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Scaffolding learning model assisted by augmented reality to improve students' cognitive skills

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ABSTRACT
Students' cognitive abilities are crucial for developing higher-order thinking skills, including the ability to analyze, evaluate, and solve problems. However, Indonesia ranked 66th out of 81 countries in the 2022 Programme for International Student Assessment (PISA). Therefore, efforts to improve students' cognitive abilities are essential. This study aimed to develop and evaluate an Augmented Reality (AR)-assisted scaffolding learning model to enhance students' cognitive abilities in computer systems learning. The RnD method was employed with the ADDIE model. The study was conducted at SMA Negeri 2 Bandung and involved 30 students. Data collection was conducted using a one-group pretest-posttest design. The results showed a significant increase in students' cognitive achievement among those who attended classes using the AR-assisted scaffolding learning model. Student responses to this learning model were categorized as "very good." These findings indicate that the AR-assisted scaffolding learning model developed in this study is effective in enhancing cognitive abilities and student engagement in learning computer systems.

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ABSTRAK
Kemampuan kognitif murid merupakan aspek penting dalam pengembangan keterampilan berpikir tingkat tinggi, yang mencakup kemampuan menganalisis, mengevaluasi, dan memecahkan masalah. Namun, hasil Programme for International Student Assessment (PISA) 2022 Indonesia berada pada peringkat 66 dari 81 negara. Oleh karena itu, upaya untuk meningkatkan kemampuan kognitif murid sangat diperlukan. Penelitian ini dilakukan untuk mengembangkan dan mengevaluasi model pembelajaran scaffolding berbantuan Augmented Reality (AR) guna meningkatkan kemampuan kognitif murid dalam pembelajaran sistem komputer. Penelitian ini menggunakan metode RnD dengan model ADDIE. Penelitian dilaksanakan di SMA Negeri 2 Bandung dengan melibatkan 30 murid. Pengumpulan data dilakukan melalui desain one-group pretest-posttest. Hasil penelitian menunjukkan terdapat peningkatan signifikan pada pencapaian kognitif murid yang mengikuti kelas dengan penerapan model pembelajaran scaffolding berbantuan AR. Respons murid terhadap model pembelajaran ini termasuk dalam kategori "sangat baik". Temuan ini menunjukkan bahwa model pembelajaran scaffolding berbantuan AR yang dikembangkan dalam penelitian ini efektif dalam meningkatkan kemampuan kognitif serta keterlibatan murid pada pembelajaran sistem komputer.
Kata Kunci: *kemampuan kognitif; model pembelajaran scaffolding; realitas tertambah*

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INTRODUCTION

The 21st century is widely regarded as the knowledge age, characterized by openness and globalization. It means that every activity undertaken by people in this era is knowledge- and information-driven. In this century, information is readily accessible, communication is not constrained by space or time, computer technology is advancing rapidly, and routine jobs increasingly rely on automation. In other words, the 21st century transforms jobs from industry-based to knowledge- and digital-technology-based (Ikenga & van der Sijde, 2024; Mula & Ristiani, 2025).

As a result, education in the digital era should shift from memorization toward analytical approaches and equip students with critical thinking skills (Fadillah et al., 2022; Hassan et al., 2025). According to the OECD in its report titled "*PISA 2022 Results (Volume I): The State of Learning Worldwide*", Indonesia ranked 66th out of 81 participating countries, indicating that Indonesian students still experience difficulties in solving problems that require reasoning and problem-solving skills. Cognitive ability is the foundation for developing students' higher-order thinking skills (Hajaroh, 2021). However, many learning environments primarily focus on knowledge recall rather than conceptual understanding. Despite the importance of conceptual understanding, many learning environments still dominantly emphasize knowledge recall. In practice, students are frequently trained to memorize terms, definitions, or procedures without sufficient opportunities to explore the meaning and interconnections of concepts. As a result, students may perform adequately on recall-based assessments but struggle when asked to analyze, apply, or explain concepts in depth (Verina & Juandi, 2022). This issue is particularly evident in abstract and conceptual subjects such as computer systems. Students often report difficulties in understanding system components, their functions, and the relationships between hardware, software, and brainware. Learning materials and instructional methods often present concepts in theoretical, abstract terms, making it difficult for students to visualize how these components work together. Consequently, students' understanding remains fragmented, and misconceptions persist because learning does not move beyond surface-level memorization (Safitri et al., 2021).

The scaffolding learning model offers a pedagogical solution to address this problem. Scaffolding involves providing structured, temporary support that enables learners to accomplish tasks they would not be able to complete independently. As learners' understanding increases, the support is gradually reduced, allowing them to develop autonomy and deeper conceptual mastery. This structured guidance is particularly effective in supporting conceptual understanding because it aligns instructional support with students' cognitive readiness (Al-Fayed & Hatta, 2024).

Meanwhile, Augmented Reality (AR), which can digitally visualize real-world phenomena, offers an opportunity to enhance the scaffolding of learning quality by visualizing various concepts, including abstract ones (Radianti et al., 2020). Augmented Reality (AR) can be strategically integrated into the scaffolding model to enhance conceptual understanding, especially for abstract learning content. AR enables the visualization of complex objects and processes by overlaying digital information onto the real world, thereby transforming abstract concepts into concrete, observable representations.

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Within a scaffolding framework, AR does not function merely as a technological novelty but as a pedagogically meaningful tool. In the early stages of scaffolding (provision and explanation), AR can support remembering and understanding by introducing concepts through interactive visualizations. In subsequent stages (reviewing and restructuring), AR facilitates application and analysis by enabling students to explore, manipulate, and revisit concepts independently. At higher cognitive levels, the role of AR gradually diminishes, thereby encouraging learners to engage in critical discussion, reflection, and independent problem-solving.

Previous studies have demonstrated that scaffolding supported by digital technologies can improve learning outcomes, engagement, and motivation (Hou & Keng, 2021). Research has also shown that AR-based learning environments enhance students' understanding of complex and abstract concepts by providing immersive and interactive experiences (Hidayani et al., 2024). Some studies have further integrated scaffolding strategies within AR environments, reporting positive effects on learning performance and learner motivation (Piriyasurawong, 2020; Sari et al., 2024). However, several research gaps remain. First, many existing studies focus on general learning outcomes or motivation, rather than explicitly addressing conceptual understanding in specific subject domains. Second, the pedagogical role of AR is often insufficiently structured, with limited alignment to cognitive learning stages. Third, research on the integration of scaffolding and AR in secondary-level computer systems education is still limited.

The novelty of this research lies in three main aspects: the application of a scaffolding learning model integrated with AR for teaching computer systems, a subject characterized by abstract and conceptual content; the systematic alignment of scaffolding stages with the cognitive levels of Bloom's Taxonomy to ensure the strategic use of AR at each stage of learning; and the development and implementation of an AR-based learning application using an instructional design model, followed by empirical testing of its effectiveness on students' cognitive learning outcomes.

Based on the identified problems and research gaps, this study aims to: 1) Develop an Augmented Reality-based learning application that supports the implementation of the scaffolding learning model; 2) Examine the effects of scaffolding-assisted AR learning on students' cognitive learning outcomes in computer systems materials; and 3) Analyze students' responses toward the implementation of the scaffolding learning model supported by AR as a learning tool and media. Therefore, this research was conducted to develop an AR-assisted Scaffolding Learning Model for computer system education and to assess its effectiveness in improving students' cognitive skills.

LITERATURE REVIEW

Scaffolding Learning Model

The scaffolding learning model is a pedagogical approach that emphasizes providing temporary, structured support to learners to help them accomplish tasks that exceed their current independent capabilities. This model is grounded in Vygotsky's theory of the Zone of Proximal Development (ZPD), which explains that optimal learning occurs when students receive guidance within a range that bridges what they can do independently and what they

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can achieve with assistance. Through scaffolding, learning is framed as an active, guided process rather than a passive transfer of knowledge.

In instructional practice, scaffolding is implemented through several stages, including providing initial guidance, explaining concepts, reviewing students' understanding, restructuring knowledge, and developing conceptual thinking. These stages enable learners to progress gradually from basic comprehension to more complex cognitive processes. As students' understanding improves, the level of instructional support is progressively reduced, allowing learners to become more independent and confident in applying their knowledge.

Scaffolding can therefore be viewed as temporary support provided by teachers to facilitate students' conceptual understanding, which is gradually withdrawn as learners gain autonomy in constructing knowledge (Faisal, 2025). In contemporary educational settings, scaffolding extends beyond verbal interaction between teachers and students and is increasingly embedded in digital tools that guide learners through problem-solving processes. Such technology-supported scaffolding has been shown to enhance cognitive apprenticeship by providing adaptive learning structures aligned with students' individual needs.

Augmented Reality (AR)

Augmented Reality (AR) expands scaffolding in learning. It supports learning by visual, spatial, and interactive tools in real time. Using AR, objects, concepts, and instructional steps can be displayed in 3D, making them more realistic and functioning as contextual digital scaffolding (Garzón et al., 2020). In science learning, for example, AR can visualize specific parts of the human body and provide layered explanations, thereby enabling students to engage in self-directed exploration. In this case, AR can serve as a cognitive enhancer, helping students explore abstract concepts more concretely and providing immersive experiences.

The development of AR in education has been closely linked to advances in mobile and multimedia technologies, enabling AR applications to be accessed via smartphones and tablets. In learning environments, AR has been used to visualize concepts that are otherwise difficult to observe directly, such as internal system processes or abstract structures. Previous research has shown that AR can improve students' motivation, engagement, and understanding (Kaur & Horan, 2020). AR-based learning environments support conceptual understanding by helping learners build clearer mental representations of abstract content (Mansour & Alotaibi, 2025).

ADDIE Model

In this study, the ADDIE model serves as the foundation for integrating the scaffolding learning model with AR. ADDIE is an instructional development model comprising five interconnected stages: Analysis, Design, Development, Implementation, and Evaluation. It is systematically designed to address learning problems by considering students' needs and characteristics, ensuring that the instructional process is both structured and effective (Abuhassna et al., 2024). Previous studies have highlighted that the ADDIE model is effective

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for developing technology-enhanced learning media that are pedagogically sound and systematically evaluated (Adeoye et al., 2024).

Cognitive Skills of Students

Cognitive skills refer to learners' mental abilities related to acquiring, processing, understanding, and applying knowledge. In educational contexts, cognitive skills are commonly described using Bloom's Taxonomy and its revised version, which categorize cognitive processes from remembering and understanding to applying, analyzing, evaluating, and creating (Hamzah et al., 2022). These cognitive levels remain a foundational framework for designing learning activities and assessing students' thinking skills.

Recent studies emphasize that the development of cognitive skills is essential for enabling students to engage in problem-solving, reasoning, and critical thinking required in 21st-century learning environments (Bariyyah, 2021). Learning environments that promote active engagement, conceptual exploration, and reflective thinking are more effective at fostering higher-order cognitive skills than instructional approaches that focus primarily on memorization (Hao & Tasir, 2024).

METHODS

This research employed the Research and Development (R&D) method using the ADDIE model, with stages of analysis, design, development, implementation, and evaluation. The study was conducted at SMA Negeri 2 Bandung and involved 30 students as participants. The topic of computer systems was chosen for its abstract and visual features, which make it suitable for AR integration in scaffolding learning.

The development of the AR-assisted scaffolding learning model in this research was initiated by analyzing the difficulties students face and the needs of teachers, followed by the design of learning activities that integrate AR-based scaffolding. AR media in this research were developed using Unity 3D, allowing students to interact with 3D computer components. Before implementation, the learning media and AR interface were validated by experts, yielding a "very good" rating. The implementation stage applies the developed application in classroom learning, while the evaluation stage examines its effectiveness in improving students' cognitive learning outcomes. During implementation, students followed learning activities that employed scaffolding steps: guided explanation, semi-guided exploration, and independent practice.

To measure improvement in cognitive achievement, a one-group pretest-posttest design was employed. The data of this research were collected through observations and questionnaires. Quantitative data were then analyzed statistically by using paired t-test and N-gain calculations, while qualitative responses were descriptively analyzed. **Figure 1** below presents the stages of the ADDIE development model applied in this study.

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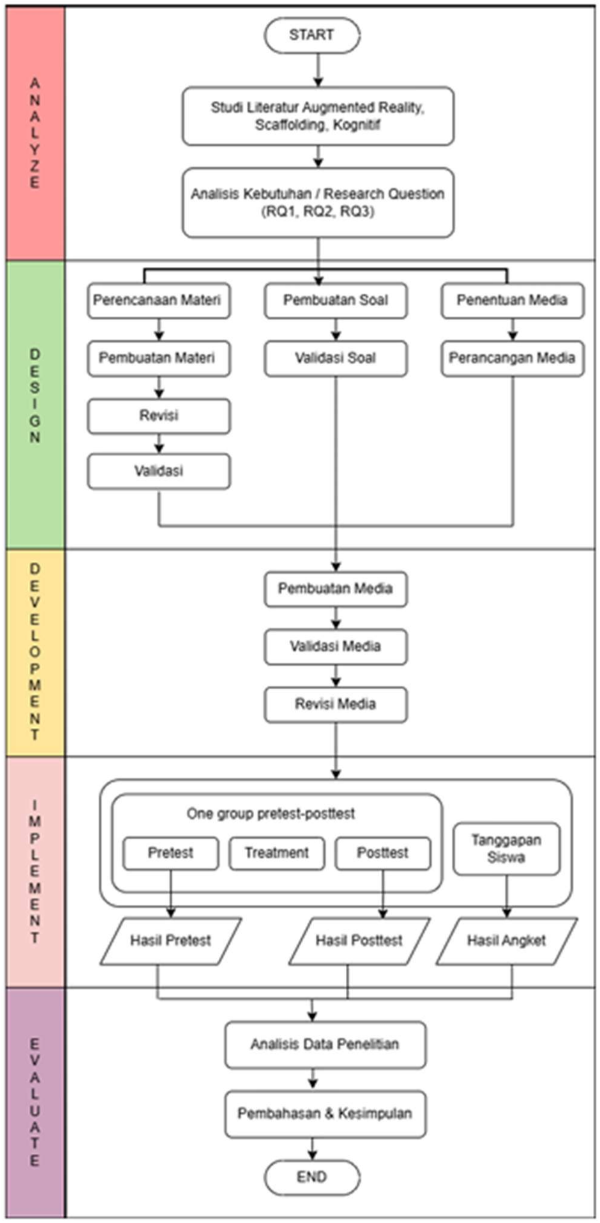

Figure 1. Flow of the ADDIE development steps used in this study
Source: Research 2025

RESULTS AND DISCUSSION

The development of AR learning media in this study followed the ADDIE instructional design model, comprising the analysis, design, development, implementation, and evaluation stages. Each stage was conducted systematically to ensure that the developed media aligned with the learning objectives and students' needs.

At the analysis stage, a needs analysis was conducted through questionnaires and interviews with students and teachers to identify learning problems in computer systems materials. The results indicated that students had difficulty understanding abstract concepts related to computer system components, attributable to the predominance of conventional instructional methods and the absence of interactive learning media. **Figure 2** illustrates students'

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perceived difficulties in comprehending computer system concepts as a whole, indicating that a considerable proportion of learners experience moderate to high levels of difficulty in understanding the integrated structure of computer systems.

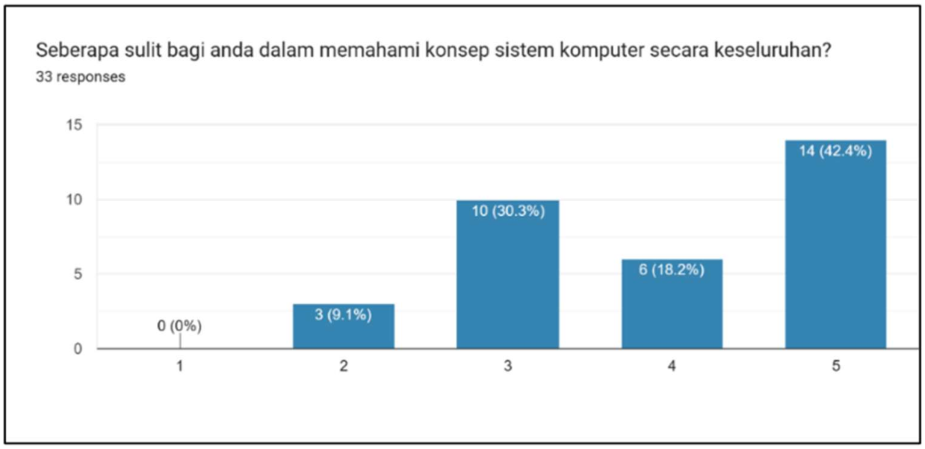

Figure 2. Students' Difficulties in Understanding Computer System Concepts
Source: Research 2025

Curriculum analysis was also conducted using the Informatics subject syllabus to identify the relevant foundational competencies and learning objectives to be addressed through AR-based media.

During the design stage, the learning content was selected and organized in accordance with the identified learning objectives. The computer systems material was structured based on the scaffolding learning model stages and aligned with the cognitive levels of Bloom's Taxonomy. The following table illustrates the correlation among the scaffolding model stages, students' cognitive levels according to Bloom's taxonomy, and the role of AR media in supporting learning activities.

Table 1. Correlation between the Scaffolding Model, Cognitive Levels, and the Role of AR Media

Scaffolding Stages	Cognitive Focus (Bloom's Taxonomy)	Teacher's Role/ Learning Activities	Role of AR Media
Provisions (Activating prior knowledge and providing initial learning support)	C1 (Remembering), C2 (Understanding)	Providing learning context, eliciting prior knowledge, and posing guiding questions to stimulate recall	Introduction to initial AR media
Explaining (Facilitating media use and providing guidance)	C2 (Understanding), C3 (Applying)	Explaining concepts concretely, providing examples, and guiding early thinking processes	AR plays a primary role in explaining object concepts
Reviewing (Providing feedback to enhance understanding)	C3 (Applying), C4 (Analyzing)	Giving practice exercises, feedback, group discussions, and reflection on understanding	AR is used for concept exploration, visualization-based exercises, and quiz completion

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Scaffolding Stages	Cognitive Focus (Bloom's Taxonomy)	Teacher's Role/ Learning Activities	Role of AR Media
Restructuring (Encouraging discussion and exchanging understanding)	C3 (Applying), C4 (Analyzing)	Encouraging students to organize concepts, engage in discussions, and compare different perspectives	AR serves as a supporting medium; students are more actively involved in discussion and critical thinking
Development of Conceptual Thinking (Developing students' conceptual thinking skills)	C5 (Evaluating)	The teacher acts as a facilitator; students learn independently and construct their own concepts	AR is no longer dominant and is used only as a supporting tool for advanced exploration

Source: Research 2025

The framework presented in **Table 1** served as a guideline for determining instructional strategies and the role of AR at each learning stage. Based on this framework, the study proceeded to the design phase, during which storyboards, flowcharts, and interface layouts of the AR application were developed. This phase also defined the role of AR across learning stages, particularly in facilitating visualization and supporting students' conceptual understanding of abstract components of computer systems.

Following completion of the design phase, the study proceeded to the development stage, in which the AR learning application was implemented in accordance with the established design specifications. Three-dimensional objects, animations, and interactive elements were created to represent computer system components. The completed media were subsequently validated by materials and media experts to assess content accuracy, instructional suitability, interface design, and technical quality. The validation results indicated that the developed AR media was feasible for implementation after minor revisions. The following section presents the AR application interface.

Figure 3. Main Menu Page
Source: Research 2025

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In **Figure 3**, the main menu page contains several functions and consists of seven main buttons. The "Processing Devices," "Jenis Komputer," and "Storage Devices" buttons are used to scan target images, which then display 3D objects. The "i" button located at the top-right corner of the page provides usage instructions for new users. Furthermore, the "Materi" button is used to view a preview of computer system learning materials. The "Soal" button allows users to practice questions. Finally, the "Quit" button functions to exit the application after it has finished being used.

Figure 4. Instruction Page
Source: Research 2025

The instruction page contains usage guidelines for new users of the application. It consists of four instructional steps and includes a "Back" button that returns to the main page, as shown in **Figure 4**.

Figure 5. Material Preview Page
Source: Research 2025

In **Figure 5**, the material preview page displays computer system learning materials across two pages. Arrow buttons are provided to navigate to the next page of the material. The "Back" button functions to return to the main page.

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Figure 6. AR Scan Page for Computer Types
Source: Research 2025

In **Figure 6**, the AR scan page for computer types includes a camera for scanning target images of computer types. When the target image is successfully scanned, a 3D object is displayed. Once the object appears, a "Penjelasan" button is displayed, providing explanatory information. A total of six computer-type objects are available: supercomputer, mainframe computer, minicomputer, mini PC, PC, and microcomputer.

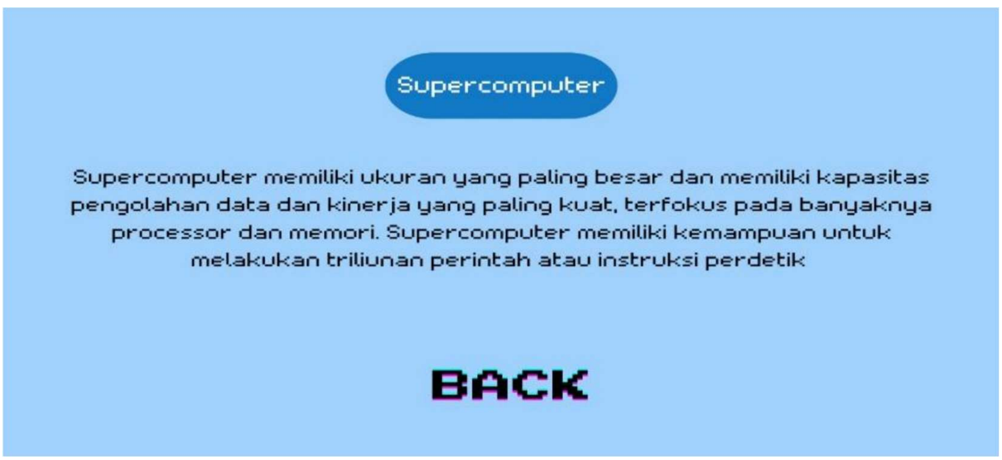

Figure 7. Computer Types Description Page
Source: Research 2025

In **Figure 7**, the description page provides explanations for each object previously scanned with the AR camera. A "Back" button is provided to return to the AR scan page.

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Figure 8. Evaluation Page
Source: Research 2025

In **Figure 8**, the evaluation page contains 10 practice questions. After an answer is selected, the system automatically displays whether the answer is correct or incorrect and proceeds to the next question. Users can return to the previous page after completing all questions. Once all questions have been completed, a results page is displayed that shows the number of correct and incorrect answers and the final score.

The validated AR learning media was then implemented in classroom learning. Prior to the learning intervention, a pretest was administered to assess students' initial cognitive understanding of computer systems material. The pretest was administered via an online questionnaire developed in Google Forms, comprising multiple-choice items aligned with the learning objectives and cognitive indicators. Following the pretest, students participated in learning activities using the scaffolding-assisted AR learning media. The learning process was conducted according to the designed scaffolding stages, in which students interacted with the AR application to explore computer system components under guided instruction.

At the end of the learning activities, a posttest was administered via Google Forms, using the same format and difficulty level as the pretest. The posttest aimed to assess students' cognitive learning outcomes following implementation of the AR-assisted scaffolding learning model. The use of online assessment tools facilitated efficient data collection and ensured consistency between the pretest and posttest instruments.

Prior to implementation, students had a limited understanding of the relationships between hardware and software components. After intervention using the scaffolding learning model assisted by AR, the mean score was 46.67, increasing to 75.50 in the posttest. Analysis done statistically using a paired t-test, resulting in -6.054, which is lower than 0.05. It indicates a significant difference between pretest and posttest scores (see **Table 2**).

Table 2. Paired T-Test Results

N	t	Df	Sig.(2-tailed)
30	-6,054	29	0,000

Source: Research 2025

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Meanwhile, N-gain scores for every student's group of 0.48 (high group), 0.57 (moderate group), and 0.55 (low group) showed a moderate level of improvement in students' cognitive achievement. **Table 3** is presented below.

Table 3. Results of the Gain Test for Each Group

Group	Number of Students	Mean Pretest Score	Mean Posttest Score	Gain	N-Gain Score
High	10	71	85	0,48	48
Moderate	14	43	75,5	0,57	57
Low	6	26	66	0,55	55

Source: Research 2025

The next phase is evaluation, which focuses on analyzing the effectiveness of the AR-assisted scaffolding learning model. Pretest and posttest results were compared to determine changes in students' cognitive learning outcomes. In addition, students' responses regarding the use of AR learning media were collected via questionnaires to evaluate usability, attractiveness, and perceived learning support. The results showed a significant improvement in students' cognitive understanding of computer systems and positive responses toward the use of the AR-based scaffolding media. The following **Table 4** summarizes students' responses to the augmented-reality-based learning media across several evaluation dimensions.

Table 4. Students' Responses to the Learning Media

No.	Statement	Ideal Score	Obtained Score	Percentage
Content Quality				
1.	The learning media help improve students' understanding of the material	150	139	92.7%
2.	The learning media improves learning effectiveness	150	144	96%
	Average	150	141.5	94.35%
Learning Goal Alignment				
3.	The learning media supports the achievement of learning objectives	150	133	88.7%
4.	The learning media enhances learning goal attainment	150	136	90.7%
	Average	150	134.5	89.7%
Interaction Usability				
5.	The learning media is easy to use	150	135	90%
6.	The way the learning media works is easy to understand	150	147	98%
	Average	150	141	94%

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Motivation				
7.	The learning media make learning more engaging	150	150	100%
8.	The learning media make learning more enjoyable	150	142	94.7%
9.	The learning media are suitable for use as a learning tool	150	130	86.7%
	Average	150	140.6	93.8%
Reusability				
10.	I will use this learning media again	150	136	90.7%
11.	I will frequently use this learning media	150	146	97.3%
12.	I will recommend this learning media to others	150	139	92.7%
	Average	**150**	**140.3**	**93.5%**
	Overall Average	**150**	**140**	**93.2%**

Source: Research 2025

Discussion

The findings of this study indicate that students' responses to the implementation of the AR-assisted scaffolding learning model were overwhelmingly positive. Based on the questionnaire results, 93.2% of students rated their learning experience as "very good," indicating that the integration of scaffolding and AR was well received. This result supports previous research suggesting that technology-enhanced scaffolding can improve students' engagement and learning experiences, particularly when learning abstract content (Chen et al., 2023). An innovative classroom learning process creates an experience that meets students' needs in the digital era (Fatmaningrum & Jazuli, 2025; Nurdiyanto et al., 2024).

Observations conducted during the implementation revealed that students demonstrated higher motivation and more active participation throughout the learning process. Despite these positive outcomes, several challenges hindered implementation, particularly when some students' devices could not download the application due to insufficient storage capacity. This limitation was addressed by encouraging students to share devices and take turns using the application within their respective groups. Within this learning context, the use of AR media enabled students to visualize computer system components tangibly, thereby facilitating conceptual understanding. This finding aligns with previous studies indicating that AR-based learning environments support learners in constructing clearer mental representations of abstract concepts (García-Robles et al., 2024). Furthermore, the structured scaffolding steps implemented in this study enabled students to gradually develop independence in understanding computer system concepts, consistent with Vygotsky's theory of the Zone of Proximal Development.

These findings are consistent with previous studies reporting the effectiveness of integrating AR with scaffolding-based learning. Research has confirmed that AR-supported scaffolding can enhance students' cognitive performance and metacognitive awareness (Lin et al., 2023; Roman & Belda-Medina, 2025). Additionally, immersive learning experiences provided

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through AR function as cognitive anchors that help learners internalize complex concepts more effectively (Yang, 2023). Therefore, the results of this study suggest that scaffolding-assisted AR learning not only improves students' cognitive outcomes but also enhances motivation and engagement, which are essential factors for successful learning in 21st-century educational contexts (Gesilanda & Nurkhamid, 2025; Sari & Setiawan, 2024).

CONCLUSION

Based on the explanation above, it can be concluded that the Scaffolding Learning Model Assisted by AR can effectively improve students' cognitive abilities in learning computer systems. It can also improve students' satisfaction. The integration of scaffolding, structured guidance, and AR-generated interactive visualization can produce a synergistic effect that supports independent and meaningful learning. However, further research is recommended to extend the application of this model to other subjects and to explore teachers' readiness to adopt an AR-assisted scaffolding learning model in daily classroom activities. Future research is recommended to employ experimental or quasi-experimental designs involving control groups to strengthen the evaluation of the effectiveness of scaffolding-assisted AR learning. In addition, further studies may examine other learning variables, such as metacognitive skills, critical thinking, and long-term retention, to provide a more comprehensive understanding of the impact of learning. Expanding implementation across different topics, grade levels, and learning contexts, as well as improving the technical features and accessibility of AR learning media, is also recommended to enhance generalizability and instructional effectiveness.

AUTHOR'S NOTE

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