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Enhancing Vocational Students' Cognitive Skills in Computer Networking Through Augmented Reality

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Abstract

This study aimed to develop and evaluate Augmented Reality (AR)-based learning media to enhance students' cognitive abilities at State Vocational High School (SMK Negeri) 2 Pati, particularly in the subject of Computer Networking and the Internet. The research was motivated by low student achievement in meeting the Minimum Mastery Criteria (KKTP), which was primarily attributed to the continued reliance on traditional teaching methods and low student motivation. A research and development (R&D) approach was employed using the ADDIE model. The resulting AR media is an Android application that integrates text, audio, images, animations, interactive 3D objects, and simulations, and is in accordance with the Merdeka Curriculum. Expert evaluations showed a very high level of feasibility, with ratings of 94% from a subject matter expert and 91% from a media expert. These results were further supported by Aiken's V index, which indicated very high validity for the material (0.921) and high validity for the media (0.881). A practicality test was conducted, revealing a high level of effectiveness, with a 94% approval rating from both teachers and students. Moreover, a pretest–posttest control group design demonstrated significant progress in learning outcomes. The experimental group achieved an average post-test score of 83.75, significantly higher than the control group's 73.60. Based on the N-Gain test, the experimental group achieved an average gain of 65.52% (moderately effective), whereas the control group achieved only 38.75% (ineffective). This study contributes to the theories of learning transfer, connectivism, and heutagogy, and offers practical implications for vocational education in adopting innovative technologies.

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INTRODUCTION

Vocational high schools hold a crucial role in preparing qualified and skillful human resources to face the digital era. In Indonesia, Vocational High School (SMK) is expected to provide graduates who are not only technically competent, but also adaptive and innovative. However, many challenges are faced, especially in the Merdeka Curriculum implementation that demands flexibility, contextual learning, and relevance to the industrial world. Less innovative and interactive learning media are the biggest challenge that contributes to the difficulty in transforming knowledge into practical understanding.

In the informatics subject, especially in the material Computer Networking and Internet, many students faced difficulty in mastering theoretical concepts through conventional methods such as textbooks and PowerPoint presentations. The former observation at SMK N 2 Pati showed that 40% students achieved Minimum Mastery Criteria (KKTP≥ 70), which indicated the need for a new learning strategy. Conventional learning media are unable to provide learning engagement and deep learning, especially in topics that need spatial and procedural concepts.

The Indonesian curriculum positions the teacher not as the primary learning source, but as a facilitator in the teaching and learning process. Qudus et al (2025) stated that teachers' pedagogical ability can determine the success of teaching. Teachers' readiness and their role in optimizing technology to attract students' interest in learning (Firmadani, 2020). The advanced technology and the availability of supporting tools can be a new learning source that is needed in the learning process. These resources can help students face the challenges and difficulties in technical skills through interactive learning (Was, 2022).

However, Augmented Reality (AR) holds great potential, there remains a significant gap that needs to be addressed. First, most Augmented Reality (AR) research focused on higher and basic education levels, and only a few researchers chose vocational high school (SMK), which has unique characteristics and practical needs. This research aimed to fill the gap in AR research, especially at the vocational level, by providing knowledge through bibliometric and literature review (Ramadhan et al., 2024). Second, AR-integrated media in vocational education has emerged as a promising tool to enhance students' learning experiences and align educational content with industry demands. However, various challenges have been identified, such as high implementation cost, limited digital literacy for students and teachers, and infrastructure constraints (Hidayat et al, 2025). Third, AR-integrated media in the Merdeka Curriculum, which emphasizes flexibility, contextuality, and relevance to the industrial world, has not been explored deeply.

In the state vocational high school (SMK Negeri) 2 Pati, the data showed that 40% of students who took the Informatics and Technology subject did not pass the minimum score (KKTP ≥ 70), and this indicates that 60% of students have not achieved the passing grade. The initial observation indicated that: (1) the learning process was inclined with conventional methods such as blackboard, handbook, which can not stimulate students' participation and cognitive skills, especially in abstract concepts, and computer and internet. (2) Limited interactive learning media such as AR. (3) Traditional tools such as PowerPoint can create inactive students in dynamic learning. (4) Students are less motivated toward conventional media since they commonly use advanced media such as computers and smartphones. This condition aligns with the findings of Hidayat et al. (2025), who noted that the lack of interactive media, safety concerns, and high training costs pose significant barriers to effective learning. Augmented Reality (AR) presents a potential solution by offering realistic simulations that can enhance the learning experience in more effective activities.

Based on the research problem and the gap found by the researcher, this study was designed to create a new learning medium for the Informatics Technology subject at Vocational High School. This research and development can help students enhance critical thinking, support dynamic and interactive learning, and strengthen

their understanding of materials and industrial competency.

Much research has proven AR's effectiveness in improving learning output, building conceptual and stimulating critical thinking. Ibáñez & Delgado-Kloos (2018) depicted that AR was effective in advancing learning output, especially in the STEM field. The informatics subject focuses not only on mastering the knowledge but also on applying concepts in information and communication. These materials must be explained with supported visualization so that the students can understand. However, based on the researcher's observation in vocational high school (SMK Negeri) 2 Pati, the Informatics and Technology subject is explained and practiced manually with the lecture method. The result is that most students feel bored and find difficulty in understanding the materials (Pramesti & Makbul, 2023). Sofan et al (2024) also elaborated that creative and interactive media can improve learning results tremendously, further supporting learning effectively.

Media can be used to increase students' cognitive skills through Augmented Reality (AR) to deliver the materials through *Unity 3D & Vuforia* application. The experiment changes the image into a moving picture in the *Unity 3D & Vuforia* program. This research aimed to fill the gap by developing and evaluating an AR-based application for Computer Networking and the Internet in the E phase of the Merdeka Curriculum.

The research focused on feasibility analysis, practicality, and media effectiveness in improving students' cognitive skills. In addition, it also contributed to learning transfer theory, cognitivism, and heutagogy of vocational education.

Augmented Reality learning media has been developed successfully by adopting the ADDIE model (*Analysis, Design, Development, Implementation, and Evaluation*). This approach ensures that the development process is controlled and systematic, leading to a high-quality outcome. The process begins with needs identification and continues through to the final product evaluation. The research product is an Android application (.apk) that is designed for students' smartphones. This application integrates interactive multimedia elements such as text, sound, pictures, animations, 3D objects, and simulations.

METHOD

This research employs a Research and Development (R&D) aimed at creating an Augmented Reality (AR) based. In addition, the study also tested the feasibility, practicality, and effectiveness in enhancing the cognitive abilities of vocational high school (SMK) students in the Informatics subject. The development process follows the ADDIE model, which consists of five systematic phases. (1) Analysis: This phase involves identifying learning needs based on observation and students' learning achievement. (2) Design, at this stage, the instructional design is developed, including the creation of storyboards and technical specifications for the AR media. (3) Development This phase focuses on the development of an AR application prototype using Unity 3D and Vuforia software. (4) Implementation: The developed AR media is tested in the experiment class. (5) Evaluation: The final phase involves assessing the feasibility, practicality, and effectiveness of the media.

The research subject was grade X vocational high school (SMK) students enrolled in the Informatics subject at Phase E, with a specific focus on the topic of *Computer Networks and the Internet*. The study involved two classes: an experimental class, which utilized the AR-based learning media, and a control class, which received instruction through conventional teaching methods.

The researcher applied various techniques in each media evaluation phase. (1) Media feasibility analysis, this analysis was conducted by a material expert and a media expert using a validation questionnaire. The data were analyzed through the calculation of the percentage of feasibility scores, Aiken's V index to measure content validity, and inter-rater reliability, determined by calculating the coefficient of agreement among validators. (2) Media practicality analysis was measured using teacher and student response questionnaires. The data analysis included the calculation of the Reproducibility Coefficient (Kr), the Scalability

Coefficient (Ks), and the average percentage of practicality. (3) Media effectiveness analysis was tested using a Pretest-Posttest Control Group Design method. The participants were given a test to assess students' cognitive ability. After that, the researcher applied various tests, such as the normality test and homogeneity test, to ensure the prerequisites for parametric analysis. A Paired Sample t-test was used to examine the improvement in learning scores within each group. Also, an Independent Sample t-test was employed to compare the differences in learning outcomes between the experimental and control groups. Additionally, the N-Gain Score was calculated to measure the effectiveness of the learning intervention. The interpretation of the N-gain Score followed the criteria proposed by Hake (1999), as follows: G > 76%: Effective, 56% < G ≤ 75%: Sufficiently Effective, 40% < G ≤ 55%: Less Effective, and G ≤ 40%: Ineffective.

RESULT AND DISCUSSION

Media Development Result

The instructional media developed in this study is an Android-based Augmented Reality (AR) application (.apk) designed in the *Computer Networks and the Internet* subject for vocational high school students (Phase E). This application is designed with integrated elements including text, audio, images, animation, interactive 3D objects, and simulation. The media is developed in alignment with the principles of the *Merdeka Curriculum* and *P5* Project (Proyek Penguatan Profil Pelajar Pancasila).

Media Feasibility

The validation results from two content experts and two media experts indicate that the instructional media have a very high level of feasibility. The summary of the results is presented as follows:

Table 1. Augmented Reality Media Feasibility on Computer Networks and the Internet

Name	Validator 1	Validator 2
Material Expert		
Total score	180	176
Maks	190	190
Percentage	95%	93%
Average	94%	
Media Expert		
Total Score	190	186
Maks	200	200
Percentage	92%	90%
Average	91%	

Table 1 presents a quantitative proof of the expert validation result, and it directly fills the second research aim. The data depicted a high percentage 94% for the materials and 91% for the media. It can be stated that the tool was highly validated by experts and served as a crucial key indicator of the product's quality.

Further data showed that material feasibility achieved 94% with an Aiken index of 0.921 (very high category) while media feasibility got 91% with an Aiken V index of 0.881 (high category). The reliability among the experts showed a 0.792 score for materials and 0.744 for the media, which can be declared at a good category level. This result indicates that the presented media is feasible to use based on the content, presentation, and performance.

Media Practicality

Practicality expert was measured based on teachers' and students' responses toward media in the learning process. The analysis results indicated that the media were highly practical for use, as shown in Table 2 below.

Table 2. Media Practicality of Augmented Reality in Computer Networking and the Internet

Name	Teacher 1	Teacher 2	Teacher 3	Students
Total of Agreement	15	14	14	444
Maximum Score	15	15	15	480
Percentage	100%	93%	93%	92%
Average	95%			92%
Total Average	94%			

Table 2 elaborates on the media practicality result test in Augmented Reality-based learning. The data elaborated teachers' and students' responses in experiencing the media, the high percentage showed that the media is acceptable and easy enough to use in the learning process. The practicality score was measured based on the reproducibility coefficient (Kr) and the scalability coefficient (Ks) as follows.

- reproducibility coefficient (Kr): 0.943
- reproducibility coefficient (Kr): 0.860
- Average of practicality percentage: 94%

This result came from participants' experiences in using the presented media, which was simple and supported with attractive visuals. So, it became a crucial factor that affected high media practicality.

Media Efectivity

Media effectiveness was tested with a pre-test and post-test design. The experimental group used AR media, while the control group applied a conventional method. The data showed that the post-test average score of the experimental group was 83.75 or higher than control group, which achieved 70.63. N-Gain average score of the experiment group gained 65,52% (sufficient category), while the control group only got 38,75% (ineffective category). *Paired sample t-test* showed a huge difference in scores between pre-test and post-test in the experimental group ($p < 0.05$). In addition, *the independent sample t-test* also depicted a big difference between the two groups ($p < 0.05$). In other words, the usage of AR media was statistically proven to increase students' cognitive skills compared to the conventional method.

The effectiveness of AR media enhances students' cognitive skills, particularly in mastering abstract concepts such as data and network topology. This finding aligns with the principles of Cognitive Load Theory (Sweller, 2020). AR ability presents complicated information through 3D interactive visuals and minimizes the material's intrinsic simulation burden. By reducing mental effort in processing abstract information, AR enables students to focus their cognitive resources on deeper learning experiences rather than struggling with basic understanding (Lee & Kim, 2020; Wang & Shen, 2023). The result explicitly stated that AR media can be a bridge to fill the gap that currently exists; it can also stimulate students' engagement and understanding in the learning process. In conclusion, AR media can decrease cognitive burden and facilitate learning experiences to be more active and efficient.

DISCUSSION

The presented study found that adapting AR media in learning activities is very effective in increasing students' conceptual understanding and motivation. This result is in line with many researchers (Ibáñez & Delgado-Kloos, 2018; Sari & Rachman, 2020) who take AR media as their research interest. An AR decreased cognitive burden as explained in Cognitive Load Theory (Sweller, 2020), through interactive visual information that makes it easy for the user to process abstract concepts. Furthermore, this media also strengthens Learning Transfer Theory (Perkins & Salomon, 2020) since it provides an opportunity for the students to apply the concept in a virtual context that is similar to the real world. The connectivism principle (Siemen, 2005) is also covered through digital information connectivity, while Heutagogy was mirrored in students' learning autonomy in exploring materials through AR media.

This result recommends that AR learning media development can be an alternative to address learning challenges in the Informatics Subject at Vocational High School, especially for abstract material, computer networking, and the internet.

Although the AR media is primarily used for individual interaction, its design includes multimedia and links to external resources (e.g., through QR codes as referenced in the theoretical benefits). These features help students build connections between different pieces of information, which supports the idea of learning as a network, based on Connectivism Theory (Siemens, 2005). The quiz feature, which gives instant feedback, also helps students learn better by adjusting their understanding right away. AR is also equipped with a feature that can give direct feedback and facilitate adaptive learning in

networking knowledge. AR media practicality allows students to learn independently and decrease dependence on teacher assistance. This finding aligns with the principles of Heutagogy, as proposed by Stewart Hase and Chris Kenyon (2000). AR features such as 3D visualization, scenario-based simulations, and adaptive feedback support students in developing self-directed learning habits.

The research findings consistently demonstrated the positive effects of AR, including increased student engagement, improved conceptual understanding, and enhanced learning outcomes (Radu, 2012). Akçayır & Akçayır's research (2017) reported that AR practicality improves motivation for vocational high school students. That study is also in line with Hadju et al (2024), who stated that AR effectively visualizes abstract concepts like algorithms and computer networking. The improvement of participants' critical thinking in the current study is also aligned with Aurum & Surjono (2021), who explained that the use of mobile-based interactive multimedia effectively improves students' critical thinking in vocational subjects, including computer and networking. The implementation of Augmented Reality(AR) in computer networking and the Internet at Vocational High School (SMK) solves the gap in previous research, where AR is more focused on the STEM field rather than complicated concepts in the informatics subject.

CONCLUSION

Augmented Reality (AR) media developed by the researcher to improve vocational students' cognitive skills in the Informatics subject phase E have been proven successful through ADDIE (Analysis, Design, Development, Implementation, and Evaluation). The research product is an Android application (apk) that can be installed on students' smartphones. This application can integrate text, voice, picture, animation, interactive 3D objects, and simulations.

The feasibility of Augmented Reality learning media to improve vocational students' cognitive skills in the Informatics subject phase E showed excellent results. The reliability among material and media experts indicated that the media is valid, reliable, and exceeds the required standard in terms of content and technical design. The effectiveness of the presented media significantly increases students' understanding of informatics concepts, especially in applying local networking connectivity, data communication via mobile phone, internet connectivity through cable networking and non-cable (bluetooth, WiFi, internet), encryption to protect the data in connecting the device to the local networking or available internet. The practicality of Augmented Reality in enhancing vocational students' cognitive abilities can be classified as very high, with an average practicality score of 0.943 (meeting the criterion of > 0.90), and a scalability coefficient (Ks) averaging 0.860 (meeting the criterion of > 0.60).

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