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Augmented reality in computer systems integrated with project-based learning in vocational schools

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Abstract. The development of technology and the demands of 21st-century skills require innovative learning that enhances student engagement and learning outcomes, particularly in Vocational High Schools (VHS). This study aims to examine the effectiveness of Augmented Reality (AR) media integrated with Project-Based Learning (PjBL) in improving student learning outcomes in computer systems at vocational high schools. A quasi-experimental method with a posttest-only control group design was employed, involving three groups: the experimental class (AR with PjBL), control group 1 (AR only), and control group 2 (conventional learning), each consisting of 38 students. Data collection techniques included learning outcome tests and documentation. The research instrument used was a standardized essay test to measure students' understanding of computer systems. Data were analyzed using one-way ANOVA, which indicated significant differences among the groups. Post hoc Tukey tests revealed that the experimental group achieved significantly higher learning outcomes than both control groups. These findings suggest that the integration of AR and PjBL creates a more contextual, interactive, and meaningful learning experience. The study supports constructivist theory and active learning as effective approaches in technology-based VHS.

Introduction

Industrial Revolution 5.0 requires enhancing digital competencies in VHS, especially in computer system informatics subjects, so that graduates are prepared to face global competition (Gašević et al., 2023; Kamal Eldeen et al., 2023; Лысенко et al., 2018) .Abstract topics such as hardware structure are often difficult to understand through conventional methods, leading to low motivation and poor learning outcome (Pacher et al., 2023; Wang & Wang, 2023). AR technology offers interactive 3D visualizations that improve understanding of technical concepts (Akçayır & Akçayır, 2017; Bacca et al., 2014; Ibáñez & Delgado-Kloos, 2018). Meta-analyses by (Wu et al., 2013) show that AR significantly improves information retention and student engagement, especially in STEM. AR blends the real world with digital objects viewable via devices such as smartphones, tablets, or AR glasses. This technology allows users to see virtual elements integrated with their physical environment. Unlike Virtual Reality (VR), which entirely replaces the real world, AR adds a digital layer to it, enriching the user experience without isolation. In education, AR can be used to project 3D models, text, images, videos, and other information directly into the classroom or learning environment.

However, implementing AR without pedagogical support such as PjBL tends to have minimal impact on the development of higher-order thinking skills (Bell, 2010; Thomas, 2000; Purnadewi & Widana, 2023). PjBL promotes student engagement in real-world projects that drive problem-solving and collaboration (Del Cerro Velázquez & Méndez, 2021; İbili̇ et al., 2024; Saidani Neffati et al., 2021). Research on the combination of AR and PjBL shows better learning outcomes than using AR alone or traditional methods (AlNajdi, 2022; Del Cerro Velázquez & Méndez, 2021; Zhu et al., 2014). C. H. Chen, (2020) reported improvements in conceptual understanding and creativity through interactive technology and PjBL. Other studies highlight the benefits of AR-PjBL in developing soft skills such as communication, collaboration, and digital literacy, which are essential for future job readiness (Rovithis et al., 2019; Shaltout et al., 2021; Zhang, 2023). Additionally, research by Smith et al. (2021) found positive effects on student motivation and satisfaction.

However, based on initial observations in several VHS in Bali, the implementation of AR media in computer systems learning is still limited to simple visualizations without integration with pedagogical models that promote 21st-century skills. Teachers tend to use AR as an illustrative aid rather than as part of an active and collaborative learning strategy. This results in low student participation in meaningful learning and suboptimal learning outcomes. Meanwhile, most studies examining the effectiveness of AR or PjBL have been conducted separately, with few specifically investigating the integration of both in the context of computer systems learning in vocational education. This research gap indicates the need for an empirical study that directly tests the impact of integrating AR and PjBL on VHS students' learning outcomes through an experimental approach.

Based on this background, the research problem in this study is: How do the learning outcomes of VHS students in computer systems who learn using Augmented Reality media integrated with PjBL compare to those of students using AR media alone and conventional learning? This study aims to identify and describe the learning outcomes of students on computer systems material after participating in learning using AR-based PjBL, AR alone, and conventional learning. The descriptive hypothesis of this study is that computer systems learning using AR-based PjBL media results in learning outcomes categorized as high.

Computer System Learning in VHS

Computer system learning in VHS is an integral part of the Computer and Informatics Engineering program. The learning material includes the introduction and understanding of hardware, the relationship between computer system components, and the assembly and maintenance process of computers. However, limited practice facilities and visual aids often become major obstacles in achieving optimal learning outcomes. Computer systems as subject matter demand a contextual and practice-oriented learning approach. According to (Hadju et al., 2024), VHS students are more interested in hands-on, experiential learning as it aligns with workforce demands. The materials cover introductions to motherboards, CPUs, RAM, hard drives, power supplies, and how each component is interconnected to form a complete computer system.

In terms of curriculum implementation, computer system learning usually begins with an introduction to hardware and software components, followed by identification and functions of the components. It concludes with assembly and system testing practice. This learning is integrated into the phase E learning achievements based on national vocational curriculum standards, emphasizing work skill mastery and higher-order thinking skills (Kemdikbud, 2022). Therefore, pedagogical approaches that encourage active student participation are highly necessary (Widana & Ratnaya, 2021).

Integration of AR with Project-Based Learning

PjBL is a learning model that emphasizes active student engagement through authentic and collaborative projects to solve problems or create products. In VHS contexts, PjBL is highly relevant as it demands practical skills and real-world problem-solving abilities, two aspects essential in the workplace (Scaravetti & Doroszewski, 2019; Widana et al., 2021). Integrating AR into PjBL enhances student learning experiences by creating interactive and applicable learning environments. In AR-based projects, students can produce outputs such as 3D models of computer systems, AR markers to identify hardware components, or interactive simulations to understand computer workflows.

Krüger et al. (2022) emphasized that AR-based learning media integrated into PjBL activities improve learning outcomes and student motivation, especially in programming education contexts. In their experiments, AR significantly benefited students with lower spatial abilities by bridging understanding gaps through dynamic visualization. The integration of AR and PjBL also supports the development of 21st-century skills, namely communication, collaboration, critical thinking, and creativity (4Cs). This is vital in VHS aimed at producing job-ready graduates. According to (Ibáñez & Delgado-Kloos, 2018), students tend to be more motivated and active in learning involving interactive technology such as AR, especially when allowed to become designers of the learning content themselves. Overall, integrating AR into PjBL provides an ideal combination of authentic PjBL experiences and interactive educational technology that facilitates a deep understanding of technical concepts. This model has high potential to be applied in computer system subjects in VHS to improve student learning outcomes comprehensively.

Augmented Reality in Computer Systems

The use of AR in teaching computer system material (Image 1) allows students to experience interactive and immersive visualizations of abstract and complex computer components. In the first topic, Understanding the Basic Components of a Computer System, AR can be used to display 3D models of essential hardware such as the CPU, RAM, motherboard, and hard drive. Students can rotate, zoom in, and closely observe the physical form and placement of each component within the computer system structure directly through a mobile device or tablet.

For the second topic, Identifying the Components of a Computer System, AR technology enables students to recognize and distinguish the names and basic functions of each part through virtual labels and interactive animations that appear when a component is tapped. Meanwhile, in the third topic, Functions and Working Mechanisms of Computer System Components, AR allows simulations of data flow or electrical current between components such as the processor and RAM, helping students understand how the system operates internally in a dynamic way.

Thus, AR not only enhances conceptual understanding but also makes the learning process more engaging and contextual, aligning with the needs of technology-based VHS.

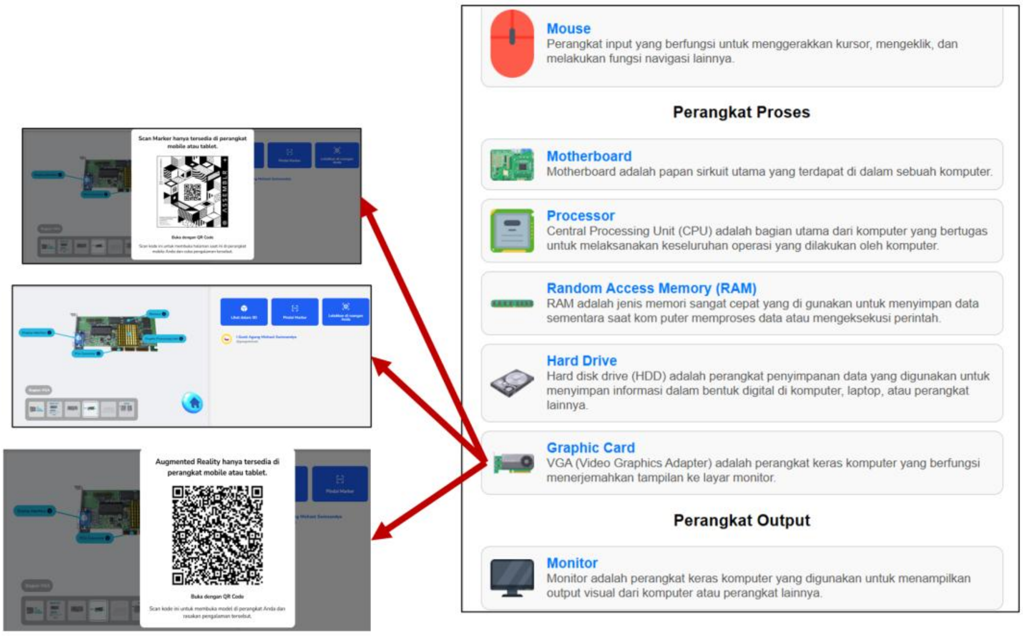

Image 1. AR-based computer system (in Indonesian)

Method

This study is experimental research with a quasi-experimental approach using a posttest-only control group design. This design was chosen because the researcher did not randomly assign subjects, but used existing classes within the school. The procedure of the research can be seen in Image 2.

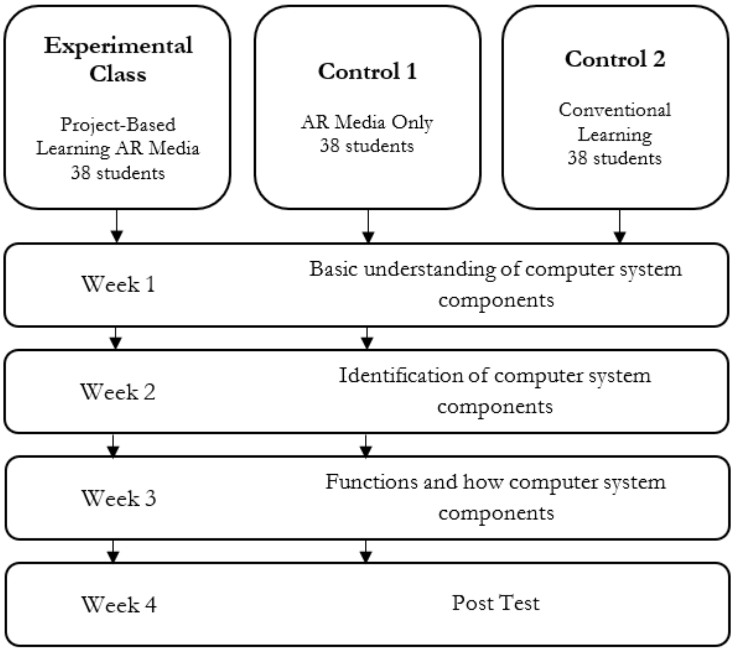

Image 2. Experimental Research Procedure

An experimental study was conducted over four weeks involving three research groups. The experimental class (Table 1) used AR media based on the PjBL approach, control class 1 used AR media without the PjBL approach, and control class 2 followed conventional learning. Each class consisted of 38 students. The learning activities were carried out in stages: the first week covered basic understanding of computer system components, the second week focused on identifying the components of a computer system, the third week discussed the functions and working mechanisms of these components, and the fourth week was dedicated to administering the post-test to measure each group's learning outcomes. This procedure was designed to compare the effectiveness of different learning approaches on student achievement.

Table 1. Experimental Class Steps

Time	Time/ minute (8 x 50 minutes)	Project-Based Learning	Activity Description
Week 1: Basic Understanding of Computer System Components	1	Essential Question & Project Orientation	The teacher initiates with trigger questions, conveys the objectives and divides the group.
	2	Project Planning	Students create a group work plan to create an AR-based infographic of basic computer components.
	3-4	AR Investigation & Exploration	Students explore AR objects (CPU, RAM, PSU, Motherboard, etc.), observing their shapes and characteristics.
	5-6	Project Product Development	The group begins to create infographics using the results of the exploration.
	7	Project Presentation	Each group presents the results of the project to the front of the class.
	8	Evaluation & Reflection	Teachers assess the project, and students reflect on the use of AR & PjBL.
Week 2: Identification of Computer System Components	1	Orientation and Assignment	Students are tasked with creating an AR Interactive catalog for component identification.
	2	Identification Plan	Students create an identification format: component name, physical form, position on the motherboard, and connecting devices.
	3-4	Exploration AR	Students use AR to scan components and match them to characteristics (labels, ports, connectors).
	5-6	Digital Catalog Compilation	Students create digital output in the form of an interactive PDF/HTML catalog with AR visual support.
	7	Presentation & Feedback	Groups display digital catalogs in class, and teachers provide feedback.
	8	Evaluation & Reflection	Individual reflection and assessment of project results.
Week 3: Functions and Working Mechanisms of Computer System Components	1	Questions & Problems Contextual	The teacher poses a problem: "What are the consequences if one of the components of a computer system does not function optimally?"
	2	Mini Project Planning Simulation of Component Functions	Students design short videos/digital sketches showing how CPU, RAM, HDD, etc. work with the help of AR.

Time	Time/ minute (8 x 50 minutes)	Project-Based Learning	Activity Description
	3-4	AR Experiments and Function Observations	Using AR to view simulations of data paths and relationships between components.
	5-6	Final Product Creation	Students compile explanations of component functions & workflows in an interactive presentation/short video format.
	7	Project Presentation, Q&A	Each group explains the functional scheme of the computer system and the relationship between components.
	8	Evaluation, Reflection, and Closing	Final assessment and class discussion on the overall understanding of computer system functions.
Week 4	1-8	Post-test	

Research Subjects

This study was conducted at a public VHS in Bali, in the Department of Computer and Telecommunications Network Engineering during the even semester. The research subjects were students from three classes, each comprising 38 students, for a total of 114 participants. These three classes were assigned as follows: 1) Experimental class, which received instruction using AR media integrated with the PjBL learning model, 2) Control group 1, which received instruction using AR media without the PjBL model, 3) Control group 2, which received conventional instruction without the use of AR media or the PjBL approach.

The learning process in the three classes was taught by teachers based on the learning design provided by the researcher. Meanwhile, the posttest given to the three groups consisted of the same questions, administered according to the learning schedule in each class.

Data Analysis Techniques

The posttest data were analyzed using SPSS 26 through descriptive statistics to examine the mean and standard deviation, as well as inferential statistics to test the hypothesis. Preliminary tests such as normality and homogeneity tests were conducted beforehand. Subsequently, data were analyzed using One-Way ANOVA to examine the differences in learning outcomes among the three groups. If a significant difference was found, a post-hoc test (e.g., Tukey test) was conducted to identify which groups differed significantly.

The research hypotheses were as follows: 1) H_0: There is no significant difference in learning outcomes among the experimental class, control group 1, and control group 2, 2) H_1: There is a significant difference in learning outcomes among the experimental class, control group 1, and control group 2.

Results and Discussion

Research Instrument

The instrument used in this study was an essay-format learning outcome test, administered after the instructional activities (post-test). The test was developed based on competency achievement indicators derived from the taught material and was intended to assess students' conceptual understanding. The blueprint of the learning outcome instrument is presented in Table 2.

Table 2. Research Instrument

Learning Outcome	Contents	Learning Objectives	Cognitive Levels	Question Items
Students can describe the components, functions, and workings of computers that form a computing system, as well as explain the process and use of codification for storing data in computer memory.	Basic computer system components	Students understand the basic concepts of hardware.	C1. C2	Q1. Q2
		Students understand the basic concepts of software	C1. C2	Q3. Q4
		Students understand the basic concepts of brainware.	C1. C2	Q5. Q6
	Identify the components of a computer system.	Students can identify various computer hardware components.	C2. C3	Q7. Q8
		Students can identify various software components in a computer system.	C3. C4	Q9. Q10
	Functions and how computer system components work	Students can describe the main functions of a computer system.	C3. C4	Q11. Q12
		Students can describe how the main components of a computer system work.	C3. C4	Q13. Q14. Q15

Validity and Reliability Testing

Before being used, the post-test items were validated by two experts to assess content validity. The expert validation process underwent two rounds of revisions until a Gregory coefficient score of 1.0 was achieved. Subsequently, the test items were piloted on students outside the experimental and control classes to conduct item analysis. After completing the testing stages, the developed test was deemed suitable for measuring learning outcomes. Therefore, the test items met the required standards for both validity and reliability.

Assumption Testing

Before conducting hypothesis testing using one-way ANOVA, assumption tests were carried out, including normality testing and homogeneity testing.

Normality Test

The normality test was performed using the Shapiro-Wilk test for each group of post-test data (Experimental, Control 1, and Control 2). The results of the test are presented in Table 3.

Table 3. Shapiro-Wilk Normality Test Results

Group	N	W (Shapiro-Wilk)	Sig. (p-value)
Experiment	38	0.963	0.242
Control 1	38	0.963	0.242
Control 2	38	0.963	0.242

Based on Table 3, since all p-values are greater than 0.05, it can be concluded that the data in all three groups are normally distributed.

Homogeneity Test

The homogeneity test was conducted to determine whether the variances among groups are homogeneous. This test used Levene's Test. The results are presented in Table 4.

Table 4. Homogeneity Test Results (Levene's Test)

Statistic	df1	df2	Sig. (p-value)
0.000	2	111	1.000

Based on Table 4, the p-value = 1.000 (> 0.05) indicates that the data have homogeneous variances.

Hypothesis Testing

To determine the differences in learning outcomes among the three treatment groups, a one-way ANOVA test was conducted. A summary of the results is presented in Table 5 below:

Table 5. One-Way ANOVA Results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	304.00	2	152.00	4.25	0.0167
Within Groups	3971.73	111	35.77		
Total	4275.73	113			

Based on Table 5, the results of the ANOVA test showed a p-value of 0.0167, which is less than the significance level of 0.05. Therefore, it can be concluded that there is a statistically significant difference in learning outcomes between at least two of the three treatment groups.

Post Hoc Test (Tukey HSD)

To determine which groups have significant differences, a post hoc Tukey HSD test was conducted. The test results are presented in Table 6.

Table 6. Results of Tukey HSD Test

Group 1	Group 2	Mean Difference	Sig.	CI 95% Lower	CI 95% Upper
Experiment	Control 1	2.67	0.287	-1.31	6.65
Experiment	Control 2	6.67	0.015	2.69	10.64
Control 1	Control 2	4.00	0.157	-0.09	8.08

Based on Table 6, the results of the Tukey HSD test showed that: 1) There was a significant difference between the Experimental group and Control 2 group (p = 0.015), 2) There were no significant differences between the Experimental group and Control 1, nor between Control 1 and Control 2.

Based on the overall test results, it can be concluded that computer systems learning using AR-based PjBL media is significantly more effective in improving students' learning outcomes compared to conventional learning. The average learning outcomes of the experimental class were the highest compared to the Control 1 and Control 2 classes (Table 7).

Table 7. Average Scores

Group	N	Mean	Std. Deviation	Minimum	Maximum
Experiment	38	85.27	5.98	73.33	96.67
Control 1	38	83.27	5.98	71.33	94.67
Control 2	38	81.27	5.98	69.33	92.67

The results of the study indicate a significant difference between the experimental group using AR-based PjBL media and the control groups, one using AR only and the other employing conventional learning. Statistical analysis of the experimental research shows that students using AR combined with PjBL achieved a very high average score of 85.27. Students using AR alone had an average score of 83.27, while those in the conventional learning group scored an average of 81.27. These learning outcomes demonstrate that computer systems learning in VHS utilizing AR and PjBL media is the most effective method to enhance student achievement. This finding is further supported by feedback questionnaires distributed to the experimental class students. Based on descriptive analysis, 58% of students expressed very positive responses toward the use of AR and PjBL, and 42% provided positive feedback. This indicates that VHS students enjoy learning computer systems using AR media integrated with PjBL.

These findings suggest that integrating AR technology with PjBL approaches can optimally improve student learning outcomes. This aligns with Vygotsky's constructivist theory, which states that learning is an active process of constructing knowledge through social interactions and a contextual learning environment. Implementing the PjBL model in an AR-based setting offers students more authentic and meaningful learning experiences. In the context of VHS, this approach is highly relevant because students are not only required to understand concepts but also to apply them in real-world projects. According to (Thomas, 2000), PjBL encourages active student engagement in completing complex tasks that simulate real-world activities. When integrated with AR, students can visualize and manipulate digital objects related to computer system materials interactively.

AR media facilitates the presentation of information through three-dimensional visualizations that enhance the understanding of abstract concepts. Previous research by (Akçayır & Akçayır, 2017) concluded that AR increases motivation, engagement, and conceptual understanding in science and technology subjects. Additionally, AR provides immediate feedback that greatly aids the learning process. These advantages support the significant results found in the experimental group in this study. Control group 1, which used AR without the PjBL approach, showed higher learning outcomes than the conventional learning group; however, this difference was not statistically significant. This indicates that using technology alone, without appropriate pedagogical strategies, is insufficient to achieve optimal learning improvements. As emphasized by (Nurhikmayati & Darhim, 2023), integrating technology in learning must be accompanied by instructional designs that promote student engagement and reflection.

The significant advantage of the experimental group can also be explained by cognitive learning theory, which highlights the importance of active information processing. When students engage in projects involving problem-solving and collaboration, they are better able to transfer and retain knowledge. Research by (Bower et al., 2014) demonstrated that AR environments designed with cognitive approaches can significantly enhance retention and conceptual understanding.

Furthermore, these findings are supported by Cheng & Tsai (2020), who reported that integrating AR into engineering education with task-based approaches significantly improves students' critical thinking skills and learning outcomes. This strengthens the argument that successful learning depends not only on technology but also on instructional strategies that foster higher-order thinking activities. In the era of Industry 5.0, critical thinking, collaboration, and problem-solving skills are essential. AR-based PjBL supports the development of these 21st-century skills by providing an adaptive and interactive learning environment. As Su (2024) stated, integrating innovative technology in education should empower students as active learners capable of facing global challenges.

Impact of AR and PjBL on Deep Learning

AR combined with PjBL has been proven to have a significant impact on deep learning in the context of computer systems education in VHS. AR creates immersive learning experiences and three-dimensional visualizations that enable students to understand abstract concepts concretely (Ibáñez & Delgado-Kloos, 2018). In this study, students in the experimental class using AR-based PjBL media showed significantly higher post-test scores than the two control groups, indicating deeper cognitive engagement. Deep learning encompasses not only memorization but also critical thinking, problem-solving, and the application of concepts in real contexts (Biggs & Tang, 2011). The PjBL approach encourages students to explore, design, and realize projects based on real-world problems relevant to computer system materials. When PjBL is combined with AR, students gain richer spatial representations of technological objects such as motherboards, processors, and other components, supporting both conceptual and applied understanding simultaneously (Chu et al., 2025; Lin et al., 2025; Novalia et al., 2025).

Recent research by (Küçük et al., 2016) emphasized that combining AR media and PjBL enhances self-regulated learning and students' sense of ownership of learning outcomes. Furthermore, AR accelerates the formation of students' mental models due to its realistic and contextual interactions (Alghamdi et al., 2020). This is evident in the significant results of the experimental class in this study, which not only understood computer system structures but were also better able to explain the functions and relationships among components. The implementation of AR-based PjBL also fosters collaborative learning activities, higher-order thinking, communication, and reflection skills, which are key pillars of deep learning (Solmaz et al., 2021). During projects, students do not merely receive information but actively construct knowledge through discussions, digital simulations, and the creation of digital artifacts. Thus, AR and PjBL create an active, authentic, and meaningful learning environment (Gong et al., 2024; Kozlova et al., 2025; Machala et al., 2022).

The advantages of AR media also support social constructivist theory, where effective learning occurs through interactions between students and media as well as among peers (Jailungka et al., 2020; Wen, 2021; Zhu et al., 2014). This active involvement creates learning experiences that impact not only cognition but also students' affect and motivation. AR makes the learning process more engaging and enjoyable, minimizing boredom when studying complex technical material such as computer systems (C. H. Chen, 2020; L. Chen et al., 2020; Jacques & Langmann, 2021; Mohammad et al., 2019). Therefore, this study's findings have important implications for vocational educators to design learning that integrates advanced technology with constructive pedagogical approaches. The integration of AR with PjBL has been proven not only to improve learning outcomes but also to create meaningful and contextual learning experiences for students.

Theoretical and Practical Implications

The findings of this study offer theoretical contributions by reinforcing social constructivist theory and cognitive learning theory, particularly within the context of technology-based VHS. The integration of AR with the PjBL approach strengthens the understanding that meaningful learning occurs when students actively construct knowledge through authentic and contextual experiences. Theoretically, these findings support the notion that technologies such as AR not only serve as visual aids but also act as cognitive mediators that deepen students' learning processes. Practically, the results guide teachers and curriculum developers in vocational schools to implement innovative learning media that combine digital visualization with project-based tasks. Educators can leverage AR to simplify abstract computer system materials while encouraging active student engagement through realistic project assignments. Thus, the application of AR-based PjBL is not only relevant for improving learning outcomes but also for developing 21st-century skills essential in the era of the Fifth Industrial Revolution (Nigam & C, 2022).

Conclusion

Based on the implementation results of AR media in the computer systems subject, it can be concluded that the application of AR-based PjBL media is significantly more effective in improving students' learning outcomes on computer systems material in VHS compared to the use of AR alone or conventional learning. The integration of AR and PjBL creates an interactive, contextual learning environment that encourages active student engagement in independently constructing knowledge. This shows that PjBL strategies combined with advanced technology can enhance the overall quality of VHS. Therefore, it is recommended that vocational educators integrate the PjBL approach with AR technology to create a more comprehensive and practical learning experience. Furthermore, teacher training related to the implementation of AR technology and project-based instructional design needs to be improved so that technology use is not partial but integrated with pedagogical strategies to achieve 21st-century learning goals.

Study Limitations

This study has several limitations that should be considered. First, the sample size was limited to three classes in a single VHS, which restricts the generalizability of the findings to broader populations or schools with different characteristics. Second, the duration of the intervention using AR-based PjBL was relatively short, making it difficult to assess the long-term effects on students' retention and higher-order thinking skills. Third, this research focused solely on cognitive learning outcomes, without exploring affective and psychomotor domains, which are also essential in vocational education. These limitations highlight the need for future research to adopt a broader scope, involving diverse school settings, more extended intervention periods, and comprehensive assessments that include affective and psychomotor aspects. Addressing these gaps will provide a deeper understanding of how AR and PjBL can holistically enhance vocational students' learning experiences.

Further Research

Future research is advised to expand the subject coverage by involving more VHS from various regions to obtain more representative results. In addition, exploring the effectiveness of AR-based PjBL media in enhancing other skills, such as collaboration, communication, and problem-solving, is necessary. Subsequent studies could also integrate various other active learning approaches, such as problem-based learning or inquiry-based learning, to compare their effectiveness. Moreover, the use of learning analytics technology can be leveraged to gain a more profound and real-time understanding of students' learning processes. Longitudinal studies are also required to assess the sustained impact of AR-based PjBL implementation on vocational students' job readiness and 21st-century skills development.

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