Enhancing Network Systems Programming Learning through Augmented Reality: A Study on Student Engagement and Understanding

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***Abstract*—The development of Augmented Reality (AR) technology has rapidly expanded in the educational field. Subjective observations in network systems programming learning have revealed a decline in student interest and understanding, caused by conventional teaching methods, which present significant obstacles in the learning process and negatively impact students' cognitive abilities. This study developed AR as a learning medium for network systems programming using the 4D design model and an R&D approach. Performance assessment instruments, questionnaires, and interviews with students and lecturers were used as primary data. The subjects of this study were 41 students from the Department of Electronic Engineering at Universitas Negeri Padang in the 2023–2024 academic year. The results showed that the use of AR-based learning media had a positive impact on students' understanding of basic concepts and skills. Additionally, AR media supported independent learning and provided direct feedback to students. Validation results from material experts reached 90.18%, media experts 90.13%, and linguists 89.95%. The average results from practical tests indicated 87.50% from lecturer responses and 86.90% from student responses. Therefore, the development of the AR mobile application, which is deemed valid and practical, offers a more interactive and engaging learning experience for students, enhancing their interest and understanding in learning. As such, mobile AR presents an exciting option for further integrating programming education into higher education.**

***Keywords*—augmented reality, network systems programming, computational thinking, mobile application**

I. Introduction

In an ever-evolving digital era, global education faces significant challenges in preparing graduates who can adapt to the increasingly dynamic demands of the workforce. The Fourth Industrial Revolution, driven by automation technology, Artificial Intelligence (AI) [1], and the Internet of Things (IoT) [2], places heightened expectations on vocational education graduates [3]. It is no longer sufficient for them to merely master technical competencies; they must also develop advanced thinking skills such as Computational Thinking (CT) skills, which encompass critical, creative, and algorithmic thinking. These skills are crucial in addressing the complexities and challenges of the modern industrial landscape.

However, many current vocational education models have yet to fully integrate and optimize the development of CT skills. This gap is a significant concern, as the demand for professionals who can navigate the intricate digital and industrial environment continues to rise. Without effective strategies for cultivating these competencies, graduates may find it challenging to meet the expectations of an Industry 4.0 workforce, which requires systematic problem-solving, adaptability, and technological innovation [4].

To address these challenges, this research focuses on bridging the gap in current vocational education by proposing an innovative approach that enhances Computational Thinking (CT) skills. The study emphasizes the integration of Augmented Reality (AR) and IoT technologies within vocational education, aiming to develop a more interactive and engaging learning environment. By leveraging AR, the study not only seeks to make complex concepts more accessible but also aims to strengthen problem-solving abilities, foster creativity, and promote collaboration among students. This research contributes by offering a model that aligns educational strategies with the demands of Industry 4.0, ultimately preparing graduates with the skills needed to thrive in an increasingly technological and dynamic workforce.

Computational Thinking Skills (CT skills) are a set of advanced thinking skills essential for solving problems in a logical and systematic manner, particularly through approaches inspired by computer science [5]. These skills include the ability to break down complex problems into smaller, more manageable parts (decomposition), identify recurring patterns (pattern recognition), simplify information by focusing on key elements (abstraction), and design logical steps or procedures to solve problems (algorithmic thinking). Additionally, the ability to review and correct errors (debugging) is a crucial part of the problem-solving process. In vocational education, CT skills are particularly important as they help students tackle the challenges of Industry 4.0 by thinking systematically and innovatively, applying technology, and creating effective new solutions [6].

Research [7] emphasizes that the integration of CT not only enhances problem-solving abilities but also sharpens critical and creative thinking skills. To address this, integrating modern technologies such as Augmented Reality (AR) and IoT in educational contexts has shown promising results [8]. AR technology enables the creation of interactive learning environments that not only facilitate students' understanding of complex concepts but also increase their interest and academic achievement. AR, as a technology that merges

virtual elements with the real world, has become a trend optimized in learning to enhance student engagement and improve learning outcomes.

Augmented Reality (AR) is a technology that superimposes virtual elements, including 3D objects, animations, sounds, and other forms of digital information, onto the real-world environment. This integration enhances users' perception and interaction with their surroundings by combining physical and virtual realities, resulting in a more immersive and engaging experience. AR transforms passive learning into an interactive process, allowing users to interact with digital content in real time, which can significantly enhance understanding, engagement, and retention of complex concepts [9]. Using devices like smartphones, tablets, or AR glasses, users can view the world around them enhanced with these digital components, which are tailored to the real-world context they are interacting with. Unlike Virtual Reality (VR), which fully immerses users in a completely artificial environment, AR enhances the perception of the real world by adding visual elements and supplementary information that users can directly engage with. In an educational setting, AR allows students to visualize abstract or complex concepts, such as the structure of computer networks or simulations of scientific processes, making learning more dynamic, engaging, and easier to comprehend [10]. AR also supports exploratory learning, enabling students to interact directly with lesson materials in a more contextual and relevant environment [11]. As a result, AR not only increases student engagement but also helps improve understanding and mastery of the subject matter more effectively.

AR-based learning media has been shown to improve student learning motivation [12], simplify material comprehension [13], and enhance the overall quality of learning [14]. By providing a more engaging and interactive learning experience, AR can also stimulate the development of computational thinking skills and support collaboration and teamwork [15, 16]. Therefore, the integration of AR in Collaborative Problem Solving (CPS) based learning models represents a highly relevant innovation for vocational education [17]. This research offers novelty in developing a CPS learning application based on AR, designed to enhance CT skills and competencies among vocational students. This application not only presents more interactive and engaging learning content but also encourages collaboration among students in solving complex problems. Thus, this research aims to develop computational thinking skills through collaborative learning in solving problems based on Augmented Reality (AR) in network systems programming. To achieve this research goal, the research questions posed are as follows:

1) What are the results of developing collaborative-based augmented reality for network systems programming learning?
2) What are the results of the validity and practicality of augmented reality in enhancing computational thinking skills in network systems programming learning?

Based on the research questions, it is evident that the research problem focuses on the gap in vocational education models, which fail to fully integrate CT skills needed to meet the demands of the Industry 4.0. This shortcoming poses a significant challenge as the workforce increasingly requires professionals who can systematically solve problems, think critically, and adapt to complex, technology-driven environments. Logically, it can be stated that the underlying basis of this problem is the rapid advancement of automation technology, Artificial Intelligence (AI), and the Internet of Things (IoT), which demands that graduates possess not only technical competencies but also advanced thinking skills. Without modern teaching strategies that incorporate interactive and engaging technologies, such as AR, students may struggle to acquire these essential competencies.

By integrating AR into Collaborative Problem Solving (CPS) learning models, this research seeks to address this gap. AR can transform passive learning into interactive experiences, making abstract concepts more accessible, fostering creativity, and encouraging teamwork.

Thus, this research concludes that enhancing vocational education with an AR-based CPS model can effectively develop CT skills, aligning educational outcomes with the dynamic needs of Industry 4.0. This approach ensures that graduates are better prepared to thrive in an increasingly technological and innovative workforce.

II. Methods

The development model for the learning media used in this research is the 4D model (Four-Dimensional Model). The researchers chose this 4D model because of its straightforward and organized approach [18], which allows for testing and refinement at each stage of the design cycle without interruption [19]. The 4D model consists of four main phases: definition, design, development, and distribution [20]. In the definition phase, the researchers identify and define the learning needs and objectives to be achieved [21]. During the design phase, the researchers design the learning media to be developed, including the content, format, and techniques to be used [22]. The development phase includes creating and testing the learning media, as well as evaluating and refining it based on feedback received [21]. The final phase, distribution, involves disseminating the developed and evaluated learning media to end users, such as instructors and students, and gathering feedback for further improvement [11].

This research produces a mobile learning product based on AR technology, including teaching materials (e-modules), instructional videos, and animated simulations with background audio, as well as infographics on network systems programming material. The students involved in the AR media development trials are students from the Electronics Engineering department at Universitas Negeri Padang, who are taking the theoretical course on Network Systems Programming during the 2023/2024 academic year. They consist of four learning groups, including Group F1 as the experimental class with 21 students and Group F2 as the control class (not using augmented simulation media) with 20 students. The item testing was conducted in two other classes with a total of 30 students. The research instrument used a validation questionnaire designed for experts, practitioners, and students to collect data related to the developed media, as stated by Aithal & Aithal (2020) [23]. The instrument in the AR-based learning media questionnaire was validated by nine experts, three of whom are Doctors and Professors, assessing

the aspects of media, content, and language. They have teaching and research experience ranging from 20 to 30 years at Universitas Negeri Padang.

The assessment of each question item considers the structure of the language. The accuracy aspect of the valid measurement can perform its measurement function precisely and has high accuracy. This application successfully passed the validation test with nine experts, where revisions and evaluations of the application prototype were carried out, along with practicality tests to determine the ease of use of the media. This assessment involved feedback from three practitioners/lecturers who teach the Network Systems Programming course and 41 students from the Electronics Engineering department during the 2023-2024 academic year, using simple random sampling techniques.

Data collection was conducted through a questionnaire distributed via Google Forms, utilizing a Likert scale measurement consisting of several positive and negative statements regarding the application development results. This process includes several steps: a) needs analysis based on essential competencies in the network systems programming curriculum, b) selection of media format and application prototype development, c) preparation of the questionnaire for validity and practicality, d) validity testing by content experts on aspects of learning design, content presentation, and learning quality, e) validity testing by media experts on aspects of user interface quality, software navigation, and interactivity, f) validity testing by linguistic experts on aspects of language in the content, communicative language, and media guidance language, g) validation by three expert validators: content expert, media expert, and linguistic expert, with a total of nine validators, h) once the media is declared valid, revisions and evaluations are conducted based on comments, suggestions, and recommendations from the validators, and i) practicality testing aimed at evaluating the responses of lecturers and students to the use of mobile AR with simple random sampling techniques. The obtained data will be processed using Excel software.

The validity and practicality tests utilize the following formulas [24]:

$$P = \frac{\sum x}{\sum xi} \times 100\%$$

Description:

P: Percentage of validity and practicality (%)

$\sum x$: Total score obtained from respondents

$\sum xi$: Maximum score in one aspect

The percentage of validity and practicality scores is calculated based on the formula proposed by Cheung et al. (2024). Table 1 presents the classification based on the validity and practicality criteria of the mobile augmented reality application.

Table 1. Scale of Validity and practicality criteria

Validity		Practicality	
Percentage	Criteria	Percentage	Criteria
81–100	Very valid	81–100	Very practical
61–80	Valid	61–80	Practical
41–60	Fairly valid	41–60	Fairly practical
21–40	Not valid	21–40	Not practical
0-20	Very invalid	0-20	Very impractical

Table 1 presents the scale of validity and practicality criteria used to evaluate the Augmented Reality (AR)-based application in this study. In this context, the validity and practicality of the application are measured using percentages, which are calculated based on the assessment results from the respondents involved in the testing.

Construct validity refers to the extent to which the mobile AR application effectively measures the intended learning outcomes, such as enhancing students' understanding of network systems programming or developing computational thinking skills. A high validity score, such as "very valid" (81–100%) or "valid" (61–80%), indicates that the application is aligned with its educational goals and accurately reflects the concepts it aims to teach.

Conversely, lower validity scores suggest that the application may need improvements to better align with its intended objectives. On the other hand, predictive validity concerns how well the application can predict future learning outcomes or academic performance. A high practicality score, such as "very practical" (81–100%) or "practical" (61–80%), implies that the AR application is not only effective in content but also easy to use and engages students in a way that enhances their learning and performance. A "very practical" rating suggests the application is user-friendly and helps students achieve the desired learning outcomes. Lower practicality scores, such as "fairly practical" (41–60%) or lower, may indicate that the application needs further refinement to improve usability and better support students' academic success. Both construct and predictive validity are essential for evaluating the AR application's overall effectiveness in achieving its educational goals and enhancing student learning.

The next step in the development process of the mobile AR application is to conduct revisions and evaluations based on the feedback, comments, and suggestions from the validators. This practicality test focuses on collecting responses regarding the ease of use from instructors and students who have utilized the successfully developed mobile AR application by the researchers.

III. Result and Discussion

A. User Analysis

This research successfully developed a mobile application utilizing Augmented Reality (AR) to enhance the learning of network systems programming for vocational education students at Universitas Negeri Padang. Traditional teaching methods, primarily consisting of lectures, PowerPoint presentations, and other conventional materials, have led to a learning process that lacks variety and effectiveness. These methods fall short, particularly given the complexity of network systems programming, where the theoretical content is intricately linked to technical concepts and hands-on practice. This shortcoming was highlighted during student interviews, in which many expressed that unclear explanations and a lack of interactive elements in the learning process diminished their motivation to study. As a result, students often struggled to understand the fundamental concepts essential for mastering network systems programming, leading to less-than-optimal learning outcomes. Therefore, the AR-based application is expected to

enhance students' understanding and interest in the learning material while creating a more interactive and engaging learning experience [25].

B. User Analysis

The learning objectives based on the Merdeka Campus curriculum for network systems programming in the vocational education program at Universitas Negeri Padang, along with the criteria for achieving these objectives, are as follows: a) to understand the basic concepts of network systems programming and their applications in software development, b) to comprehend the fundamental principles underlying data communication and information processing within networks, c) to grasp problem-solving methods in the context of network systems programming collaboratively, and d) to apply computational thinking skills to resolve complex problems related to networking. After conducting observations and literature reviews, these formulated learning objectives will serve as a reference for developing AR-based learning media in network systems programming, which has been established based on a thorough analysis of student needs.

C. Select, Method, Media, and Material

The developed learning media is called Network Systems Programming-AR, equipped with various features including e-modules, interactive learning videos, 3D object animations, and object description panels that provide details about network systems programming. The main and supporting software used in designing the Network Systems Programming-AR application includes: a) Blender, a software for building 3D objects with repeating animation simulations; b) Vuforia Engine SDK, which functions to build augmented reality developed by Qualcomm with computer vision capabilities for marker-based tracking to realize 3D objects; c) Android Studio, which is an IDE development environment for building mobile learning applications that have efficient functionality and a user-friendly interface on Android devices; d) Unity 3D, which integrates 3D objects as an Android platform to create mobile augmented reality visualizations by combining all design outputs from Blender, Vuforia Engine SDK, and Android Studio, as well as a machine system using programming languages such as C#, JavaScript, and boot scripts built in APK format for Android mobile application devices.

The initial design stage of the developed mobile augmented reality application is displayed in the Use Case Diagram, targeting users who utilize Android devices to run the application. The development process of the Network Systems Programming-AR application includes several steps: a) designing a blueprint layout for the interface, b) building the user interface in Unity and creating 3D objects in Blender, c) integrating all designed assets into the Unity 3D application based on needs analysis, d) building the application in prototype form suitable for mobile learning, and e) running the prototype on mobile devices by activating the smartphone's rear camera and pointing it at the marker, triggering the appearance of 3D objects according to the established layout.

Fig. 1 illustrates the operational steps for the Network Systems Programming-AR application, which can be accessed by lecturers and students through Android devices. The process begins with installing the application and registering a user account. Once connected, users will enter the main menu, which can be navigated according to their needs. Specifically, users can explore 3D object animations related to the learning material for network systems programming, which includes components such as e-modules, interactive learning videos, practice questions, and discussion forums that facilitate remote interaction between lecturers and students.

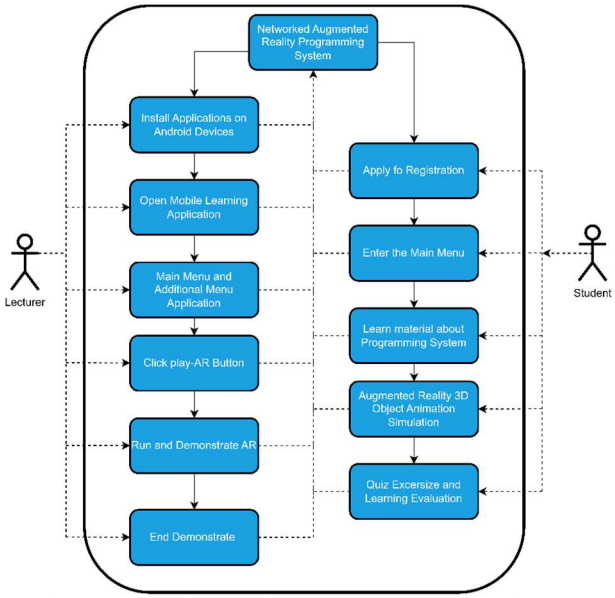

Fig. 1. Use case diagram of network systems programming-AR.

Fig. 1 illustrates the design of a standalone mobile augmented reality application that is self-instructive and user-friendly. To detect markers at specified coordinate points, the system must identify these markers to render 3D objects in real-time, adapting to the user's needs.

D. Utilizing Media and Material

Answer for RQ1: The Impact of the Application of the Results of the Development of Mobile Augmented Reality Learning in Network Systems Programming

Augmented Reality (AR) technology plays a crucial role in helping students understand abstract concepts in network systems programming by visualizing them in a more tangible way. Learning applications that utilize AR, particularly in the context of self-directed learning, can capture students' attention through interactive learning experiences. The use of animated 3D object simulations in this application provides a deeper and more detailed explanation of the material, allowing students to visualize the models of the objects being studied. This technology and media serve as tools to encourage greater student engagement and better participation in the teaching and learning process.

In the development of the Network Systems Programming-AR application, the design and implementation process is crucial to ensure that the application is effective and engaging for users. Fig. 2 provides an overview of the application's development interface using Unity software, which is the primary tool for designing the user interface and integrating interactive elements. This software enables developers to create an intuitive and user-friendly experience, facilitating seamless interaction between students and the learning materials.

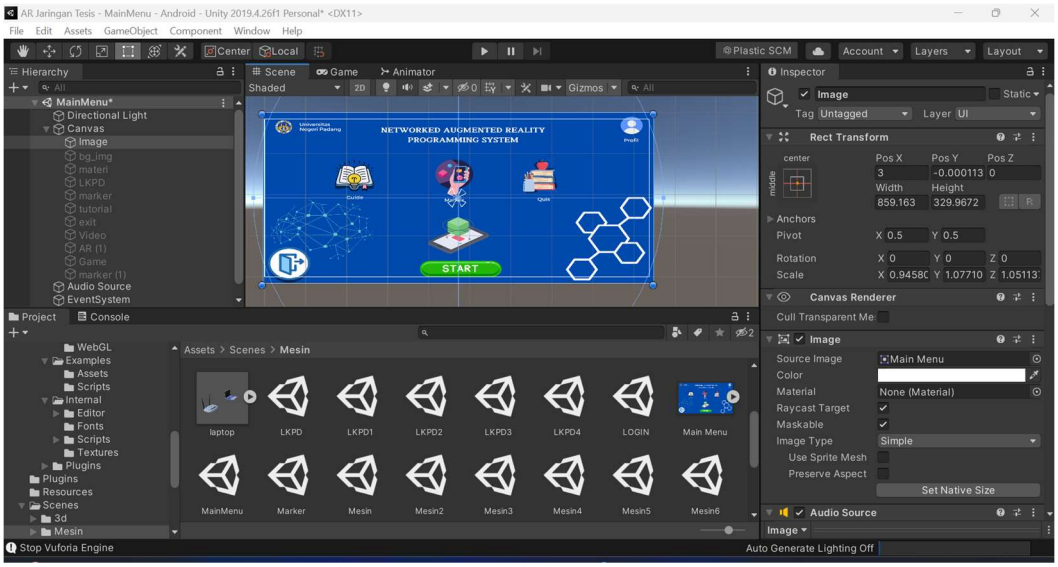

Fig. 2. Development interface of the application using unity software.

Fig. 2 illustrates the development interface of the application using Unity software, which is employed to design and integrate visual and interactive elements within the Network Systems Programming-AR application. In this view, users can observe the Unity interface presenting various components, such as the object hierarchy, programming panel, and inspector that enables developers to customize the properties of each element. Meanwhile, Fig. 3 displays the user interface of the Network Systems Programming-AR application, designed with the following navigation:

1) The Menu Guide serves as the main guide that provides information and instructions on how to use the application.
2) The Marker Menu allows users to point the camera at specific markers to visualize 3D objects related to network systems programming material.
3) The Quiz Menu offers interactive quizzes designed to test users' understanding of the material they have studied.
4) The Guide Menu enables users to customize the application's display and audio preferences.

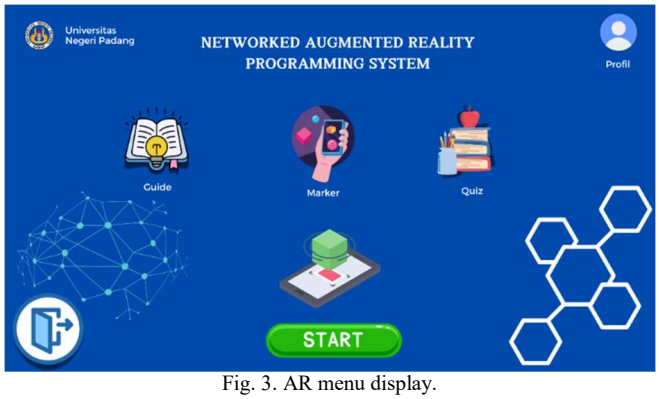

Fig. 3. AR menu display.

In Fig. 4, the Guide page will display important information for users of the Network Systems Programming-AR application. This page includes a brief description of the application and a step-by-step guide on how to use the available features. Users will be provided with explanations on how to access and use markers for visualizing 3D objects, as well as instructions on participating in interactive quizzes, including how to receive feedback on quiz results. Additionally, this page will also include the developer's contact information for further support, along with tips and tricks to maximize the learning experience with this application.

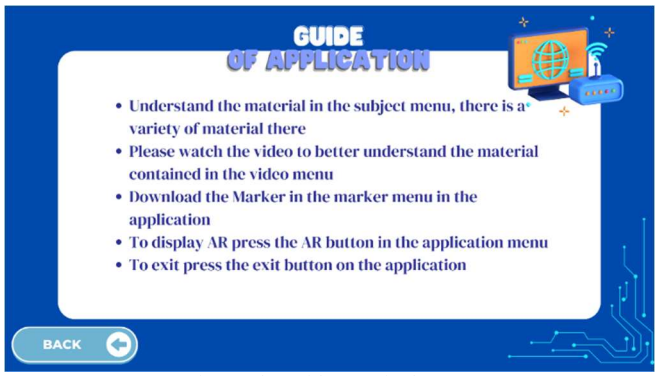

Fig. 4. The guide page in the AR.

Fig. 5 displays the Quiz page, which serves as an evaluation tool for users of the Network Systems Programming-AR application. This page is designed to test users' understanding of the material they have learned through a series of interactive questions. Users will have the opportunity to answer quizzes covering various aspects of network systems programming and will receive immediate feedback on their quiz results.

Fig. 5. The Implementation of AR.

E. Results of Validation, Revision, and Practicality Tests

Answer for RQ2: results of the validity and practicality of augmented reality in learning network systems programming?

The questionnaire used aimed to collect data on the validity and effectiveness of the Augmented Reality (AR)-based

application in network systems programming education, distributed via Google Forms. This questionnaire was validated by nine experts, including three from each relevant field, consisting of 30 questions divided into three main dimensions: media, content, and language. There were 10 questions for each dimension, with 20 closed-ended questions using a Likert scale and 10 open-ended questions to gather feedback and suggestions from the respondents.

The evaluation of the developed application yielded the following findings: Table 2 presents the average scores for the learning design aspect at 90.76%, the content aspect at 91.90%, and the learning quality aspect at 87.90%. The overall average score across all aspects was 90.18%, categorizing the application as "very valid." Comments and suggestions from the validators indicated that the content within the application should more thoroughly address the effectiveness of learning network systems programming.

To measure the internal consistency of the instrument used in this study, a Cronbach's Alpha coefficient test was conducted. This test aims to ensure that each dimension or aspect of the questionnaire is consistently related to each other. The Cronbach's Alpha coefficient was calculated for each evaluated dimension in the questionnaire, including media, content, and language. The Cronbach's Alpha formula is as follows:

$$\alpha = \frac{\kappa}{\kappa - 1}\left(1 - \frac{\sum S\frac{2}{i}}{S\frac{2}{t}}\right)$$

where κ is the number of items in the questionnaire, $S\frac{2}{i}$ is the variance of each item, and $S\frac{2}{t}$ is the total variance of all items. The resulting Cronbach's Alpha values were analyzed, with values above 0.70 considered acceptable, between 0.80 and 0.90 indicating good reliability, and above 0.90 suggesting very good reliability. The results of the calculation show that the instrument used has good reliability, as reflected in the Cronbach's Alpha values for each dimension. The results of the Cronbach's Alpha testing are presented in the following Table 2.

Table 2. The results of the Cronbach's Alpha testing

Evaluation Dimension	Cronbach' Alpha	Category
Media Design	0.85	Good
Content Presentation	0.88	Good
Language in Instructions	0.92	Very Good
Overall Average	**0.88**	**Good**

Based on Table 2, the results of the Cronbach's Alpha test indicate that the instrument used in this study has good internal consistency. This confirms that the instrument is reliable for measuring the validity and effectiveness of the Augmented Reality (AR)-based application in network systems programming education, as well as supporting the construct validity of the research conducted. The expert validation results for the content will be presented on the Table 3.

The validation by media experts was conducted to assess and evaluate the development of the augmented reality-based application. The evaluation results for the developed media aspects are shown in Table 4, indicating that the average score for user interface quality is 89.25%, the average score for software navigation is 91.15%, and the average score for interactivity and communication is 90.00%. The assessment results across all aspects yield an overall average of 90.13%, categorized as "very valid."

Table 3. Expert validation results for content

Evaluation Aspect	V1	V2	V3	Average (%)	Criteria
Learning Design	90.76	91.00	90.00	90.76	Very valid
Content Presentation	91.90	92.50	90.00	91.90	Very valid
Quality of Learning Process	87.90	86.00	90.00	87.90	Very valid
Overall Average				90.18	Very valid

Table 4. Media expert validation results

Evaluation Aspect	V1	V2	V3	Average (%)	Criteria
User Interface Quality	89.00	89.50	90.00	89.25	Very valid
Software Navigation	90.00	92.00	91.50	91.15	Very valid
Interactivity and Communication	89.50	90.00	90.50	90.00	Very valid
Overall Average				90.13	Very valid

To determine the accuracy of English and Indonesian grammar in the application, the validation results by linguistic experts evaluated spelling, grammar, and vocabulary. The linguistic validation results are presented in Table 5, which shows the language validation outcomes for three assessment aspects. The average for user language usage is 92.00%, the language communication aspect is 87.85%, and the media instruction language reaches 90.00%. The assessment results for all aspects achieved an overall average of 89.95%, which falls into the "very valid" category. However, some grammatical and spelling errors need to be revised according to the comments and suggestions from the validators.

Table 5. Validation results by language experts

Evaluation Aspect	V1	V2	V3	Average (%)	Criteria
Language in Content	90.00	95.00	92.00	92.00	Very valid
Communicative Language	90.00	90.00	87.00	87.85	Very valid
Media Instruction Language	90.00	90.00	100.00	90.00	Very valid
Overall Average				89.95	Very valid

The mobile AR application has successfully passed the validation testing process concerning content, media, and language aspects and has been revised based on feedback and suggestions from the validators. Next, this application will be evaluated based on the usability of the media by lecturers as educators and students participating in network systems learning. Practical testing from the responses of lecturers and students will be assessed based on the following aspects: visual media presentation, learning delivery, ease of media use, and the educational benefits presented in Table 6.

Based on the practical testing results, the overall average rating from lecturer responses is 87.50% (very practical), while the average rating from student responses is 86.90%

(very practical). These findings indicate that the mobile AR application for Network Systems learning can be effectively implemented in both face-to-face and distance learning environments, making it a viable solution and alternative for 21st-century education. The study on the development of a mobile-based Augmented Reality application, as a cutting-edge technology, considers the possibility of applying learning processes in both offline and online formats, in line with the Merdeka Campus curriculum, which emphasizes the competencies and skills to be achieved in the semester learning plan. This Android-based application is designed to be self-sufficient, instructional, adaptive, and user-friendly, supporting an interactive, creative, and innovative learning process. By offering a 360-degree reality experience, the application encourages students to actively engage in the learning process. As a result, the increased interest and motivation for learning among students serve as indicators of the success of the semester-long courses.

Table 6. Practical testing results of the network systems programming-AR application

Evaluation Aspect	Lecturer Responses	Criteria	Student Responses	Criteria
Visual Media Presentation	90.00	Very Practical	85.00	Very Practical
Learning Delivery	85.00	Very Practical	86.00	Very Practical
Ease of Media Use	84.00	Practical	87.00	Very Practical
Learning Benefits	92.00	Very Practical	86.00	Very Practical
Overall Average	87.50	Very Practical	86.90	Very Practical

Augmented Reality (AR) as a learning tool enhances education by merging digital content with the real world, providing an interactive, immersive experience that deepens student engagement. In technical fields like network systems programming, AR allows students to visualize complex, abstract concepts such as network configurations or data flows through 3D models, making them easier to comprehend. This hands-on learning approach fosters better understanding by enabling students to experiment with virtual objects and configurations, offering real-time feedback and problem-solving opportunities. AR also caters to diverse learning styles, supports collaboration, and enables personalized learning experiences. It provides an accessible, scalable alternative to traditional learning tools, particularly for students who may lack physical resources. Overall, AR enriches the learning process by making it more interactive, engaging, and practical, especially in fields that require both theoretical knowledge and practical application.

The practical significance of this study lies in the real-world impact of the mobile AR-based application for network systems programming education. By transforming abstract concepts into interactive 3D visualizations, the application enhances students' understanding, engagement, and motivation, ultimately leading to improved learning outcomes. Its flexibility allows it to be seamlessly used in both face-to-face and distance learning environments, addressing the increasing demand for adaptable educational tools in the Industry 4.0 era. Additionally, the application supports the development of 21st-century skills, such as computational thinking, critical thinking, and problem-solving, which are crucial for success in technology-driven careers. Aligned with the Merdeka Campus curriculum, this tool enables educators to deliver effective and modern instruction while reducing costs associated with physical resources. Thus, the application bridges the gap between traditional teaching methods and innovative educational technology, preparing students to thrive in dynamic, technology-centric workplaces.

IV. Conclusion

Based on the results of the validation and practicality assessments conducted, it can be concluded that the research questions (RQ1 and RQ2) have been answered effectively. This can be seen from the research successfully in developed a mobile application based on Augmented Reality (AR) for teaching network systems programming among vocational education students at Universitas Negeri Padang. The analysis results indicate that the conventional teaching methods currently employed are less effective in conveying complex material related to network systems programming, leading to low student motivation and understanding. With the introduction of the Network Systems Programming-AR application, equipped with interactive features such as 3D object animations and instructional videos, it is expected to enhance students' comprehension and engagement in the learning process. Validation evaluations demonstrate that the application possesses a very high level of validity in terms of content, media, and language use. Practical testing also indicates that the application is highly practical and can be effectively implemented in both face-to-face and distance learning contexts. Therefore, the integration of AR technology in network systems programming education is an innovative step that aligns with the Merdeka Campus curriculum, encouraging students to actively participate and improving their interest and motivation in learning.

The research has several limitations that should be considered. First, although the developed AR application has undergone validity evaluations and practical testing, there are external factors that may affect the results obtained, such as differences in students' technical backgrounds, their comfort level with using AR technology, or limitations in the hardware used by participants. These factors could influence how students interact with the application and affect the learning outcomes. Furthermore, this study focused on the media, content, and language aspects of the AR application, while other aspects such as social influence, internal motivation, and psychological factors of students have not been fully considered. Future research could expand the understanding of how these factors contribute to the effectiveness of using AR applications in educational contexts.

Lastly, although the AR application is designed to support both face-to-face and distance learning, there are accessibility limitations in some locations or for some students, such as network connectivity issues or inadequate devices. These limitations could affect the implementation and effectiveness of the application in remote learning contexts. Therefore, further testing in diverse learning environments and with a broader range of technologies is necessary to ensure that this AR application can be accessed and utilized effectively by all students.

The urgency of this research stems from the growing demand for effective educational tools that can address the challenges posed by conventional teaching methods, particularly in the field of network systems programming. As the complexity of programming concepts increases, traditional instructional approaches often fail to engage students adequately, leading to diminished motivation and poor comprehension. Moreover, with the rapid advancement of technology and the need for educational practices to evolve accordingly, integrating Augmented Reality (AR) into learning processes represents a crucial step in modernizing education. This research not only contributes to enhancing the teaching and learning experience but also aligns with national educational policies aimed at fostering innovative learning environments.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The first author wrote the paper, helped with the data analysis, and did all the necessary revisions to comply with the standards of the journal. Meanwhile, the second and third authors enabled the gathering of data with the former, helped in the data analysis, and reviewed/edited the final version of the paper and all authors approved the final version.

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