality, and compatibility with mid-range Android devices (minimum: Android 11, 4 GB RAM, 8 MP camera), reflecting the technological realities of the target context.

The Development phase involved the actual construction of the AR application using Unity 3D as the primary game engine and Vuforia SDK for marker-based tracking. Three-dimensional models of hardware components were sourced from Sketchable and optimized for mobile performance. Each model was paired with a printed marker designed in Canva; when scanned by the device camera, the marker triggered the display of an interactive 3D object accompanied by audio narration. Additional features included a built-in quiz (10 multiple-choice items) and an "Install Marker" function to redownload lost or damaged markers. The application was developed to operate entirely offline, eliminating dependency on internet connectivity—a critical consideration for rural educational settings.

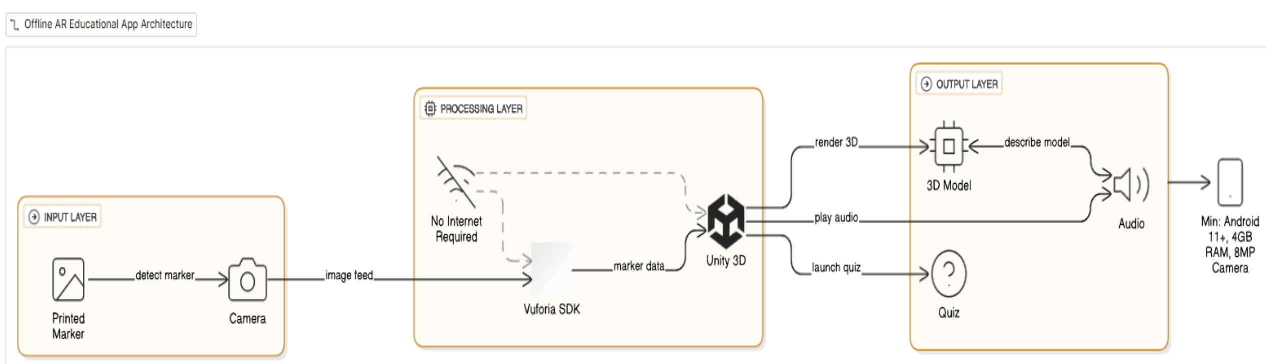

Figure 2. System architecture of the offline Android-based AR application for computer hardware education.

To ensure methodological rigor, the **Evaluation** phase incorporated both expert validation and user testing. Three categories of experts were engaged: (1) two media specialists (lecturers in Educational Technology), (2) two instructional designers (also from the same department), and (3) one subject-matter expert (an ICT teacher at the school). Each expert completed a 20-item Likert-scale questionnaire assessing dimensions such as content accuracy, instructional quality, visual design, and usability. The instrument was adapted from established validation protocols in educational media research (Rustandi, 2021) and scored on a 5-point scale (1 = strongly disagree to 5 = strongly agree). Feasibility was determined using Rustandi's criteria: ≥81% = "Very Feasible," 61–80% = "Feasible."

Following expert validation and iterative refinement, the application underwent two rounds of user testing. A **small-scale trial** involved five students from Class X TKJ B, aimed at identifying technical bugs and usability issues. Subsequently, a **large-scale trial** was conducted with 30 students from Class X TKJ A. Participants used the application individually on their personal smartphones during a dedicated instructional session. Immediately afterward, they completed a 35-item user response questionnaire measuring perceived usability, visual clarity, aesthetic appeal, and instructional effectiveness. The instrument employed the same 5-point Likert scale and was validated through pilot testing. Quantitative data were analyzed using descriptive statistics (percentages, means); qualitative feedback from open-ended prompts and observational notes was thematically coded to capture emergent insights about engagement and cognitive support.

Ethical considerations were upheld throughout the study. Informed consent was obtained from the school principal, the participating teacher, and all student participants (with parental consent for minors). Participation was voluntary, and students were assured that their responses would not affect academic grading. Data were anonymized and stored securely.This methodological approach, while developmental in nature, adhered to principles of transparency, systematicity, and stakeholder engagement—key markers of rigor in design-based and R&D research (Plomp & Nieveen, 2013). By integrating theory-informed design, multi-source validation, and contextual responsiveness, the study aimed not only to produce a functional prototype but also to generate actionable knowledge about the feasibility of low-cost AR solutions in under-resourced vocational education.

4. Results

The empirical evaluation of the Android-based Augmented Reality (AR) application yielded consistently positive outcomes across multiple stakeholder groups, including domain experts and end-users. The validation process followed a multi-phase approach, beginning with expert assessment and culminating in large-scale user trials, ensuring both technical rigor and pedagogical relevance.

Table 1. Expert validation results across three validator categories, based on Likert-scale questionnaires (N = 5 experts). Feasibility thresholds follow Rustandi (2021): ≥81% = Very Feasible; 61–80% = Feasible.

Validator Category	Evaluation Dimension	Mean Score (%)	Feasibility Category
Media Experts (n=2)	Relevance	97.5	Very Feasible
	Content & Objective Quality	95.5	Very Feasible
	Instructional Quality	91.4	Very Feasible
	Overall	94.5	Very Feasible

Design Experts (n=2)	Visual Design	90.0	Very Feasible
	Navigation & Interactivity	97.5	Very Feasible
	Content Alignment	93.0	Very Feasible
	Creativity & Innovation	93.0	Very Feasible
	User Appropriateness	90.0	Very Feasible
	Overall	92.5	Very Feasible
Subject-Matter Expert (n=1)	Usability & Navigation	80.0	Feasible
	Aesthetics	80.0	Feasible
	Media Integration	80.0	Feasible
	Technical Quality	80.0	Feasible
	Overall	80.0	Feasible

Three categories of experts—media specialists, instructional designers, and a subject-matter expert—evaluated the application using structured Likert-scale instruments. Two media experts assessed the application across three dimensions: relevance, content and objective quality, and instructional quality. Their combined evaluation yielded an average feasibility score of **94.5%**, placing the application firmly in the “Very Feasible” category. Similarly, two instructional design experts evaluated the application across five criteria, yielding an overall average score of **92.5%**, again classified as “Very Feasible.” In contrast, the subject-matter expert—a vocational ICT teacher—provided a more conservative but still favorable assessment, assigning a uniform score of **80%**, categorized as “Feasible.”

Following expert validation and iterative refinement, the application underwent two rounds of user evaluation. A small-scale pilot involving five students yielded an average score of 96%. Subsequently, a large-scale trial was administered to 30 students from Class X TKJ A.

Table 2. Student perception of the AR application in a large-scale field trial (N = 30). All dimensions exceeded the 81% threshold for “Very Feasible” classification.

Evaluation Dimension	**Mean Score (%)**	**Feasibility Category**
Usability and Navigation	87.3	Very Feasible
Visual Clarity	92.0	Very Feasible
Aesthetic Appeal	91.0	Very Feasible
Instructional Design	90.0	Very Feasible
Overall Acceptance	90.0	Very Feasible
Evaluation Dimension	Mean Score (%)	Feasibility Category

The aggregate mean score was 90%, placing the application in the “Very Feasible” category from the learners’ perspective. Qualitative feedback collected through open-ended prompts and observational notes further enriched these quantitative findings. Students frequently described the experience as “like holding real computer parts in my hand” and noted that rotating and zooming 3D models helped them “see how components fit together.”Collectively, these results demonstrate that the AR application is not only technically viable but also pedagogically effective in the target context. The convergence of high expert validation scores and strong learner acceptance underscores its potential as a scalable, low-cost solution for computer hardware education in resource-constrained vocational settings.

5. Discussion

The findings of this study demonstrate that an offline, marker-based Android AR application for computer hardware education is not only technically feasible but also pedagogically effective in a vocational high school context characterized by limited laboratory infrastructure. The convergence of high expert validation scores (94.5% from media experts, 92.5% from design experts) and strong learner acceptance (90% in large-scale trials) underscores the viability of low-cost AR as a scalable solution for experiential learning in under-resourced settings. These results gain deeper significance when interpreted through the dual theoretical lenses of Mayer's Cognitive Theory of Multimedia Learning (CTML) and the Technology Acceptance Model (TAM), which together explain why and how the intervention succeeded.

From a CTML perspective, the application's design directly operationalized core principles of effective multimedia instruction. By presenting 3D models of hardware components alongside synchronized audio narration—rather than static text or isolated images—the application leveraged dual-channel processing (visual + verbal) to reduce extraneous cognitive load and support generative learning. Students' qualitative feedback—such as "I finally understand what RAM and CPU actually look like"—reflects successful knowledge construction through the integration of spatial and semantic information, precisely as CTML predicts. Moreover, the self-paced, interactive nature of the AR experience aligns with the *segmentation principle*, allowing learners to process information in manageable chunks.

Simultaneously, TAM elucidates the behavioural drivers behind high user acceptance. In a context where students possess personal Android devices but lack consistent access to physical hardware, the application's offline functionality, intuitive navigation (97.5% interactivity score), and compatibility with mid-range smartphones directly enhanced *perceived ease of use*. Furthermore, by enabling independent exploration of hardware components—previously constrained by shared lab time—the application significantly increased *perceived usefulness*. This dual alignment with TAM constructs explains the overwhelmingly positive student response (90% overall feasibility).

The slightly lower score from the subject-matter expert (80%) also offers a critical insight. While the expert affirmed content accuracy, suggestions for institutional branding and textual refinement highlight a gap between *technical feasibility* and *curricular embeddedness*. This echoes concerns raised by Nistrina (2021) regarding the slow institutional adoption of AR despite its pedagogical promise.

Theoretically, this study contributes to the growing validation of CTML and TAM in immersive educational technology. Practically, it offers a replicable model for TVET institutions facing similar infrastructure constraints. Unlike high-fidelity AR/VR systems requiring dedicated hardware, our solution leverages ubiquitous smartphones and printed markers a combination that is affordable, distributable, and sustainable without internet dependency.Nevertheless, limitations warrant acknowledgment. The absence of a control group and pretest-post test design precludes causal claims about learning gains. Future work should employ quasi-experimental methods to measure actual knowledge acquisition, not just perception.

6. Conclusion

This study successfully designed, developed, and evaluated an offline, Android-based Augmented Reality (AR) application for teaching computer hardware concepts to vocational high school students in a resource-constrained setting. Grounded in Mayer's Cognitive Theory of Multimedia Learning and the Technology Acceptance Model, the application leverages marker-based AR to deliver interactive 3D visualizations of hardware components through widely available smartphones. Empirical validation by media experts (94.5%), design experts (92.5%), and a subject-matter expert (80%), coupled with strong learner acceptance (90% in large-scale trials), confirms the feasibility and pedagogical relevance of the intervention. Qualitative feedback further underscores its capacity to enhance spatial understanding, motivation, and autonomous learning—addressing a critical gap in contexts where physical lab access is limited.

Nevertheless, this research has notable limitations. First, the absence of a control group and pretest-posttest design precludes causal inference regarding learning gains; the study measures perceived usability and acceptance, not actual knowledge acquisition. Second, the sample was confined to a single vocational school in West Kalimantan, limiting generalizability across diverse educational or cultural contexts. Third, the AR implementation relies on static markers and pre-rendered 3D models, lacking adaptive or interactive simulation features (e.g., virtual assembly or troubleshooting scenarios) that could deepen technical competence.

Future research should address these gaps through quasi-experimental or randomized controlled trials to quantify learning outcomes, expand testing to multiple schools or countries, and enrich the application with dynamic, task-based interactions grounded in authentic vocational practices. Additionally, integrating the AR tool with school learning management systems or aligning it with national competency standards could facilitate institutional adoption. Exploring cross-platform compatibility (e.g., iOS, web-based AR) and cloud-based content updates would further enhance scalability. Ultimately, this study offers a validated, low-cost blueprint for immersive technical education in under-resourced environments a step toward more equitable and engaging digital learning ecosystems in global vocational education.

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