OmniaScience

Journal of Technology and Science Education

JOTSE, 2026 – 16(2): 470-485 – Online ISSN: 2013-6374 – Print ISSN: 2014-5349

https://doi.org/10.3926/jotse.3677

IMPROVING STUDENTS COGNITIVE LEARNING OUTCOMES IN COMPUTER SYSTEMS LEARNING THROUGH UNITY-BASED VIRTUAL REALITY MEDIA

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Received July 2025

Accepted March 2026

Abstract

This study addresses the persistent challenges in students' cognitive learning outcomes in computer systems, particularly due to abstract content, high cognitive load, and limitations of conventional teacher-centered instruction. To overcome these issues, the study investigates the effectiveness of integrating Unity-based Virtual Reality (VR) with the Problem-Based Learning (PBL) model. A quasi-experimental nonequivalent control group design was employed involving 72 tenth-grade vocational students, divided into an experimental group using VR and a control group receiving conventional instruction. Data were collected through validated cognitive tests aligned with Bloom's taxonomy and analyzed using descriptive statistics and ANCOVA. The results revealed a significant improvement in cognitive learning outcomes in the experimental group ($M = 95.61$) compared to the control group ($M = 81.06$), with a large effect size ($\eta^2 = 0.471$), indicating the strong impact of the VR-PBL integration. Furthermore, VR facilitated more active learning behaviors, improved conceptual understanding, and reduced performance gaps among students. The findings suggest that immersive VR environments enhance cognitive processing by enabling interactive visualization, contextual problem-solving, and deeper engagement with complex concepts. However, this study is limited to short-term cognitive outcomes and a specific subject context. Future research should explore long-term retention, integration with artificial intelligence for adaptive learning, and the impact on affective and psychomotor domains to provide a more comprehensive understanding of immersive learning technologies.

Keywords – Cognitive outcomes, Computer systems, Education, Problem-based learning, Virtual reality.

To cite this article:

Wahyudin, Akbar, A., Nugraha, E., Riza, L. S., Nazir, S., & Al Husaeni, D. N. (2026). Improving students cognitive learning outcomes in computer systems learning through unity-based virtual reality media. *Journal of Technology and Science Education, 16*(2), 470–485. https://doi.org/10.3926/jotse.3677

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1. Introduction

The cognitive abilities of senior high school students constitute a fundamental foundation in the learning process, as they encompass aspects such as memory, logical reasoning, information processing speed, and higher-order thinking skills that directly influence academic achievement across various subjects, including computer systems (Shi & Qu, 2021). However, numerous studies indicate that the current state of students' cognitive abilities still faces significant challenges, with approximately 38% of students experiencing cognitive dysfunctions such as difficulties in concentrating, remembering, and making decisions, which are influenced by mental health factors, stress, and lifestyle patterns such as sleep deprivation and excessive screen use (Desai et al., 2022; Iverson & Iverson, 2022). Furthermore, cognitive ability is not solely determined by intellectual factors, but is also shaped by non-cognitive factors such as motivation, grit, and self-regulation, which play a crucial role in academic success, particularly in STEM fields (Segal & Kalfon-Hakhmigari, 2025).

The condition of students' cognitive abilities is also closely related to various challenges in learning computer systems, particularly because this subject requires abstract thinking skills, an understanding of system hierarchies, and the processing of complex information. Students often encounter difficulties due to limitations in cognitive development, such as low working memory capacity, limited attention, and inadequate understanding of conceptual structures (Kuhlmann et al., 2024; Sweller et al., 2019). In addition, the high cognitive load resulting from text-based and less contextualized instructional materials can hinder the learning process, especially when it is not aligned with students' cognitive and affective conditions (Mayer, 2021; Paas & van Merriënboer, 2020). This condition also contributes to the emergence of learning difficulties in computer systems subjects, where students struggle to integrate abstract concepts, understand relationships among system components, and transfer knowledge into more complex problem-solving contexts (Pathak & Mishra, 2023; van Merriënboer et al., 2024).

Based on these conditions, the learning process implemented in classrooms has not fully accommodated students' cognitive needs in optimally understanding computer systems material. Instruction that tends to be teacher-centered and dominated by lecture-based methods results in low interactivity and limited active student engagement in constructing deep conceptual understanding (Hamcha et al., 2023; Khoirunnisa et al., 2024; Loke et al., 2012). Moreover, approaches that emphasize memorization rather than conceptual understanding make it difficult for students to connect knowledge with real-world contexts and practical applications in computer systems (Kharatova et al., 2022; Morozova et al., 2023). Another significant limitation is the inability of conventional learning approaches to effectively visualize abstract and complex processes in computer systems, such as data processing flows, interactions among hardware components, and the dynamic mechanisms of system operations. As a result, the concepts being taught become difficult for students to comprehend concretely (Basogain et al., 2017; Munir et al., 2024; Siraj et al., 2019). These conditions lead to a learning process that remains limited in supporting the development of comprehensive understanding in computer systems subjects.

One technology that has significant potential to address various challenges in learning computer systems is Virtual Reality (VR), which provides an immersive, interactive, and experiential learning environment. VR enables students to interact with three-dimensional representations of abstract concepts, such as computer system workflows, hardware structures, and computational processes, making concepts that were previously difficult to visualize more concrete and easier to understand (Malik et al., 2023; Pirker et al., 2020; Zabir & Tisha, 2025). In addition, the immersive learning characteristics of VR enhance student engagement and motivation by offering more authentic and contextual learning experiences compared to conventional methods (Ai et al., 2025; Lowell & Yan, 2024). The use of VR also contributes to improved knowledge retention, as students are not merely passive recipients of information but are actively involved in exploring and manipulating learning objects in real time (Thangavel et al., 2025). Furthermore, VR supports the development of practical skills through simulations of real-world environments that are safe and controlled, allowing students to understand computer system concepts in a more applied and meaningful way (Masood et al., 2025; Reddy et al., 2024).

A number of previous studies have shown that the use of Virtual Reality (VR) in computer systems learning, particularly in hardware-related topics, has a positive impact on the quality of learning. VR enables students to simulate the assembly and disassembly of computer components virtually, thereby creating an immersive learning experience that closely resembles real-world practice (Arshad et al., 2024; Li, 2023). Research findings also indicate improvements in students' cognitive achievement, especially in accurately identifying and understanding the functions of hardware components compared to conventional methods (Ebrahimi & Al-Humairi, 2024). In addition, the integration of gamification elements within VR environments has been shown to enhance student motivation and engagement during the learning process (Janecký et al., 2025). However, most existing studies still focus on procedural and structured simulation activities, resulting in learning interactions that are largely limited to exploration and object manipulation without deeply engaging higher-order thinking processes. Students are not sufficiently guided to confront contextual problems, conduct analysis, formulate solutions, or connect learned concepts to real-world situations. As a result, the potential for developing more complex cognitive abilities has not been fully facilitated (Baur et al., 2026; Tihova & Petkov, 2025). This condition highlights the need for developing learning approaches that not only emphasize simulation but also promote active student engagement in systematic problem-solving.

This study aims to examine the effect of using Unity-based VR learning media integrated with the PBL model on improving students' cognitive abilities in computer systems subjects. To achieve this goal, this study uses a quantitative approach with a one-group pretest-posttest design, which allows measuring the effectiveness of the media through a comparison of learning outcomes before and after the learning intervention. This approach was chosen to identify the extent to which the integration of VR technology and the PBL model can contribute to improving students' cognitive learning outcomes. The novelty of this study lies in the innovative integration of Unity-based VR media with the PBL approach systematically in the context of computer systems learning at the secondary level in Indonesia, as well as the presentation of empirical data on its impact on improving cognitive abilities that are still rarely found in local and international studies.

2. Methodology

2.1. Research Design

This study employs a quantitative approach with a quasi-experimental design, specifically utilizing a nonequivalent control group design. This design involves two groups, namely an experimental group and a control group, without a randomization process; therefore, the groups utilized consist of intact, pre-existing classes (Creswell, 2012). Both groups were administered a pretest to measure their initial abilities. Subsequently, the experimental group received a treatment in the form of Unity-based Virtual Reality (VR) learning media, while the control group followed conventional instruction. After the intervention, both groups were given a posttest to identify differences in cognitive learning outcomes. This design allows for a comparison of learning results between the two groups, although it does not entirely eliminate potential biases resulting from initial differences in group characteristics.

2.2. Participants

The participants in this study consisted of 72 tenth-grade students from a Vocational High School (SMK) in Bandung, selected through purposive sampling based on their alignment with the research objectives. Specifically, the selected students were currently enrolled in the Computer Systems course, and the selection was further supported by the availability of school facilities and institutional cooperation. The participants' ages ranged from 15 to 17 years. The sample was divided into two groups: an experimental group comprising 36 students (18 males and 18 females) and a control group also comprising 36 students (17 males and 19 females). Both groups were drawn from different classes with relatively comparable characteristics.

Based on this design, the study is guided by the following research questions:

RQ1: How do cognitive learning outcomes differ between students who learn using Unity-based VR media and those who receive conventional instruction?

RQ 2: How are student errors and interaction patterns manifested during VR-based learning?

2.3. Measuring Tools

The primary instrument utilized in this study is a cognitive learning outcome test, structured based on the learning objectives of the Phase E Informatics subject (10th-grade Vocational High School) specifically within the computer systems element. This instrument was developed by referring to the Revised Bloom's Taxonomy, covering cognitive levels from remembering (C1), understanding (C2), and applying (C3), to analyzing (C4) and evaluating (C5). The test was administered as both a pretest and a posttest to both groups to measure changes in students' cognitive abilities.

However, the relationship between the intended learning outcomes and professional or industry-required competencies needs to be explicitly articulated. In the context of vocational computer systems education, cognitive skills such as analyzing system failures, selecting appropriate hardware, and evaluating solutions are directly aligned with industry demands, including troubleshooting and technical decision-making. Therefore, the formulated learning outcomes in this study are not only designed to achieve cognitive levels based on Bloom's Taxonomy but also to support the development of competencies relevant to real-world professional practice.

The learning objectives serving as the foundation for this instrument include the students' ability to define, explain, describe, analyze, and evaluate computer system concepts. These concepts encompass hardware, software, brainware, human-computer interaction, and collaboration within computer systems. Each test item was developed based on indicators derived from the learning objectives, documented in item specification cards, and reviewed by experts to ensure alignment with the measured cognitive domains.

The content and construct validity of the instrument were reviewed by three experts in the fields of computer technology and education. Nevertheless, the instrument retains certain limitations, such as an uneven distribution of difficulty levels and several items with relatively low psychometric quality. Consequently, this instrument is positioned as an adequate measurement tool for the classroom context, although it is not yet fully optimized as a standardized test.

2.4. Procedure

The research procedure was conducted over six learning sessions. The first session began with the administration of a pretest to both groups to measure the students' initial abilities. The following four sessions constituted the learning implementation phase, with each session lasting 90 minutes. During this stage, the experimental group (EG) learned using Unity-based VR media in computer systems instruction, while the control group (CG) followed conventional teacher-centered learning. In the experimental group, students interacted with a three-dimensional virtual environment featuring materials such as hardware components, computer architecture, and data processing flows, accompanied by discussion and exploration activities. Both the experimental and control groups were taught the same instructional content, followed the same curricular objectives, and were allocated an equivalent amount of learning time. The final session concluded with a posttest administered to both groups to measure changes in cognitive learning outcomes following the intervention.

Every activity within the VR environment was systematically developed, ranging from basic levels to higher-order thinking skills. The visualization of this process is presented in Figure 1. In the initial stage, students were introduced to three-dimensional objects of computer system components to support their remembering abilities. Subsequently, students were provided with interactive materials regarding the concepts of hardware, software, and brainware to strengthen their understanding through direct visualization and exploration.

In the following stage, students engaged in practice activities that required the application of concepts (applying), such as determining computer system components that match specific needs within the simulation. The learning then proceeded with the presentation of real-world scenarios or cases within the VR environment, encouraging students to analyze (analyzing) symptoms of computer system failures by examining various components. In the final stage, students were given evaluative tasks (evaluating), where they were asked to assess the effectiveness of various solutions available in the simulation and provide justifications for their choices. This sequence of activities was designed to ensure that students not only grasp concepts conceptually but are also capable of applying, analyzing, and evaluating them within an authentic context.

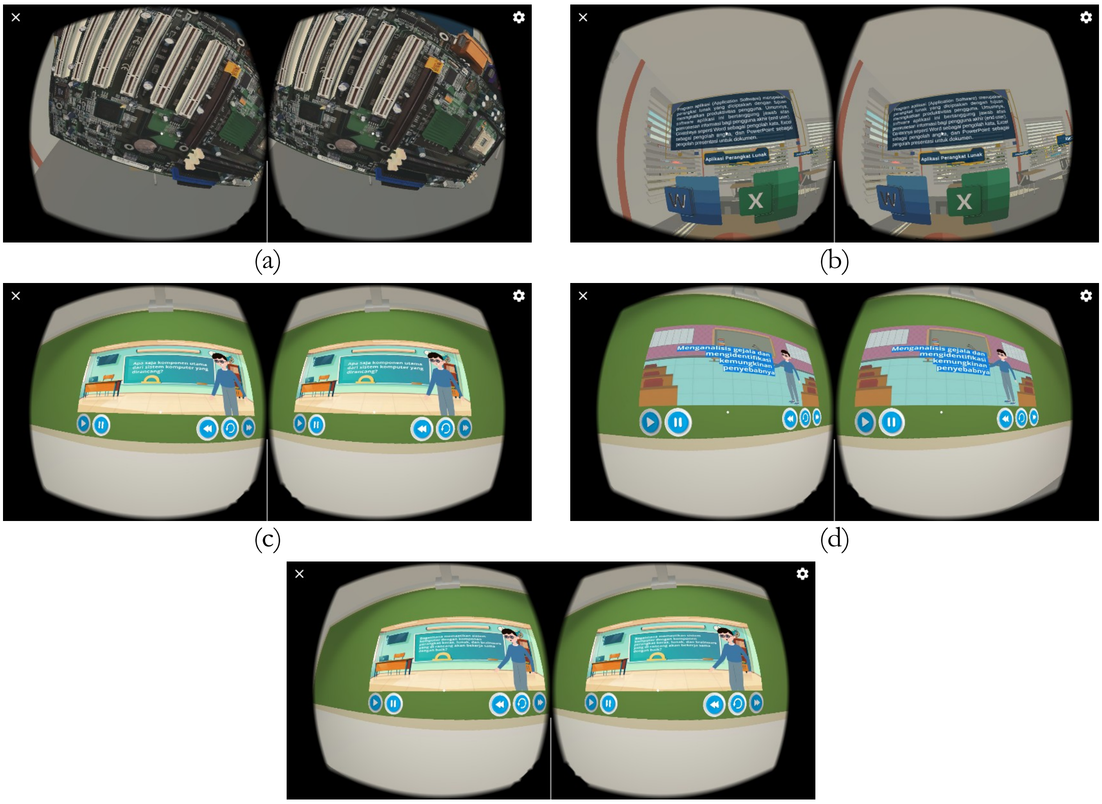

Figure 1. (a) 3D visualization of computer system components (remembering), (b) interactive material on hardware, software, and brainware (understanding), (c) application task in selecting system components (applying), (d) problem-based scenario for diagnosing system failures (analyzing), and (e) evaluation task for selecting the most effective solution (evaluating)

2.5. Data Analysis

Pretest and posttest data were analyzed using descriptive statistics, including mean values and standard deviations, to describe the distribution of student learning outcomes in each group. Descriptive statistics were conducted to identify general trends, data variation, and the equivalence of initial abilities between the experimental and control groups before the treatment was administered. In comparing posttest scores between the experimental group (EG) and the control group (CG), an Analysis of Covariance (ANCOVA) was performed, with pretest scores as a covariate to control for differences in students' initial abilities. This approach ensures that the impact of the treatment on learning outcomes can be estimated with greater accuracy.

3. Results

3.1. Test Instrument Test Questions

The testing instrument utilized in this study consisted of 60 multiple-choice items, which underwent a series of evaluations prior to data collection, including validity and reliability testing, as well as an analysis of difficulty indices and discrimination power. The results (see Table 1) indicated that a portion of the items exhibited low to very low validity, with some items being identified as invalid. Consequently, a selection process was conducted to determine the final items for the instrument. The selection of the final 30 items was based on established criteria, specifically prioritizing items with high or moderate validity, supported by adequate discrimination power and a moderate difficulty level. Items categorized as having low, very low, or invalid status were excluded from the final instrument to enhance the overall quality and precision of the measurement.

Criteria	Number of questions	Percentage (%)
Very high	0	0.00
High	6	10.00
Quite high	24	40.00
Low	18	30.00
Very low	10	16.70
Invalid	2	3.30
Total	60	100

Table 1. Results of the validity test of the question instrument

Furthermore, the reliability of the instrument was tested using the Kuder Richardson 20 (KR-20) formula. The Kuder Richardson 20 (KR-20) formula is a formula for calculating the reliability (internal consistency) of a test that has dichotomous answers (true/false, yes/no). The calculation results show a reliability value of 0.922, which is categorized as “very high”. This shows that the questions in the instrument have very good internal consistency, so they can be relied on to measure student learning outcomes stably.

To ensure that the selected test items adequately represent the measured construct, all utilized items were aligned with the learning objectives formulated based on the Revised Bloom’s Taxonomy (C1–C5) and computer systems material. Each item was mapped to specific cognitive indicators and reviewed by experts to ensure suitability and the representativeness of the measured construct. This process provides evidence that the instrument does not merely measure rote memorization but accurately reflects the targeted cognitive abilities.

Analysis of the difficulty level of the questions shows that out of 60 questions analyzed, there is 1 question that is included in the “difficult” category, 19 questions are “moderate”, and 40 questions are “easy”. The dominance of questions in the “easy” category shows that most of the questions are quite accessible to students, but care is still needed in the distribution of the level of difficulty to obtain representative measurement results. This distribution aligns with the instructional objectives that emphasize mastery of basic concepts as a prerequisite for higher-order thinking. Moreover, the inclusion of easy items does not necessarily lead to artificial score inflation, as these items function to ensure measurement reliability, reduce random guessing effects, and provide stable estimates of students’ baseline knowledge. The presence of moderate and difficult items further supports the instrument’s ability to differentiate varying levels of cognitive performance. Therefore, the distribution of item difficulty is considered appropriate for representing students’ cognitive achievement across different levels. The results of the difficulty index can be seen in Table 2.

Criteria	Number of questions	Percentage (%)
Difficult	1	1.70
Medium	19	31.70
Easy	40	66.70
Total	60	100

Table 2. Results of the validity test of the question instrument

Meanwhile, the discriminatory power test showed that 7 questions were categorized as "very good", 21 questions were "good", 24 questions were "sufficient", and 8 questions were "less good". This discriminatory power shows the extent to which a question is able to differentiate between students with high and low abilities. These results show that the majority of questions have sufficient to good discriminatory power. The results of the difficulty index can be seen in Table 3.

Criteria	Number of questions	Percentage (%)
Very good	7	11.70
Good	21	35.00
Fair	24	40.00
Bad	8	13.30
Total	60	100

Table 3. Results of the discrimination index test

Based on the results of the four tests, out of a total of 60 questions, 30 questions were declared suitable for use in the implementation of the intervention. The questions were then divided proportionally into two parts, namely 15 questions for the pretest and 15 questions for the posttest. This was done to ensure the validity and reliability of the measurement of students' cognitive abilities before and after the learning treatment using Unity-based Virtual Reality media.

No	Learning Objective	Cognitive Indicator	Test Item
1	Understand basic concept of computer systems	Understanding (C2)	A computer system consists of three main components, namely… A. Input-process-output; B. Hardware-software-brainware; C. CPU-RAM-storage; D. Data-information-program
2	Identify hardware components	Remembering (C1)	Which of the following is classified as hardware? A. Operating system; B. Application software; C. CPU; D. User
3	Explain function of CPU	Understanding (C2)	The main function of the CPU is to… A. Store data; B. Process data; C. Display output; D. Input data
4	Identify input devices	Remembering (C1)	Which device is used to input data? A. Monitor; B. Printer; C. Keyboard; D. Speaker
5	Identify output devices	Remembering (C1)	Which of the following is an output device? A. Mouse; B. Keyboard; C. Monitor; D. Scanner
6	Explain software role	Understanding (C2)	Software functions to… A. Control hardware operations; B. Replace hardware; C. Store electricity; D. Connect cables
7	Identify operating system role	Understanding (C2)	An operating system serves as… A. Hardware component; B. Interface between user and hardware; C. Storage device; D. Output device
8	Apply storage concepts	Applying (C3)	Which device is used for permanent data storage? A. RAM; B. Cache; C. Hard disk; D. Register
9	Differentiate RAM and ROM	Understanding (C2)	RAM differs from ROM because RAM is… A. Permanent; B. Temporary; C. External; D. Mechanical
10	Identify brainware	Remembering (C1)	Brainware refers to… A. CPU; B. User; C. Software; D. Monitor

No	Learning Objective	Cognitive Indicator	Test Item
11	Analyze system failure	Analyzing (C4)	If input devices fail, what happens? A. No data input; B. No output; C. No processing; D. System shutdown
12	Understand data processing cycle	Understanding (C2)	The correct sequence is… A. Output-input-process; B. Input-process-output; C. Process-input-output; D. Input-output-process
13	Identify storage devices	Remembering (C1)	Which is a secondary storage device? A. RAM; B. Cache; C. Hard disk; D. Register
14	Explain function of RAM	Understanding (C2)	RAM is used to… A. Store permanent data; B. Temporarily store data; C. Display output; D. Input data
15	Apply hardware selection	Applying (C3)	For graphic design tasks, which component is most important? A. GPU; B. Keyboard; C. Speaker; D. Mouse
16	Analyze hardware-software interaction	Analyzing (C4)	Without software, hardware will… A. Work normally; B. Not function properly; C. Overheat; D. Shutdown
17	Identify types of software	Remembering (C1)	Which is system software? A. Microsoft Word; B. Windows OS; C. Photoshop; D. Browser
18	Understand application software	Understanding (C2)	Application software is used for… A. Managing hardware; B. User tasks; C. Controlling CPU; D. Processing signals
19	Apply concept of OS	Applying (C3)	Which OS is used in smartphones? A. Windows; B. Linux; C. Android; D. DOS
20	Analyze system components	Analyzing (C4)	Which component connects all hardware parts? A. CPU; B. Motherboard; C. RAM; D. GPU
21	Identify input-output distinction	Understanding (C2)	Scanner is categorized as… A. Output; B. Input; C. Storage; D. Software
22	Understand data storage hierarchy	Understanding (C2)	Which is the fastest memory? A. Hard disk; B. RAM; C. Cache; D. SSD
23	Apply troubleshooting concept	Applying (C3)	If monitor shows no display, possible issue is… A. CPU failure; B. Input failure; C. Storage error; D. Software update
24	Analyze role of brainware	Analyzing (C4)	Brainware is important because… A. Controls software; B. Operates system; C. Stores data; D. Displays output
25	Identify peripheral devices	Remembering (C1)	Which is a peripheral device? A. CPU; B. RAM; C. Printer; D. Motherboard
26	Understand function of GPU	Understanding (C2)	GPU is mainly used for… A. Audio processing; B. Graphic rendering; C. Data storage; D. Input handling
27	Apply system knowledge	Applying (C3)	For typing documents, the most essential device is… A. Keyboard; B. GPU; C. RAM; D. Speaker
28	Analyze data flow	Analyzing (C4)	Data flows from input to… A. Output directly; B. Storage; C. CPU processing; D. Network
29	Identify types of storage	Remembering (C1)	SSD is categorized as… A. Primary memory; B. Secondary storage; C. Input device; D. Output device
30	Understand integrated system	Understanding (C2)	A computer system works effectively when… A. Only hardware exists; B. Only software exists; C. All components interact; D. Only user operates

Table 4. Results of Test Items

3.2. Implementation of Learning Interventions Using Virtual Reality Media

Descriptive statistics were conducted to illustrate general trends and the distribution of student learning outcomes in each group, both before and after the treatment, thereby providing an initial overview of the performance differences between groups. The descriptive statistical results (see Table 5) indicate that the mean pretest scores between the experimental group (M = 74.11, SD = 17.08) and the control group (M = 73.89, SD = 16.95) were relatively equivalent, suggesting that the initial abilities of both groups were at a comparable level. Following the treatment, an increase in scores occurred in both groups, albeit with a notable disparity. The experimental group, which utilized Unity-based Virtual Reality (VR) media, demonstrated a higher post-test mean (M = 95.61, SD = 4.72) compared to the control group (M = 81.06, SD = 10.12). Additionally, the standard deviation in the experimental group was smaller, indicating that student learning outcomes were more homogeneous and consistent. Conversely, the control group exhibited greater variation in learning outcomes.

Group	N	Pretest Mean (SD)	Post-test Mean (SD)
Experimental Group	36	74.11 (17.08)	95.61 (4.72)
Control Group	36	73.89 (16.95)	81.06 (10.12)

Table 5. Descriptive statistics of students' cognitive achievement

An ANCOVA analysis was then conducted to examine the differences in post-test scores between the experimental group and the control group while controlling for students' initial ability (pretest), thereby providing a more accurate estimate of the treatment effect. The results of the ANCOVA indicated that the overall model was significant, with $F(2, 69) = 33.03$, $p < 0.001$, suggesting that the combination of the covariate (pretest) and the treatment (group) jointly contributed to the variance in post-test scores. The pretest variable, as a covariate, had a significant effect on post-test scores ($F = 5.21$, $p = 0.026$, $\eta^2 = 0.071$), indicating that students' initial ability contributed to learning outcomes after the treatment, although with a relatively small to moderate effect size.

Furthermore, there was a significant difference between the experimental group and the control group after controlling for pretest scores ($F = 60.87$, $p < 0.001$, $\eta^2 = 0.471$). The partial eta squared value of 0.471 indicates that the treatment had a large effect size on the improvement of students' cognitive abilities. This finding suggests that the use of Unity-based Virtual Reality learning media made a significant contribution to improving learning outcomes compared to conventional instruction.

Overall, these results indicate that although students' initial ability plays a role in learning outcomes, the treatment factor is more dominant in explaining differences in cognitive achievement between groups. Thus, these findings reinforce that the instructional intervention applied in this study is significantly effective in improving cognitive learning outcomes in the subject of computer systems.

Source	Type III Sum of Squares	df	Mean Square	F	p-value	Partial Eta Squared
Corrected Model	0.489	2	0.244	33.03	< .001	0.489
Intercept	1.730	1	1.730	233.78	< .001	0.772
Pretest	0.039	1	0.039	5.21	0.026	0.071
Group	0.451	1	0.451	60.87	< .001	0.471
Error	0.511	69	0.007	—	—	—
Total	11.112	72	—	—	—	—
Corrected Total	1.000	71	—	—	—	—

Table 6. ANCOVA results for students' cognitive achievement

3.3. Analysis of Student Errors and Interaction Patterns in VR-Based Learning

During the implementation of Unity-based Virtual Reality (VR) media, several recurring patterns of student errors were identified, particularly during the initial sessions of using the media (see Table 8). Common errors that frequently emerged included inaccuracies in identifying hardware components, difficulty understanding the overall workflow of the computer system, and inconsistencies in sequencing simulation steps. This pattern aligns with previous findings that suggest initial barriers to VR-based learning often arise from students' limited conceptual understanding and spatial perception.

However, student interaction patterns with the media showed improvement over time. In the initial sessions, most students tended to be passive and simply followed instructions without further exploration. In the second and third sessions, students began to show initiative in exploring VR features independently. This increased interaction was driven by problem-based learning (PBL) challenges that encouraged students to logically associate information and develop solutions within the context of computer systems.

This pattern also demonstrated informal collaboration among students, particularly when they encountered difficulties in completing simulation scenarios. Some students spontaneously engaged in discussions and helped each other, indicating that VR media served not only as a visual aid but also as a catalyst for collaboration and constructive discussion.

Furthermore, teacher observations indicate that students with visual and kinesthetic learning styles tend to adapt more easily to VR-based learning environments. They demonstrate higher levels of engagement and comprehension compared to students with verbal preferences who require more intensive guidance. This reinforces previous findings suggesting that immersive media is more effective for visual-spatial and active learning styles.

However, the pattern of student interaction with the media showed an increase over time. In the first session, most students tended to be passive and only followed instructions without much exploration. Entering the second and third sessions, students began to show initiative in exploring VR features independently. Student interaction became more active when they were given problem-based challenges (PBL), which encouraged them to logically associate information and construct solutions in the context of a computer system.

This interaction pattern also shows informal collaboration among students, especially when facing difficulties in completing the simulation scenario. Some students spontaneously discussed and helped each other, indicating that VR media not only functions as a visual aid, but also as a trigger for collaboration and constructive discussion. In addition, the instructor noted that students with visual and kinesthetic learning styles showed a more positive response to the use of this media compared to students who were more dominant in the verbal approach.

Aspects Analyzed	Observed Patterns	Notes
Common Error Types	• Misidentifying hardware components • Difficulty understanding the flow of the computer system • Incorrect sequence of steps in the simulation	Occurs mainly in the initial sessions of media use
Changes in Interaction Patterns	• Early sessions: passive interaction, just following instructions • Later sessions: increased independent exploration	Increased engagement after being given a PBL-based scenario
Responses to PBL Challenges	• Increased conceptual understanding • Emergence of problem-solving initiatives	PBL challenges encourage active engagement and critical thinking
Collaboration Between Students	• Spontaneous discussions when faced with difficulties • Helping each other in completing the simulation	Occurs naturally, even though learning is individualized
Learning Styles and Responses	• Visual and kinesthetic students adapt more easily • Students with verbal preferences require more guidance	VR media is more effective for visual and kinesthetic learning styles

Table 8. Analysis of Errors and Student Interaction Patterns in VR-Based Learning

4. Discussion

The findings of this study confirm that the integration of Unity-based Virtual Reality (VR) media within the Problem-Based Learning (PBL) model facilitates a significant transformation in the quality of students' cognitive understanding. This success is evident not only in final academic achievements that surpass conventional methods but also in how this immersive technology reshapes the way students process complex information in Computer Systems subjects. This aligns with Liu et al. (2025), who suggest that immersive VR enhances cognitive learning outcomes through its ability to create a high sense of presence. This allows students to feel situated within the learning environment and process information more deeply. This condition strengthens cognitive engagement and facilitates the integration of new information with prior knowledge. Furthermore, Wu et al. (2020) reported that VR yields higher learning performance compared to traditional instruction because it provides concrete and dynamic visual representations, which help to mitigate conceptual abstraction and assist in the formation of accurate mental models. In other words, the effectiveness of VR lies not only in its immersion but also in its capacity to align visual representation, direct interaction, and contextual learning experiences that support profound conceptual mastery.

A key factor in the success of this intervention is the capability of the Unity engine to deliver detailed and interactive simulations. Computer Systems is often perceived as a challenging subject because it involves invisible internal hardware processes. VR media digitizes these abstract concepts into an explorable three-dimensional space. Students no longer merely memorize static diagrams; instead, they are present within the system architecture, observing data flow and visually comprehending component interactions. This first-person experience helps students construct more robust mental models compared to verbal explanations or two-dimensional imagery. This is consistent with Parong and Mayer (2018), who demonstrated that immersive VR experiences enhance learning transfer because students are actively engaged in the simulated environment. This allows them to construct knowledge through meaningful direct experience rather than passively receiving information. This process enables a stronger integration between conceptual knowledge and its functional context. Additionally, Mutiaz and Fatihah (2026) emphasize that 3D visualization in VR improves spatial ability and relational understanding between concepts, as students can observe the dynamics between components simultaneously. This is a feat that is difficult to achieve through 2D representations. Thus, VR assists students in understanding not only the "what" of a concept but also the "how" and "why" behind conceptual relationships.

The effectiveness of this learning approach is also rooted in the alignment between VR technological features and the phases of Problem-Based Learning (PBL). Within the virtual environment, problem scenarios become more realistic and immersive. Students are required to explore, identify problems, and test solutions in a safe yet challenging setting. The interactivity offered by the Unity engine enables instant feedback, where every student action within the simulation results in immediate visual consequences. This fosters higher cognitive engagement and intrinsic motivation, as students feel a sense of agency over their problem-solving process. These findings correspond with Lampropoulos and Kinshuk (2024), who indicated that integrating VR into problem-based approaches enhances critical thinking skills by confronting students with situations that demand active exploration, alternative evaluation, and experience-based decision-making. The VR environment allows students to test hypotheses directly and observe the consequences of their actions, making the thinking process more reflective and analytical. Moreover, Huang et al. (2021) highlight that VR supports contextual learning and problem-solving by providing authentic and situational environments where concepts are integrated into real-world usage contexts rather than learned in isolation.

An interesting phenomenon discovered is the ability of VR to narrow the achievement gap within the classroom. The use of this media appears to have a more equitable impact, where students who initially struggled reached mastery levels comparable to their peers. The immersive environment minimizes external distractions and provides essential visual scaffolding for visual and kinesthetic learners. Consequently, VR media functions as an inclusive instrument that enables all students, regardless of their initial learning pace, to consistently achieve high competency standards. This is in line with Hamilton et al. (2021), who showed that VR can increase the consistency of learning outcomes by providing a standardized learning experience. In this environment, every student receives the same visual exposure and interaction toward the material, which reduces variations in understanding. Furthermore, Cordero and Rodriguez-Morales (2026) assert that VR environments support more equitable engagement because their immersive and interactive nature allows students with various learning styles to participate actively in the learning process. Thus, VR not only raises average learning outcomes but also helps create a more balanced distribution of understanding within the class.

The implications of these findings suggest that the integration of Virtual Reality (VR) in education should be viewed as a pedagogical approach capable of transforming instructional design toward more exploratory, contextual, and student-centered experiences. The use of VR encourages educators to move beyond mere content delivery and instead design learning environments that allow students to construct knowledge through direct interaction, problem-solving, and immersive experiences, particularly for abstract and complex topics. This also necessitates an enhancement of teacher competency in integrating technology with instructional strategies like PBL, including designing authentic scenarios and providing appropriate scaffolding. Furthermore, teachers must consider activity design, information complexity, and support for diverse learning styles to ensure optimal impact.

Despite the significant effectiveness shown in using Unity-based VR and PBL, several limitations must be acknowledged. First, this study focuses solely on measuring short-term cognitive learning outcomes immediately following the intervention, and thus it cannot evaluate long-term memory retention of complex computer system materials. Second, the generalizability of these findings is limited by the sample size and the specific subject context. It does not account for external variables such as individual digital literacy or physical fatigue that may arise from extended use of VR devices. Additionally, students' affective and psychomotor aspects within social classroom interactions during the use of immersive media have not been explored in depth, even though they are critical components of a comprehensive educational ecosystem.

5. Conclusions

This study concludes that the implementation of Unity-based Virtual Reality (VR) media, integrated with the Problem-Based Learning (PBL) model, significantly enhances students' cognitive learning outcomes in Computer Systems subjects. The findings demonstrate that the utilization of immersive technology is capable of transforming abstract technical concepts into concrete and interactive visual learning experiences. This not only results in a substantial increase in average student scores compared to conventional methods but also establishes a more uniform standardization of understanding within the classroom. Furthermore, the synergy between realistic simulations in VR and the problem-solving framework of PBL has proven effective as an instrument for accelerating cognitive competence. Consequently, the adoption of VR-based learning media is highly recommended as an innovative solution to address material complexity in technical and vocational education, aiming to create a more effective, efficient, and inclusive learning ecosystem.

Future research is suggested to conduct longitudinal studies to evaluate long-term memory retention and the consistent effectiveness of VR media over an extended period. Additionally, the development of VR media integrated with Artificial Intelligence (AI) presents a crucial opportunity to create adaptive and personalized learning environments. The integration of AI within the VR ecosystem is expected to detect student profiles and learning paces in real-time, allowing the system to automatically adjust the difficulty of problem scenarios for each individual. Future researchers should also explore the influence of this technology on affective and psychomotor domains to provide a more comprehensive understanding of the potential of intelligent immersive technology in transforming technical education.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Authors' contributions

Wahyudin: Contributed to conceptualization, research design, supervision, and manuscript review.

Anthonio Akbar: Contributed to data collection, data processing, and manuscript drafting.

Eki Nugraha: Contributed to formal analysis, validation, and interpretation of results.

Lala Septem Riza: Contributed to methodology, literature review, and manuscript editing.

Shah Nazir: Contributed to research supervision, validation, and critical review of the manuscript.

Dwi Novia Al Husaeni: Contributed to data curation, visualization, and manuscript preparation.

All authors contributed to the study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

All authors have read and approved the final version of the manuscript.

Data availability

Data subject to third-party restrictions

Use of Artificial Intelligence

The authors declare that they have used artificial intelligence, specifically ChatGPT, for linguistic correction.

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Journal of Technology and Science Education, 2026 (www.jotse.org)