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Original Article

DEVELOPMENT OF AUGMENTED REALITY BASED SIMULATION MEDIA FOR COMPUTER AND NETWORK ENGINEERING COMPETENCY IN VOCATIONAL HIGH SCHOOLS

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Abstract

This study aimed to develop and evaluate Augmented Reality (AR)-based simulation media to enhance the Computer and Network Engineering (TKJ) competency in Vocational High Schools (SMK). Employing a Research and Development (R&D) approach, the product was designed as an Android application that integrates interactive 3D models of networking devices, marker-based visualization, and guided configuration tutorials. The development process included needs analysis, design, systematic development, implementation, evaluation, and revision stages. Participants were TKJ teachers and Grade XI students from three SMKs in South Sulawesi, Indonesia. Data were collected through interviews, questionnaires, expert validation, and pre-test/post-test assessments. The results showed a validity score of 98.14% (very valid), practicality score of 97.09% (very practical), and effectiveness with an N-Gain of 0.97 (high). User responses recorded 85.88% positive feedback, indicating high engagement and perceived usefulness. The findings demonstrate that AR simulation media can effectively bridge the gap between theoretical instruction and practical skill development, especially in schools with limited physical resources. Its portability, ease of use, and alignment with vocational learning principles make it a promising solution for improving instructional quality and supporting the revitalization of vocational education.

Keywords: Augmented Reality, Simulation media, vocational education, TKJ competency, Instructional technology

Introduction

Education is a fundamental process in shaping a whole human being. This process not only involves the transfer of knowledge but also the formation of character, values, and skills necessary for living productively in society. As Nelson Mandela asserted, “Education is the most powerful weapon which you can use to change the world” (Mandela, 1990). This statement underscores the strategic role of education in transforming individuals’ quality of life and building a nation’s civilization. In the context of national development, education serves as one of the main pillars determining the success of achieving sustainable development goals.

Global changes in the era of the Industrial Revolution 4.0 have significant implications for the needs and demands of the labor market. Rapid technological developments, automation, and digitalization create new challenges that require a workforce equipped with professional competence, critical thinking skills, creativity, communication abilities, and collaboration capacity (Benešová & Tupa, 2017). Educational institutions, particularly Vocational High Schools (SMK), play a central role in preparing graduates capable of meeting these demands.

According to Law of the Republic of Indonesia No. 20 of 2003 on the National Education System, Article 15, vocational high schools are secondary education institutions designed to prepare students to work in specific fields. Vocational education is directed toward ensuring graduates possess applied skills, technical knowledge, and professional attitudes relevant to the needs of business and industry (DUDI). As Pavlova (2009) notes, vocational education has traditionally focused on preparing students for employment, with curricula tailored to meet labor market demands.

However, a fundamental issue in Indonesia's vocational education is the gap between graduate competencies and industry requirements. Data from the Central Statistics Agency (BPS, 2020) shows that the Open Unemployment Rate (TPT) among SMK graduates is the highest compared to other educational levels, at 10.96%. This indicates that the skills acquired during schooling have not fully met the competency standards required by industry.

One factor affecting the low quality of graduates is the availability of learning facilities and infrastructure. Government Regulation No. 32 of 2013 on National Education Standards stipulates that every educational unit must have facilities and infrastructure that meet established standards. Unfortunately, many SMKs still lack adequate laboratory facilities and practice equipment. Research by Adawiyah & Rifqi (2022) emphasizes that the availability of up-to-date, industry-standard facilities is critical to the successful implementation of competency-based curricula in vocational schools.

In the field of Computer and Network Engineering (TKJ), having a fully equipped computer laboratory is essential to support practice-based learning. However, observations and interviews with TKJ teachers at several SMKs in South Sulawesi revealed that much of the practice equipment is incomplete or damaged. As a result, the learning process often relies solely on theory without hands-on experience, which contradicts the principle of learning by doing (Dewey, 1938).

This condition is further exacerbated by the rapid development of Information and Communication Technology (ICT). Data from BPS (2021) indicates that 62.10% of Indonesia's population has accessed the internet, and a survey by the Ministry of Communication and Information (2017) reports that 79.56% of senior high school and vocational school students own smartphones. While this technology could be leveraged for learning, in many schools it has not yet been optimally managed. Research by Fitri et al. (2022) shows that smartphone use can positively influence learning interest if directed appropriately.

One promising innovation to address the limitations of practical facilities in vocational schools is the use of Augmented Reality (AR) technology. AR can combine two- or three-dimensional virtual objects with the real environment in real-time, providing a more interactive and immersive learning experience (Azuma, 1997). Research by Gusteti et al. (2023) found that AR in learning can improve students' understanding of abstract concepts, learning motivation, and learning outcomes. This is particularly relevant for TKJ subjects, which often involve abstract concepts such as network topology, communication protocols, and hardware configuration.

Furthermore, Ahmad Thirafi Haekal et al. (2022) state that AR-based learning media is considered attractive and easy to use by students, and effective in visualizing material that is difficult to understand through conventional means. This approach aligns with Sural's (2018) view that AR enables students to access and manipulate learning content dynamically via mobile devices, without being constrained by space and time.

Based on these issues, this research seeks to develop AR-based simulation media for the Computer and Network Engineering competency in vocational high schools. This development is expected to provide an alternative solution to overcome the limitations of practice facilities while harnessing the potential of mobile technology to improve the quality of vocational education.

Research methods

This study employed a Research and Development (R&D) approach, aimed at producing an instructional product in the form of an Augmented Reality (AR)-based simulation media for the Computer and Network Engineering (TKJ) vocational competency in Vocational High Schools (SMK). According to Borg and Gall (1983), R&D is a systematic process used to design, develop, and evaluate educational products to meet the criteria of validity, practicality, and effectiveness. This approach aligns with Sugiyono's (2019) view that R&D seeks to produce specific products and to test their effectiveness.

The development model in this research is a synthesis of several established instructional design and development frameworks, namely Borg & Gall, the Four-D Model (Thiagarajan et al., 1974), ADDIE Model (Dick & Carey, 2005), Richey & Klein (2009), and the Prototype Model (Pressman, 2010). This synthesis yielded six main development stages:

Research (Preliminary Investigation)

This stage involved a needs analysis through interviews, observations, and document analysis. Needs analysis ensures that the developed product aligns with learners' characteristics and competency demands (Branch, 2009). Interviews with TKJ teachers and students identified gaps between the ideal learning conditions and the actual situation in the field.

Innovation Design

This stage entailed conceptualizing the AR simulation media, creating storyboards, selecting software tools, and determining media formats. The design process followed Morrison et al.'s (2010) instructional design principles, emphasizing alignment between objectives, content, strategies, and evaluation.

Systematic Development

The AR simulation media was developed using Unity 3D software and the Vuforia SDK. The development process adhered to Mayer's (2009) multimedia learning principles, which highlight the integration of text, images, and animations to support learner comprehension.

Implementation

The product was trialed in three stages: one-to-one testing, small-group testing, and large-group testing. These trials aimed to identify technical and content-related weaknesses before large-scale classroom use (Plomp & Nieveen, 2013).

Evaluation

Evaluation assessed the product's validity, practicality, and effectiveness. Validity was determined by media and content experts using evaluation instruments adapted from Riduwan (2012). Practicality was measured based on ease of use by teachers and students, while effectiveness was evaluated through pre-test and post-test learning outcomes, with improvement calculated using the Normalized Gain formula (Hake, 1999).

Feedback and Revision

Feedback from validators and users informed iterative revisions to ensure that the product met pedagogical needs. Tessmer (1993) emphasized that repeated revision cycles are crucial for aligning products with their intended educational context.

Participants and Research Sites

The research was conducted in three vocational high schools in South Sulawesi, Indonesia: SMKN 1 Gowa, SMKN 4 Gowa, and SMKN 10 Makassar. Participants included TKJ subject teachers and Grade XI students enrolled in the Basic Computer Networking course. The schools were selected using purposive sampling based on their TKJ programs and their limited practice facilities.

Research Instruments

The instruments included: (1) teacher and student interview guidelines, (2) needs analysis questionnaires, (3) media and content validation sheets, (4) user response questionnaires, and (5) learning achievement tests. The instruments were developed in accordance with Sugiyono's (2019) guidelines for educational research and were validated for content by subject matter experts.

Data Collection Techniques

Data were collected through observation, interviews, documentation, questionnaires, and tests. Observations recorded classroom practices and available facilities. Interviews captured detailed insights from teachers and students. Questionnaires gathered quantitative perceptions from participants, and tests measured students' cognitive achievement before and after using the AR simulation media.

Research Results and Discussion

1.1. Research result

Needs Analysis

The needs analysis phase was conducted to identify the gap between the ideal and actual learning conditions in the Computer and Network Engineering (TKJ) competency at selected vocational schools. This phase employed interviews, observations, and document analysis involving three schools in South Sulawesi: SMKN 1 Gowa, SMKN 4 Gowa, and SMKN 10 Makassar. Participants consisted of TKJ teachers and Grade XI students.

Findings from teacher interviews revealed several recurring issues:

• Incomplete and damaged equipment – Although each school had a designated computer networking laboratory, much of the hardware was outdated or non-functional. SMKN 1 Gowa, for example, lacked sufficient functional routers and switches to accommodate full-class practice sessions.

• Reliance on virtual tools – Due to hardware limitations, practical sessions often relied on virtual simulators such as VirtualBox. While this provided some conceptual exposure, it did not replicate the tactile and procedural experience of handling actual devices.

• Curriculum-practice misalignment – Teachers reported difficulty meeting the practical competency targets outlined in the national curriculum because students were not able to interact directly with real hardware components.

Student feedback supported these findings. Many reported that their understanding of networking devices, such as routers, switches, and access points, was primarily theoretical. Without direct interaction, they struggled to visualize device components and comprehend how physical configurations influence network performance.

These findings echo Suharto et al. (2020), who emphasize that adequate laboratory facilities are critical for achieving vocational learning objectives. The results underscore the urgency for alternative media solutions that can provide authentic, interactive practice experiences without being constrained by hardware availability.

AR Simulation Media Development

The AR simulation media was developed using Unity 3D as the core development platform and Vuforia SDK for AR integration. Development followed Mayer's (2009) multimedia learning principles, ensuring optimal integration of visual, textual, and interactive elements. The process involved:

• Storyboard creation – A complete instructional flow was designed, mapping learning objectives to AR interactions. Each topic within the networking curriculum was translated into step-by-step simulation sequences.

• 3D asset modeling – Networking devices were modeled in realistic proportions, including visual details such as indicator lights, port labels, and internal components for some devices.

• Marker-based AR system – Each device could be activated by scanning printed markers. Once scanned, the device model appeared on the user's smartphone screen, allowing 360-degree rotation and zoom.

• Tutorial integration – Configuration procedures, such as VLAN setup or router IP addressing, were embedded as guided steps alongside the 3D model display.

The final product was packaged as an Android application compatible with most mid-range smartphones, addressing the high smartphone ownership rate among vocational students (BPS, 2021).

Media Validation

Validation was conducted by a panel of seven experts: four media design experts and three TKJ subject matter experts. They assessed the product in terms of content accuracy, visual quality, usability, and pedagogical alignment.

The aggregated validation results showed:

• Content accuracy: 98.6% (very valid), with experts noting that the instructional sequences aligned well with the TKJ competency framework.

• Visual and technical quality: 97.8% (very valid), praised for realistic modeling and smooth AR rendering without significant lag.

• Usability: 98.1% (very valid), indicating that navigation and interaction were intuitive for users.

The overall mean validation score reached 98.14%, categorized as very valid. Comments from experts included recommendations to add more troubleshooting scenarios, which were incorporated in later revisions.

Practicality Testing

Practicality testing was conducted in two phases:

• One-to-one trial – Six students individually tested the media under teacher supervision. Observations indicated that students were able to operate the application without prior training. The practicality score was 97.09%, indicating very practical.

• Small-group trial – Conducted with 12 students. Feedback highlighted the clarity of device visuals, ease of marker recognition, and relevance of instructional prompts. Minor technical issues, such as marker misalignment under low light, were recorded for further improvement.

Both trials confirmed that the media was not only functional but also easy to integrate into existing lesson plans without extensive teacher preparation.

Effectiveness Testing

Effectiveness was evaluated using a pre-test and post-test design involving 91 students across the three schools. Tests measured understanding of network device identification, configuration procedures, and troubleshooting.

The results showed:

• Pre-test mean score: 46.2 (scale 0–100)

• Post-test mean score: 94.5 (scale 0–100)

• Normalized Gain (N-Gain): 0.97 (high)

This substantial improvement suggests that AR simulation media was highly effective in enhancing student learning outcomes. The results align with Sural (2018), who reported that AR-based instruction in vocational education significantly improves both conceptual understanding and procedural skills.

User Response

User responses were collected through a Likert-scale questionnaire covering engagement, content clarity, visual quality, and ease of use. Out of 91 respondents:

• 85.88% rated the media as very interesting and engaging.

• Students particularly appreciated the ability to “see” and “handle” devices virtually, bridging the gap between theory and practice.

• Teachers noted improved student participation during AR-assisted lessons compared to conventional sessions.

This aligns with Gusteti et al. (2023), who found that AR media can significantly increase student motivation and sustained attention in complex technical subjects.

Discussion

The findings of this study confirm that Augmented Reality (AR)-based simulation media can be an effective, practical, and engaging instructional tool in vocational education, particularly in the Computer and Network Engineering (TKJ) program of Vocational High Schools (SMK). The combination of high validity scores (98.14%), high practicality ratings (97.09%), significant learning gains (N-Gain = 0.97), and overwhelmingly positive user responses (85.88%) demonstrate that AR media can successfully bridge the gap between theoretical instruction and hands-on skill acquisition in resource-limited environments.

1. Meeting Vocational Education Needs Through Authentic Simulation

The initial needs analysis showed that most participating schools lacked sufficient functional networking devices, leading to a reliance on theoretical instruction or generic simulation software such as VirtualBox. While virtual simulation tools have pedagogical value, they fail to replicate the authentic physical experience of manipulating actual networking hardware.

This gap aligns with Suharto et al. (2020), who assert that adequate laboratory resources are essential for vocational learning outcomes, as physical manipulation and procedural familiarity are integral to skill mastery. AR technology, as applied in this study, compensates for this deficiency by providing high-fidelity 3D models of routers, switches, access points, and other networking components. These models can be rotated, zoomed, and interacted with, enabling learners to explore both external and internal components in detail.

From a pedagogical perspective, this approach reflects Prosser’s (1925) real-world replication principle, which states that effective vocational training must recreate the conditions, tools, and workflows encountered in the workplace. By embedding realistic device configuration scenarios into the AR interface, the media not only provided cognitive familiarity but also procedural exposure to industry-standard practices.

2. Impact on Student Engagement and Motivation

Engagement and motivation emerged as significant benefits of using AR in the TKJ curriculum. The 85.88% positive user feedback indicates that students found the AR-based lessons more interesting and immersive compared to conventional textbook or slideshow-based approaches.

This aligns with Mayer's (2009) Cognitive Theory of Multimedia Learning, which posits that meaningful learning occurs when verbal and visual information are integrated in a way that reduces extraneous cognitive load while enhancing germane processing. In the AR context, learners could simultaneously read configuration instructions and observe corresponding 3D visualizations, reinforcing understanding through dual coding.

Gusteti et al. (2023) similarly found that AR enhances learner motivation by making abstract technical content more concrete and relatable. In this study, students frequently reported that networking concepts "came alive" when visualized in AR, enabling them to conceptualize network topology, device functions, and configuration workflows in ways that static diagrams could not achieve.

3. Practicality and Teacher Adoption

Practicality results (97.09% in the one-to-one trial) demonstrated that the AR media required minimal training for both teachers and students. Teachers could integrate the application into their lesson plans without restructuring the curriculum or undergoing extensive technical preparation.

These results resonate with Ahmad Thirafi Haekal et al. (2022), who concluded that AR applications for vocational subjects are generally intuitive and align well with students' pre-existing familiarity with mobile devices. Given that 79.56% of Indonesian high school students own smartphones (BPS, 2021), the use of Android-based AR media fits seamlessly into their digital habits.

Morrison et al. (2010) emphasize the importance of aligning instructional design with learners' existing competencies and available resources. The adoption of AR media in this study capitalized on students' comfort with smartphone technology, thereby reducing potential barriers to implementation.

4. Effectiveness in Improving Learning Outcomes

The pre-test/post-test results showed a dramatic improvement, with the mean score increasing from 46.2 to 94.5 and an N-Gain score of 0.97 (high category). This suggests that the AR simulation media not only enhanced conceptual understanding but also improved procedural competence in network device configuration and troubleshooting.

These findings are consistent with Sural (2018), who found that AR in vocational contexts significantly improves knowledge retention and skill acquisition, especially when the learning tasks involve spatial and procedural elements. In the context of TKJ, where students must understand both the physical structure of devices and the abstract logic of network configurations, AR provides a unique capacity to integrate both domains.

5. Pedagogical Contributions

The use of AR in this study supports several key principles of vocational pedagogy:

• Experiential Learning – By simulating authentic device interactions, AR creates opportunities for hands-on learning experiences, even in the absence of physical equipment (Dewey, 1938).

• Situated Learning – The simulations situate knowledge within realistic contexts, enabling learners to practice skills in an environment that mirrors the workplace (Lave & Wenger, 1991).

• Self-Paced Mastery – The portability of AR media allows learners to revisit and practice device configurations outside class, supporting self-directed learning (Hamidi & Chavoshi, 2018).

This alignment with vocational learning theory suggests that AR can serve as a bridge between the school-to-worktransition, equipping students with both the cognitive and procedural competencies needed in industry.

6. Implications for Policy and Practice

The Ministry of Education's Revitalisasi SMK program emphasizes the integration of technology into vocational curricula to meet industry standards. However, budgetary constraints often limit the acquisition of expensive networking hardware. AR-based simulation media offers a cost-effective alternative by delivering high-quality, industry-relevant training experiences without the recurring expenses of hardware maintenance and replacement.

Implementing AR across vocational programs could help reduce inequality between urban and rural schools, ensuring that all students, regardless of geographic location or school budget, have access to the same quality of technical training.

7. Limitations and Future Directions

Despite its strengths, the AR simulation media developed in this study has limitations:

1. Lighting dependency – The marker-based system requires adequate lighting for reliable recognition. Poor lighting conditions in some classrooms affected usability.
2. Lack of haptic feedback – While visual realism was high, the absence of tactile interaction may limit skill transfer in tasks requiring fine motor manipulation.
3. Content scope – The current version focuses on foundational networking devices and configurations. Advanced competencies such as multi-layer switching or enterprise-level network security remain outside its coverage.

Future research could address these limitations by:

• Exploring markerless AR systems to improve usability in varying lighting conditions.

• Integrating haptic feedback devices to simulate physical handling of tools and components.

• Expanding the content to cover more advanced competencies, enabling use across all grade levels of vocational training.

• Conducting longitudinal studies to evaluate the long-term retention of skills acquired through AR-assisted learning.

Conclusion

This study developed and evaluated Augmented Reality (AR)-based simulation media to support the Computer and Network Engineering (TKJ) competency in Vocational High Schools (SMK). The development process followed a systematic instructional design framework, resulting in an Android-based application featuring interactive 3D models of networking devices, marker-based visualization, and embedded configuration tutorials.

The results showed that the AR simulation media achieved very high validity (98.14%), very high practicality (97.09%), and high effectiveness with an N-Gain score of 0.97. User responses were overwhelmingly positive (85.88%), indicating that the media was engaging, intuitive, and relevant to the learning needs of vocational students.

These findings highlight several key contributions:

1. Bridging the gap between theory and practice – AR technology enabled realistic and interactive practice in environments with limited physical equipment.

2. Enhancing motivation and engagement – The immersive nature of AR increased students' interest and sustained attention during lessons.

3. Facilitating ease of integration – The application was user-friendly for both teachers and students, requiring minimal training and resources.

From a pedagogical perspective, AR simulation media aligns with experiential and situated learning principles, providing students with authentic, industry-relevant experiences that support skill acquisition. From a policy perspective, AR offers a cost-effective alternative for improving the quality of vocational education, particularly in resource-limited schools.

Future research is recommended to address current limitations, such as improving marker recognition under low-light conditions, integrating haptic feedback for tactile realism, and expanding the content to cover advanced networking competencies. Longitudinal studies should also be conducted to assess the sustainability of learning gains over time.

In conclusion, the integration of AR-based simulation media in vocational education is a promising strategy to improve learning quality, foster technical competence, and prepare students more effectively for industry demands in the era of rapid technological change.

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