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Design and Development of Augmented Reality-Based Learning Media Using Unity 3D for the TJKT Elective Subject among Grade XI Students at SMKN 8 Padang

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Abstract

Limited access to computer-networking equipment, combined with continued reliance on verbal explanations and static images, presents a persistent challenge in teaching the Computer and Telecommunications Network Engineering (TJKT) elective subject. This study aimed to develop and evaluate augmented reality (AR)-based learning media using Unity 3D for Grade XI students at SMKN 8 Padang. A research and development approach was employed using the ADDIE model, comprising analysis, design, development, implementation, and evaluation. The participants included three expert validators and 31 Grade XI TJKT students selected through purposive sampling. Data were collected using validation sheets, practicality questionnaires, observations, and learning-achievement tests and analyzed through quantitative and qualitative descriptive techniques. The developed learning media achieved a validity score of 93.00%, a practicality score of 94.08%, and an effectiveness score of 89.52%, placing it in the very valid, very practical, and very effective categories, respectively. The application provides interactive three-dimensional visualizations of computer-networking devices, thereby supporting more concrete learning experiences despite limited access to physical equipment. These findings demonstrate the feasibility of integrating AR-based media into vocational computer-networking education and strengthen the evidence supporting AR-assisted vocational learning. Further development should incorporate markerless AR, improve cross-platform compatibility, involve larger samples, and employ more rigorous experimental designs to establish comparative learning effects.

Keywords: Augmented Reality; Computer Network Engineering; Learning Media; Unity 3D; Vocational Education

INTRODUCTION

Vocational education is expected to provide learning experiences that connect conceptual understanding with competencies required in professional practice. This expectation has become increasingly important as digital technologies reshape the way vocational knowledge is presented, explored, and practiced. Technology-supported learning media can provide students with richer representations of objects and processes that are difficult to demonstrate through verbal explanation alone. Wal Ilham (2022) emphasizes that the rapid development of technology has encouraged educational institutions to adopt increasingly interactive and digitally oriented learning media. Nurrita (2018) similarly explains that appropriate learning media can broaden students' learning experiences and assist teachers in presenting instructional content more effectively. Such developments are particularly relevant to vocational education because students are expected not only to understand concepts but also to recognize, observe, and eventually work with technical equipment. International evidence likewise suggests that immersive and extended-reality technologies have considerable potential for supporting cognitive, affective, and practical learning outcomes in vocational education and training (Bödding et al., 2025; Sakr & Abdullah, 2024).

Computer and Telecommunications Network Engineering, or *Teknik Jaringan Komputer dan Telekomunikasi* (TJKT), represents a vocational field in which visual and practical learning experiences are particularly important. The Elective Subject (*Mata Pelajaran Pilihan* [MPP]) in TJKT requires students to understand various computer network devices, including switches, routers, hubs, access points, UTP cables, and supporting components. Students need to recognize not only the names and functions of these devices but also their physical characteristics, port configurations, and relationships within a network system.

Conventional explanations supported mainly by static images may provide basic information but offer limited opportunities for students to examine technical objects from different perspectives. Studies on computer network education have therefore increasingly explored interactive digital media capable of presenting network equipment through more concrete visual representations (Adi et al., 2024; S. Hamzah & Kurniadi, 2019; Tasrif et al., 2020). Krisdiyansah & Hakim (2023) also highlight the importance of adapting instructional media to the technological characteristics of contemporary learners so that learning becomes more participatory and relevant.

Preliminary observations conducted in Grade XI TJKT classes at SMKN 8 Padang indicated that the learning process for the MPP subject had not yet made extensive use of interactive visualization. Instruction on computer network devices was largely delivered through teacher explanations and static presentation slides, while the availability of physical network equipment was insufficient for all students to observe the devices directly. This situation became especially important when students were expected to identify devices, distinguish their characteristics, and explain their respective functions. School assessment records also showed that 19 of the 31 students in Grade XI TJKT 1, or 61.3%, obtained scores below the Minimum Completeness Criterion, whereas only 12 students, or 38.7%, achieved scores above the criterion. A similar pattern occurred in Grade XI TJKT 2, where 20 of 33 students, or 60.6%, scored below the criterion and 13 students, or 39.4%, scored above it. These findings do not by themselves establish that instructional media were the sole cause of the learning outcomes; rather, they indicate a practical need to provide students with learning resources that offer more accessible and concrete representations of network devices.

Augmented Reality (AR) offers an instructional approach that is relevant to this need because it integrates computer-generated information with the physical environment and allows virtual objects to appear as part of a real-time user experience. Azuma (1997) characterizes AR through the combination of real and virtual elements, real-time interaction, and three-dimensional registration. Educational applications have subsequently used these characteristics to visualize objects that may otherwise be difficult, expensive, or impractical to provide physically. Ramadhan et al. (2025) demonstrate how AR-based learning media can present computer-system components through manipulable three-dimensional objects, allowing learners to observe digital representations more concretely. Broader reviews have also identified improvements in learning achievement, engagement, visualization, and understanding among the commonly reported educational benefits of AR, although usability, technical design, and instructional integration remain important considerations (Akçayır & Akçayır, 2017; Garzón et al., 2019; Ibáñez & Delgado-Kloos, 2018).

Empirical studies involving computing and network-related content further support the relevance of AR to the present research. Maheswara et al. (2024) developed AR learning media for introducing computer CPU components and reported very high content and media validation results together with a high level of practicality. Hadju et al. (2024) similarly developed AR-based media for Informatics learning and reported a high level of feasibility, indicating that three-dimensional interactive representations can be integrated effectively into computing-related instruction. Research focusing more directly on networking has reached comparable conclusions. M. L. Hamzah et al. (2021) developed an AR application for learning computer network devices in which students could scan markers and access three-dimensional representations and information about devices such as routers, switches, and hubs. Efendi et al. (2023) also demonstrated the potential of AR-based competency learning for computer network instruction in vocational education, while Adi et al. (2024) developed AR learning media specifically for computer networking courses. Collectively, these studies show that AR is particularly relevant when learning content requires students to associate technical terminology with the physical structure and function of equipment.

Unity 3D provides a suitable development environment for constructing this type of interactive learning media because it enables digital three-dimensional assets, user interfaces, animations, and interactive functions to be organized within a single application environment. For network-device instruction, such capabilities allow models of routers, switches, hubs, access points, and related devices to be presented in ways that students can inspect from multiple viewpoints rather than encounter only as two-dimensional illustrations. Suparmi et al. (2024) found that Unity 3D-based instructional media could support students in exploring learning material through interactive visualization. Similar applications of Unity-supported AR have demonstrated the feasibility of combining three-dimensional representations with mobile learning environments for educational purposes. The value of Unity 3D in the present study therefore lies not simply in its technological features, but in its capacity to translate technical network objects into accessible learning experiences that can be explored through students' digital devices.

Pedagogical considerations remain necessary because the presence of advanced technology does not automatically guarantee meaningful learning. AR becomes educationally valuable when its visual and interactive features are aligned with learning objectives and the characteristics of the material. Systematic reviews indicate that AR can positively influence learning outcomes, motivation, and engagement, but these effects depend on appropriate instructional design and manageable cognitive and technical demands (Akçayır & Akçayır, 2017; Garzón et al., 2019).

Evidence from vocational education similarly indicates that immersive technologies can support knowledge acquisition and practical learning when they are incorporated into carefully designed learning activities (Bödding et al., 2025). Boel et al. (2024) further argue that effective implementation of augmented, virtual, and mixed reality in technical and vocational education requires attention to hardware, software, teacher competence, educational research, and implementation coordination. Consequently, AR in the TJKT classroom should be positioned as a learning resource that strengthens students' opportunities to observe and interpret technical objects rather than as a replacement for teachers or authentic practical activities.

Previous research provides a substantial basis for the educational use of AR, yet the reviewed studies reveal a contextual and instructional space that remains relevant for further investigation. Maheswara et al. (2024) concentrated on CPU components, whereas Hadju et al. (2024) examined AR within broader Informatics learning. Hamzah et al. (2021), (Tasrif et al., 2020), (Efendi et al., 2023), and (Adi et al., 2024), addressed computer networks or network equipment, but they were conducted within different educational settings, learning levels, or course structures. Research concerning AR in vocational education has also tended to examine the general effectiveness of immersive technologies rather than the specific learning needs of Grade XI students in the MPP TJKT subject at SMKN 8 Padang. The distinction of the present study therefore lies in developing Unity 3D-based AR media that is directly grounded in the identified classroom conditions and specifically designed to visualize computer network devices required in the Grade XI MPP TJKT learning context. This contextual orientation is important because educational media should respond to the characteristics of learners, instructional content, available technology, and the practical conditions in which the media will actually be used.

The proposed learning media is consequently designed to provide students with a more concrete way of examining computer network equipment through three-dimensional visualization on accessible digital devices. Network devices that cannot always be provided physically in sufficient quantities can be represented digitally so that students have opportunities to observe their shape, identify important components and ports, and associate those features with the functions explained during instruction. The development is expected to complement classroom explanations and practical activities rather than replace direct experience with real networking equipment. This position is consistent with evidence that AR can serve as an additional visualization layer that supports students when technical objects are difficult to access or concepts require spatial representation (M. L. Hamzah et al., 2021; Ramadhan et al., 2025). Such an approach also responds directly to the learning conditions identified at SMKN 8 Padang by connecting the technological affordances of AR with a clearly defined instructional need.

This study therefore aims to design and develop Augmented Reality-based learning media using Unity 3D for the Elective Subject (MPP) in Computer and Telecommunications Network Engineering (TJKT) for Grade XI students at SMKN 8 Padang**,** particularly for learning the identification, characteristics, and functions of computer network devices. The study is expected to produce instructional media that provides interactive three-dimensional visualization, supports students' understanding of network equipment, and offers teachers an alternative learning resource that complements existing classroom and practical learning activities.

METHODS

This study employed a *Research and Development* (R&D) approach to design and develop Augmented Reality (AR)-based learning media using Unity 3D for the Elective Subject (*Mata Pelajaran Pilihan* [MPP]) in Computer and Telecommunications Network Engineering (*Teknik Jaringan Komputer dan Telekomunikasi* [TJKT]). R&D was selected because the study was intended not only to investigate an educational phenomenon but also to produce and evaluate an instructional product. Borg and Gall, as cited in Sugiyono (2021), describe R&D as a systematic process for developing and validating educational products. The development procedure followed the ADDIE model, consisting of five interconnected stages: *Analysis, Design, Development, Implementation,* and *Evaluation*. The analysis stage identified learning needs, student characteristics, curriculum requirements, and problems encountered in MPP TJKT instruction. The design stage involved preparing the instructional content, learning objectives, interface structure, three-dimensional visualizations, and evaluation instruments. Product construction and expert validation were conducted during the development stage, followed by classroom implementation and evaluation to examine the validity, practicality, and effectiveness of the developed media. Qualitative and quantitative data were used complementarily; qualitative information was obtained from observations, comments, and suggestions provided by validators and users, whereas quantitative data were derived from validation scores, practicality questionnaires, and learning outcome assessments.

The study was conducted at SMKN 8 Padang during the first semester of the 2025/2026 academic year. Research participants were selected through *purposive sampling*, which allows participants to be chosen according to characteristics and considerations relevant to the purpose of the study (Sugiyono, 2021). The participants included expert validators with competence in instructional content and learning media, the TJKT subject teacher, and Grade XI TJKT students as the intended users of the developed application. Data were collected through expert-validation sheets, student and teacher practicality questionnaires, classroom observations, learning achievement tests, and supporting school documents. The media-validation instruments examined presentation and graphical aspects, whereas material validation addressed the appropriateness of content presentation and language. Practicality was assessed through indicators related to content presentation, language, ease of use, and perceived benefits. The effectiveness instrument was developed with reference to the learning outcomes of Phase F TJKT, particularly students' ability to identify network devices, recognize their physical components, understand their functions, and relate them to computer-network systems. A five-point Likert scale ranging from *strongly disagree* to *strongly agree* was applied to the validation and practicality questionnaires.

Data analysis was conducted descriptively to determine the validity, practicality, and effectiveness of the AR-based learning media. Validation and practicality scores were converted into percentages by comparing the obtained scores with the maximum possible scores, following the modified assessment procedure of Purwanto as cited in Yunus and Sardiwan (2018). The resulting percentages were subsequently interpreted according to predetermined categories ranging from low to very high levels of validity and practicality. Product effectiveness was examined using students' learning-test scores after the implementation of the media. Students' mean achievement was calculated following Sudjana

(2013), while the score distribution was examined descriptively to determine the overall pattern of learning outcomes. Qualitative comments and suggestions obtained from experts, teachers, and students were also reviewed and used as the basis for product revision. Through these procedures, the developed learning media was evaluated not only in terms of its technical and content feasibility but also its usability in classroom learning and its capacity to support students' understanding of computer network devices.

RESULTS

1. Development of the Augmented Reality-Based Learning Media

The development process resulted in an Augmented Reality (AR)-based learning application using Unity 3D for the Elective Subject (*Mata Pelajaran Pilihan* [MPP]) in Computer and Telecommunications Network Engineering (*Teknik Jaringan Komputer dan Telekomunikasi* [TJKT]). The application was designed to support Grade XI students in learning computer network hardware through a combination of theoretical materials, instructional videos, evaluation activities, and three-dimensional visualization. The developed media was organized through an interface that allowed students to move independently among the available learning components.

Figure 1. Initial User Interface of the AR-Based Learning Media

Figure 1 presents the initial user interface displayed when the application is opened. The page contains the application identity and three primary navigation buttons: *Start*, *About*, and *Exit*. The *Start* button directs users to the main learning menu, the *About* button provides introductory information about the application, and the *Exit* button allows users to close the application. The simple structure of the opening page was intended to make the application immediately understandable to students without requiring complicated operational instructions.

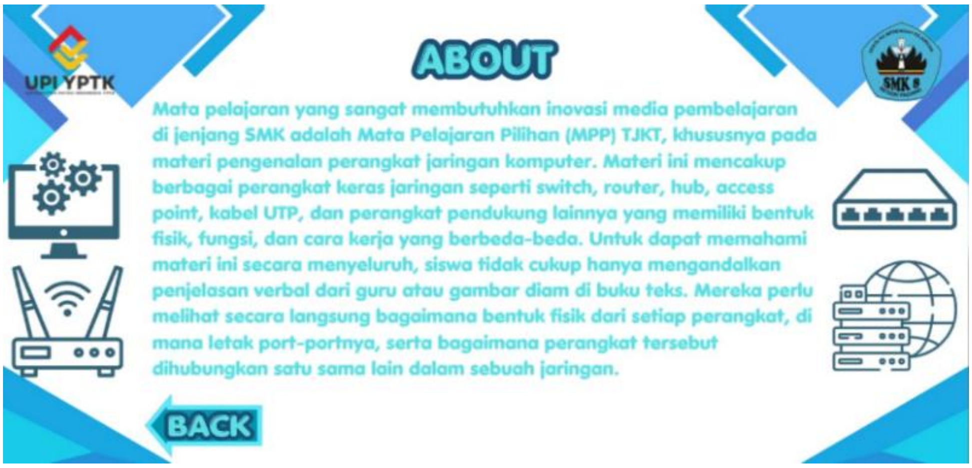

Figure 2. About Menu

Figure 2 shows the *About* page, which provides a brief introduction to the learning application and general information about computer network hardware. This page serves as an initial orientation before students proceed to more detailed learning content. A *Back* button is provided to allow students to return easily to the previous page.

Figure 3. Main Navigation Menu

Figure 3 illustrates the main navigation page displayed after users select the *Start* button. Four major learning features are available on this page: *Material*, *3D Menu*, *Evaluation*, and *Profile*. The *Material* menu provides access to theoretical content, whereas the *3D Menu* enables students to explore three-dimensional representations of network devices through AR. The *Evaluation* menu provides learning assessment activities, while the *Profile* menu contains information about the application developer. This arrangement integrates instructional content, visualization, and assessment within a single application environment.

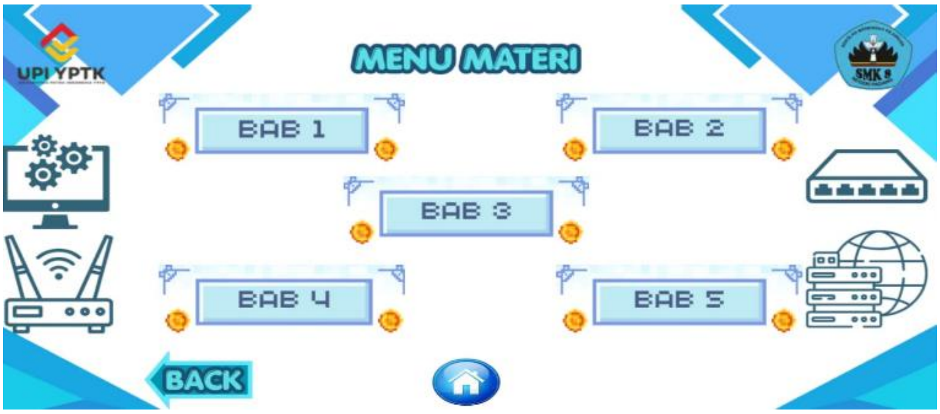

Figure 4. Learning Material Menu

Figure 4 presents the learning material menu, which organizes the instructional content into five chapters. Each chapter provides access to a specific section of computer network hardware material. The sequential organization was designed to enable students to study the content systematically while still allowing them to select a particular chapter according to their learning needs. A *Home* button is available to return users directly to the main menu.

Figure 5. Chapter 1–5 Submenu

Figure 5 shows the submenu available within Chapters 1 to 5. Each chapter includes three main features: *Learning Objectives*, *View Material*, and *View Video*. The *Learning Objectives* feature explains the competencies expected after completing the chapter. The *View Material* feature provides textual explanations of computer network hardware, while the *View Video* feature presents supporting audiovisual material. These components were intended to provide students with more than one form of learning representation.

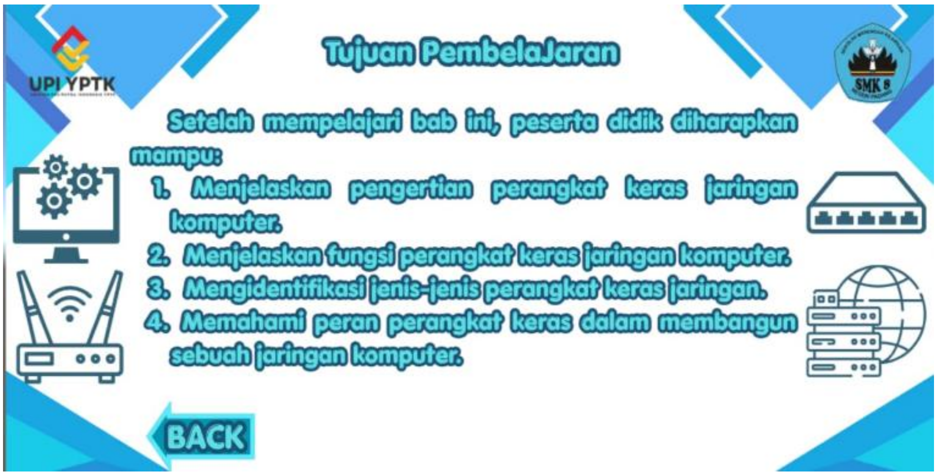

Figure 6. Learning Objectives Page

Figure 6 presents the learning objectives page. The displayed objectives emphasize students' ability to explain the meaning and functions of computer network hardware, identify different types of network devices, and understand their roles within a computer network system. Providing the objectives within the application allows students to recognize the expected learning outcomes before engaging with the instructional content.

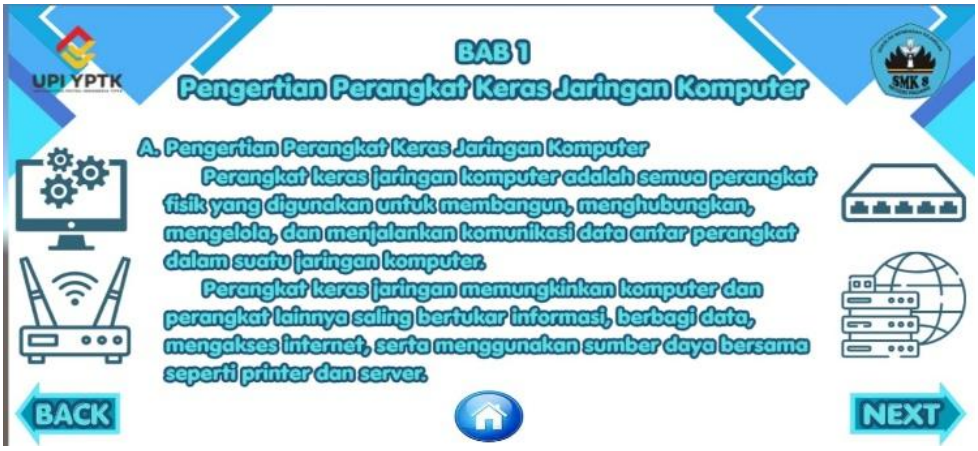

Figure 7. Learning Material Display

Figure 7 shows the content page containing explanations of the selected learning material. Navigation buttons such as *Back*, *Next*, and *Home* allow students to move between pages or return to the main menu. The organization of the content into consecutive pages was intended to prevent excessive information from being displayed simultaneously and to provide a more manageable reading experience.

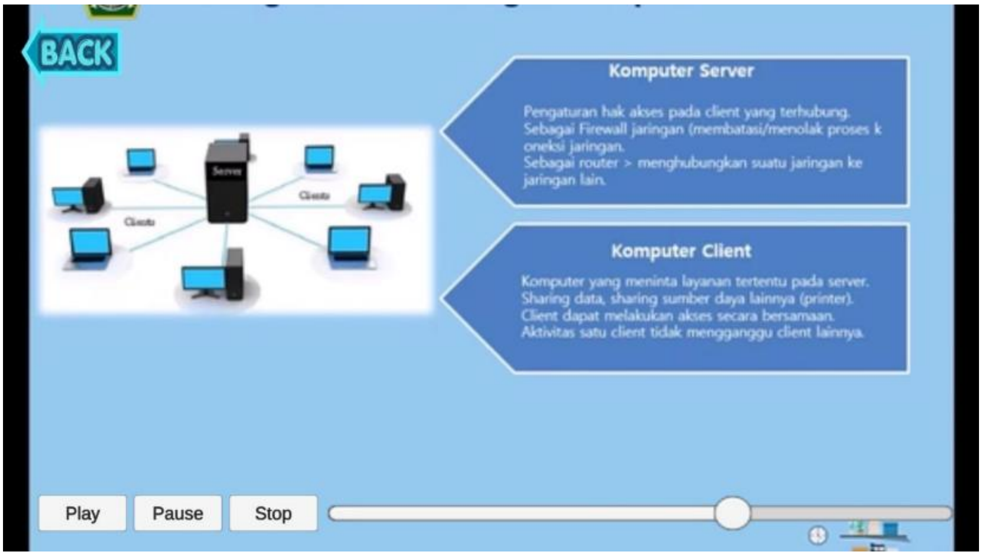

Figure 8. Instructional Video Page

Figure 8 presents the instructional video feature incorporated into the application. Students can control video playback through *Play*, *Pause*, and *Stop* functions, while a progress bar displays the duration of the video. The video component complements textual material by providing an audiovisual representation of the concepts being studied.

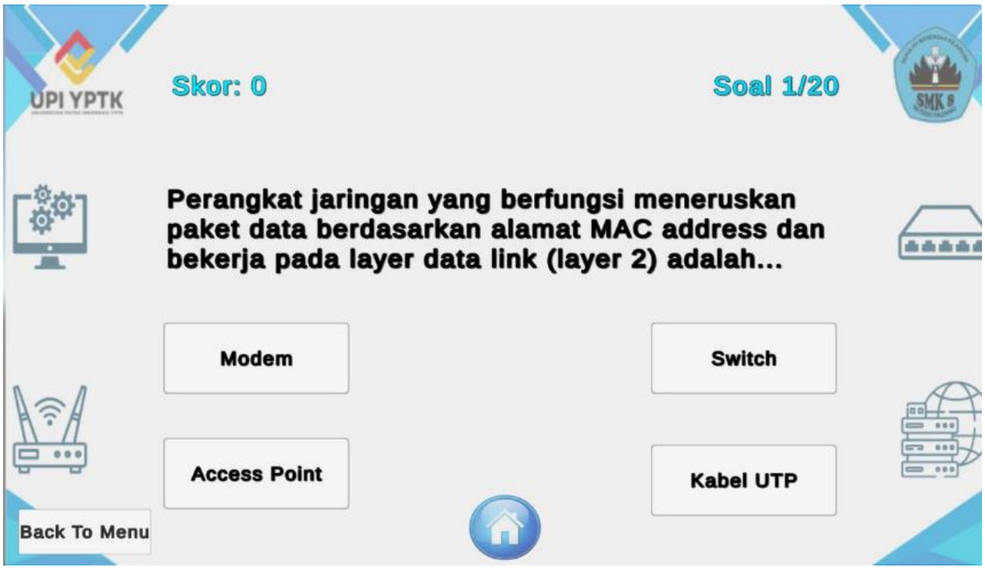

Figure 9. Evaluation Page

Figure 9 displays the evaluation page used to assess students' understanding after studying the learning materials. The application presents multiple-choice questions accompanied by four response alternatives. The page also provides a real-time score indicator and information about the current question number. The evaluation consists of 20 questions presented through the application.

Figure 10. Final Evaluation Page

Figure 10 shows the page displayed after students complete all evaluation questions. The application presents the final score so that students can immediately identify their achievement after completing the learning activity. The page also provides *Restart* and *Back to Menu* functions, enabling students either to repeat the evaluation or return to another part of the application.

Figure 11. Augmented Reality 3D Menu

Figure 11 presents the central AR feature of the developed application. Through the camera of an Android device, students can display three-dimensional representations of computer network hardware. This feature allows network devices to be examined beyond static two-dimensional illustrations. Students can therefore observe the visual characteristics of the represented equipment more directly through the mobile device.

Figure 12. Developer Profile Page

Figure 12 shows the profile page containing information about the application developer. The page includes the developer's identity, study program, university, photograph, and additional profile information. A *Back* button is provided to return to the previous page.

The overall product development resulted in an integrated learning application containing instructional material, learning objectives, videos, interactive AR visualization, evaluation activities, and supporting navigation. After the application had been developed, its quality was examined through expert validation, student practicality assessment, and an effectiveness test.

1. Validity of the Developed Learning Media

The validity assessment was conducted by three validators who examined the developed media from the perspectives of content, language, presentation, and graphical quality. Microsoft Excel was used to process the validation scores. Table 1 summarizes the validation results for each assessment aspect.

Table 1. Validity Results of the AR-Based Learning Media

Validation Aspect	Score (%)	Category
Content Feasibility	90.67	Very Valid
Language Component	93.33	Very Valid
Presentation Component	93.33	Very Valid
Graphical Component	94.67	Very Valid
Overall Mean	93.00	Very Valid

Source: Research data processing, 2026.

As presented in Table 1, all four components received scores above 90%. Content feasibility obtained a validity score of 90.67%, while both the language and presentation components obtained 93.33%. The graphical component achieved the highest percentage, at

94.67%. The overall mean validity score was 93.00%, placing the developed application in the *very valid* category. These findings indicate that the product fulfilled the assessment criteria used by the validators and could proceed to the classroom trial following the recommended revisions.

Individual validator assessments also showed relatively consistent results. The detailed scores are presented in Table 2.

Table 2. Validation Scores by Expert Validators

Validator	Validation Score (%)	Category
Validator 1	94	Very Valid
Validator 2	89	Very Valid
Validator 3	96	Very Valid
Mean	93	Very Valid

Source: Research data processing, 2026.

Table 2 shows that Validator 1 provided a score of 94%, Validator 2 provided 89%, and Validator 3 provided 96%. Although the individual scores varied slightly, all validators classified the product as very valid. The average of the three assessments was 93%.

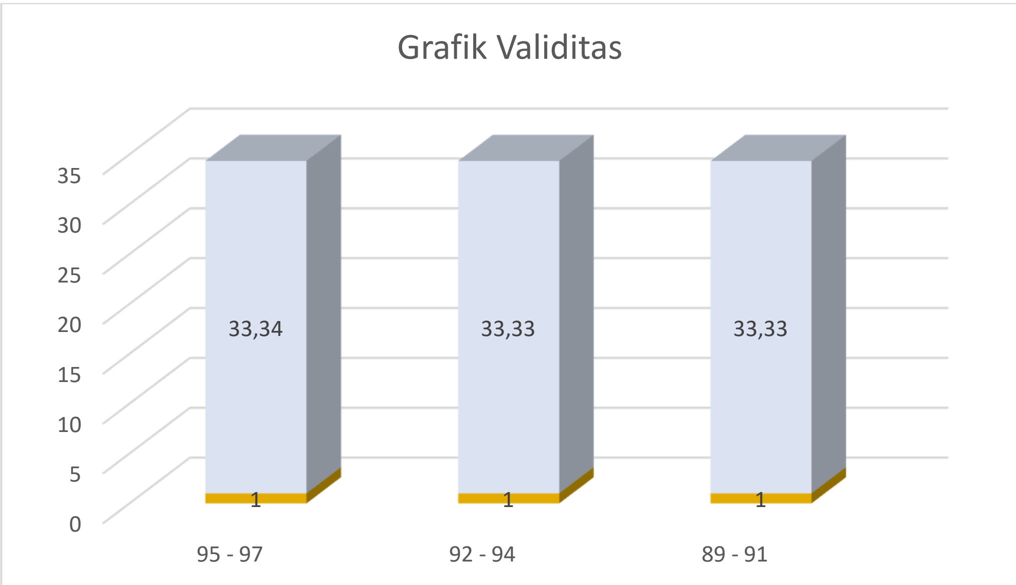

Figure 13. Frequency Distribution of Validation Scores

Figure 13 illustrates the frequency distribution of the three validator scores. One validator was located within the score interval of 89–91, one within 92–94, and one within 95–97. Each interval therefore represented 33.34% of the validator responses. The distribution confirms that the assessments were concentrated within the high validity range and supports the overall mean validity value of 93%.

2. Practicality of the Developed Learning Media

The practicality test was conducted with 31 Grade XI TJKT students after they had used the AR-based learning application. Students evaluated the media based on ease of use, language suitability, learning-time efficiency, and graphical quality. Table 3 presents the practicality results according to these four aspects.

Table 3. Student Practicality Assessment

Practicality Aspect	Score (%)	Category
Ease and Condition of Use	94.52	Very Practical
Language Feasibility	93.98	Very Practical
Learning-Time Efficiency	92.47	Very Practical
Graphical Component	95.35	Very Practical
Overall Mean	94.08	Very Practical

Source: Research data processing, 2026.

Table 3 indicates that all practicality dimensions were classified as very practical. The graphical component received the highest score at 95.35%, followed by ease of use at 94.52% and language feasibility at 93.98%. Learning-time efficiency received 92.47%, which remained within the very practical category. The overall practicality score reached 94.08%. These results indicate that the application was perceived positively by students in terms of usability, presentation, language, and its suitability for supporting classroom learning.

The distribution of individual practicality scores is presented in Table 4.

Table 4. Frequency Distribution of Student Practicality Scores

Score Interval	Frequency	Percentage (%)
90–92	7	22.58
87–89	6	19.35
84–86	11	35.48
81–83	1	3.23
78–80	1	3.23
75–77	3	9.68
72–74*	2	6.45
Total	31	100.00

Source: Research data processing, 2026.

*The original practicality table in the thesis displays intervals only from 75–77 to 90–92, while the accompanying explanation and practicality graph report two additional students in the 72–74 interval. The additional interval is shown here to reflect the stated total of 31 respondents.

Table 4 shows that the largest group consisted of 11 students (35.48%) whose scores were within the 84–86 interval. Seven students (22.58%) were in the 90–92 interval, while six students (19.35%) were in the 87–89 interval. Smaller proportions were found in the lower score ranges. The overall distribution remained concentrated in the upper intervals, consistent with the average practicality percentage of 94.08%.

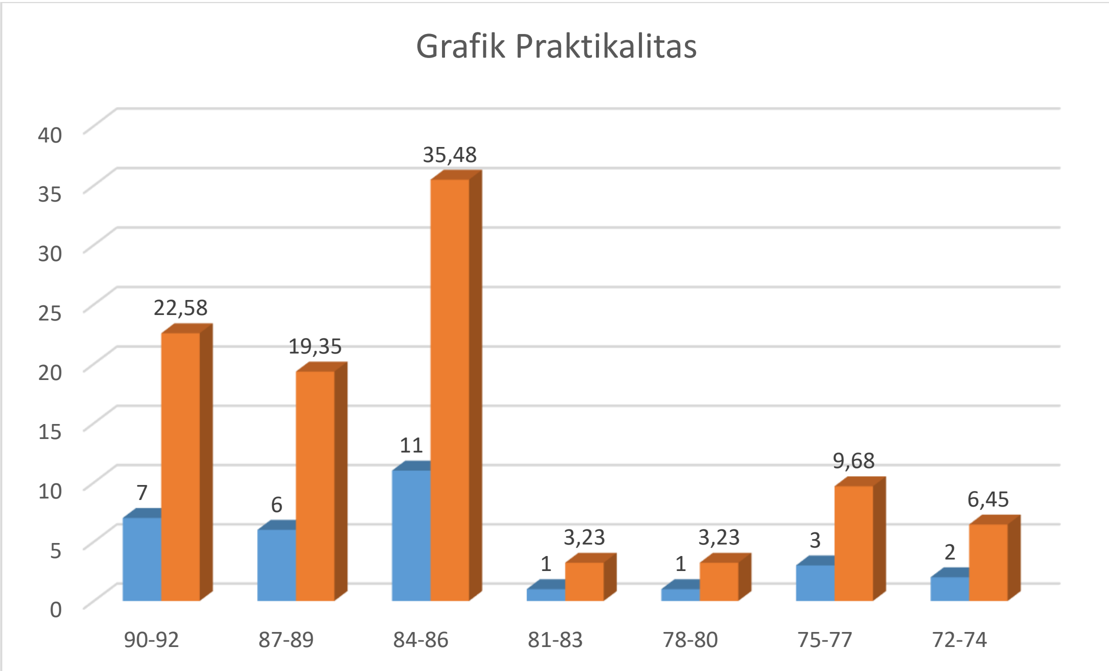

Figure 14. Frequency Distribution of Student Practicality Scores

Figure 14 visualizes the distribution of student practicality scores. The highest frequency was recorded in the 84–86 interval, comprising 11 students or 35.48% of the participants. The next largest groups occurred in the 90–92 and 87–89 intervals. The pattern shows that most students provided favorable assessments of the usability of the AR-based learning media.

3. Effectiveness of the Developed Learning Media

The effectiveness test was conducted with the same group of 31 Grade XI TJKT students. Students completed a learning assessment after using the application. The results were grouped into four effectiveness categories: very effective, effective, moderately effective, and ineffective.

Table 5. Effectiveness Test Results

Effectiveness Category	Number of Students	Percentage (%)
Very Effective	26	83.87
Effective	4	12.90
Moderately Effective	1	3.23
Ineffective	0	0.00
Total	31	100.00

Source: Research data processing, 2026.

Table 5 shows that 26 of the 31 students, equivalent to 83.87%, were classified in the very effective category. Four students (12.90%) were classified as effective, while one student (3.23%) was classified as moderately effective. No student was classified as ineffective. The distribution indicates that the learning achievement recorded after the use of the application was predominantly concentrated in the highest effectiveness category.

A more detailed distribution of students' scores is presented in Table 6.

Table 6. Frequency Distribution of Effectiveness Test Scores

Score Interval	Frequency	Percentage (%)
95–100	12	38.71
90–94	8	25.81
85–89	6	19.35
80–84	4	12.90
75–79	0	0.00
70–74	1	3.23
Total	31	100.00

Source: Research data processing, 2026.

Table 6 demonstrates that 12 students (38.71%) achieved scores between 95 and 100, representing the largest group. Eight students (25.81%) obtained scores between 90 and 94, while six students (19.35%) were within the 85–89 interval. Four students (12.90%) scored between 80 and 84, no students were found in the 75–79 interval, and only one student (3.23%) obtained a score between 70 and 74. These findings show that most student scores were concentrated in the upper achievement ranges after using the developed learning media.

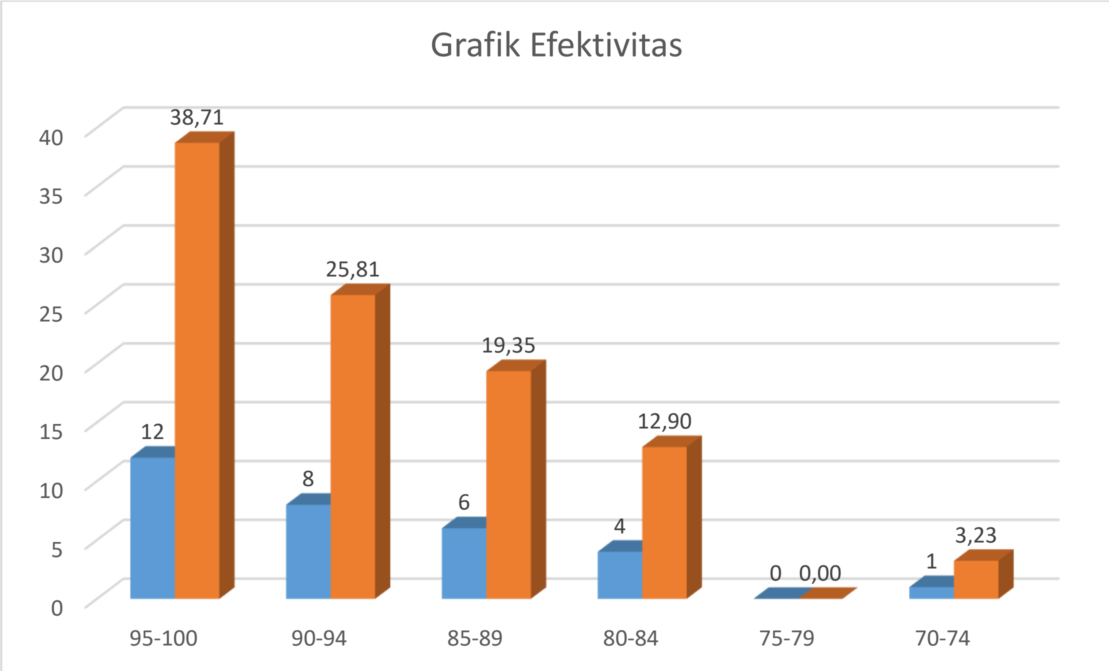

Figure 15. Frequency Distribution of Effectiveness Test Scores

Figure 15 presents the distribution of effectiveness test scores across the six score intervals. The graph shows that the highest concentration occurred in the 95–100 interval, followed by 90–94 and 85–89. Only one student was located in the lowest recorded interval of 70–74, while no students obtained scores between 75 and 79. The pattern indicates generally high learning achievement among the participating students following the implementation of the AR-based media.

The effectiveness results should be interpreted as evidence of students' achievement after using the developed application. The available results section does not provide a statistical comparison between pre-test and post-test scores; therefore, the findings demonstrate favorable post-use learning outcomes rather than establishing a causal increase in achievement.

4. Product Revision Based on Expert Validation

Expert validation also generated qualitative recommendations that were used to improve the media before the student trial. The product was revised once following comments from the three validators. Table 7 summarizes the recommendations and subsequent revisions.

Table 7. Validator Comments and Product Revisions

Validator	Comments and Recommendations	Revision/Follow-Up
Validator 1	The color of the learning material should be made more contrasting to improve readability.	The visual contrast of the learning material was adjusted according to the recommendation.
Validator 2	A Home button should be added to each page, and explanatory information should be included in the 3D menu.	Navigation was improved by adding the Home function and additional information to the 3D section.
Validator 3	The media was considered informative and visually attractive; the language was clear and communicative, and the material was consistent with the curriculum.	The existing content and overall interface were maintained while ensuring conformity with the validator's assessment.

Source: Research data processing, 2026.

Table 7 shows that the revisions mainly concerned visual readability and navigation. The first validator recommended increasing the color contrast of the material so that the text would be easier for students to read. The second validator recommended adding a *Home* button to each page and providing further explanations in the 3D menu. These recommendations were incorporated before the subsequent student trial. The third validator considered the application informative, visually appealing, linguistically appropriate for students, and consistent with the applicable curriculum, and therefore did not require substantial content modification.

Taken together, the development and evaluation results show that the Unity 3D-based AR learning media successfully integrated learning materials, audiovisual content, three-dimensional network-device visualization, and evaluation features in a single application. Expert assessment produced an average validity score of 93.00%, categorized as very valid, while students' practicality assessment reached 94.08%, categorized as very practical. The effectiveness assessment further showed that 26 of 31 students (83.87%) were classified in the very effective category, four students (12.90%) in the effective category, and one student (3.23%) in the moderately effective category. These empirical findings indicate that the developed media met the validity and practicality criteria used in the study and was accompanied by generally high student achievement after its implementation.

DISCUSSION

The findings demonstrate that the Augmented Reality (AR)-based learning media developed for the Elective Subject (*Mata Pelajaran Pilihan* [MPP]) in Computer and

Telecommunications Network Engineering (*Teknik Jaringan Komputer dan Telekomunikasi* [TJKT]) met the validity, practicality, and effectiveness criteria established in this study. The development of the media was initially motivated by classroom conditions at SMKN 8 Padang, where learning about computer network devices was still largely supported by verbal explanations and static presentation materials, while the availability of physical equipment was limited. Such conditions were particularly relevant because students were expected to recognize devices such as switches, routers, hubs, access points, UTP cables, and modems not only by name but also by their physical characteristics and functions. The AR application addressed this need by providing three-dimensional visualizations that could be accessed through students' smartphones, thereby offering an additional form of representation when real network equipment was not sufficiently available for classroom observation.

Expert validation produced an overall score of 93.00%, placing the developed media in the very valid category. Content feasibility received 90.67%, while the language and presentation components each reached 93.33%. The graphical component obtained the highest score at 94.67%. These results indicate that the media was considered appropriate not only in terms of instructional content but also in terms of its visual organization and presentation. The relatively high graphical score is particularly relevant to the characteristics of AR-based learning because the instructional value of AR depends considerably on how clearly virtual objects are presented and how easily learners can interpret the visual information. For the present study, three-dimensional representations of computer network devices provided students with opportunities to examine technical objects more concretely than would be possible through static illustrations alone. The validation results therefore support the suitability of the developed application for the intended learning context.

These findings are consistent with previous studies on AR-supported computer and hardware learning. Menrisal & Wijaya (2022) reported that AR-based learning media for computer devices achieved a validity score of 85.23%, indicating that AR can be appropriately incorporated into computer-related instructional material. Maheswara et al. (2024) similarly reported very high expert validation results for AR media developed to introduce computer hardware components. Although the numerical scores across studies should not be interpreted as directly comparable because they may employ different instruments, validators, and assessment criteria, the general pattern is consistent: AR-based learning media tends to receive positive expert assessments when its instructional content and visual elements are properly designed. The present study extends this pattern to the context of Grade XI MPP TJKT learning, particularly for the visualization of computer network equipment at SMKN 8 Padang.

The high validity of the product was also closely related to the systematic development process adopted through the ADDIE model. The analysis stage identified classroom needs, the characteristics of the students, curriculum requirements, and difficulties related to the visualization of computer network devices. These findings informed the design of the interface, learning content, navigation, evaluation features, and three-dimensional objects. The development stage then transformed these specifications into an operational AR application, which was subsequently reviewed by expert validators and revised before implementation. The revisions included improving color contrast to increase readability, adding *Home* buttons to facilitate navigation, and providing additional explanations within the 3D feature. This iterative process illustrates the importance of treating media development as a process of refinement rather than merely producing a technological application. Similar use of systematic development procedures has also been reported in studies by Hamzah et al. (2021) which emphasized the role of structured development stages in producing feasible instructional media.

Student responses further showed that the developed application was highly practical for classroom use. The overall practicality score reached 94.08%, with scores of 94.52% for ease of use, 93.98% for language feasibility, 92.47% for learning-time efficiency, and 95.35% for the graphical component. These results suggest that students were generally able to operate and understand the media without substantial difficulty. The graphical component again received the highest assessment, reinforcing the importance of visual clarity in learning materials that rely heavily on three-dimensional representation. Practicality in this context is not limited to technical operation. It also reflects whether students can navigate the application comfortably, locate relevant learning materials, understand the information presented, and use the available features without unnecessary obstacles. The combination of learning materials, instructional videos, AR visualization, and evaluation activities within one application provided students with a more integrated learning environment than conventional presentation-based instruction alone.

The effectiveness results also showed a favorable pattern of student achievement after the application was used. Of the 31 students involved in the trial, 26 students (83.87%) were classified in the very effective category, four students (12.90%) in the effective category, and one student (3.23%) in the moderately effective category. No student was classified as ineffective. The score distribution also showed that most students were concentrated in the higher achievement ranges, with 12 students scoring between 95 and 100 and eight students between 90 and 94. These findings indicate that students were generally able to achieve high learning outcomes after engaging with the AR-based media. The result is conceptually consistent with previous studies showing that AR can support the learning of computer hardware and network-related content by making technical objects easier to observe and interpret. Maheswara et al. (2024) and Ramadhan et al. (2025), for example, reported positive results from the use of AR in technology-related learning contexts. The contribution of the present study lies in applying this approach specifically to computer network devices within the MPP TJKT context.

The findings have practical implications for vocational learning. Technical subjects frequently require students to connect conceptual explanations with the physical form and function of equipment. When schools have limited quantities of network devices, AR may serve as a complementary learning resource that allows students to repeatedly observe digital representations before or alongside direct practice. Such media should not be considered a replacement for actual networking equipment or teacher guidance. Instead, it can function as an additional learning layer that helps students become more familiar with devices before engaging in practical activities. This is particularly useful for vocational schools because repeated physical access to routers, switches, access points, and other equipment may be constrained by cost, availability, or class size. Theoretically, the findings also reinforce the view that learning media become more meaningful when visual representation, learner interaction, instructional content, and assessment are designed as an integrated system rather than as separate technological features.

Several limitations should nevertheless be considered when interpreting the findings. The study was conducted only with Grade XI TJKT students at SMKN 8 Padang, so the results cannot automatically be generalized to other schools, vocational programs, or student populations. The instructional content was limited to the introduction of selected computer network devices, including switches, routers, hubs, access points, UTP cables, and modems, and did not yet cover broader TJKT competencies such as network security or system administration. The application also employed marker-based AR, meaning that successful visualization depended on printed markers and adequate lighting conditions for smartphone-camera recognition. Access was further limited to Android-based smartphones, excluding students using other operating systems. Another methodological limitation concerns the effectiveness analysis. The available data primarily describe student achievement after using the media and do not provide inferential evidence from a controlled comparison or a complete pre-test–post-test design. The findings should therefore be interpreted as evidence of favorable learning outcomes associated with the implementation rather than definitive proof that the media alone caused the improvement. Future studies may extend the application to broader TJKT content, support additional operating systems and markerless AR, involve larger and more diverse samples, and employ experimental or quasi-experimental designs to examine learning gains more rigorously.

CONCLUSION

Based on the research findings and discussion, the development of Augmented Reality (AR)-based learning media using Unity 3D for the Elective Subject (*Mata Pelajaran Pilihan* [MPP]) in Computer and Telecommunications Network Engineering (*Teknik Jaringan Komputer dan Telekomunikasi* [TJKT]) successfully produced an instructional application that responded to the learning needs of Grade XI students at SMKN 8 Padang. The product was developed systematically through the ADDIE stages of *Analysis, Design, Development, Implementation,* and *Evaluation*. The application integrates marker-based AR technology with three-dimensional representations of computer network devices, including switches, routers, hubs, and access points, and provides supporting features such as learning materials, a 3D menu, evaluation activities, and a developer profile. The media was designed particularly to address limited access to physical network equipment and to provide students with more concrete and interactive representations of technical objects through Android-based smartphones.

The evaluation results showed that the developed media achieved an overall validity score of 93.00%, with content feasibility of 90.67%, language quality of 93.33%, presentation quality of 93.33%, and graphical quality of 94.67%, placing it in the *very valid* category. The practicality assessment reached 94.08%, indicating that students perceived the media as highly practical for learning activities. The study also reported an effectiveness value of 89.52%, categorized as very effective. Taken together, these findings indicate that the AR-based learning media is valid, practical, and suitable for supporting the learning of computer network devices among Grade XI TJKT students at SMKN 8 Padang. Future development may broaden the learning content to other TJKT competencies, extend compatibility beyond

Android devices, adopt markerless AR technology, and involve larger and more diverse student groups to provide stronger evidence regarding its effectiveness across different vocational education settings.

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