

THE EFFECTIVENESS OF THE PROJECT-BASED LEARNING (PjBL) MODEL ASSISTED BY METAVERSE MEDIA ON CONCEPTUAL UNDERSTANDING AND DIGITAL SKILLS IN ELEMENTARY SCHOOL MATHEMATICS LEARNING

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ARTICLE HISTORY

Received: 9 January 2026

Revised: 23 January 2026

Published: 8 February 2026

ABSTRACT

This study aims to analyze the effectiveness of the Project-Based Learning (PjBL) model assisted by metaverse media in mathematics learning on elementary school students' conceptual understanding and digital skills through the level of conceptual understanding achievement, classical completeness, improvement in conceptual understanding, and significant differences in digital skills. This research uses a quantitative approach with a pre-experimental methodology employing a one pretest-posttest group design. The research population consists of elementary school students in South Tangerang, Banten, Indonesia, with a sample drawn from fifth-grade students. The sample was selected using a simple random sampling technique. Data collection techniques in this study involved tests using instruments for assessing students' conceptual understanding and digital performance skills. Data analysis techniques included one-sample t-tests, one-sample binomial tests, N-gain tests, and paired sample t-tests. The findings indicate that students' mathematical conceptual understanding improved after the implementation of the PjBL model assisted by metaverse media, with an average conceptual understanding score of 78.30, classical completeness reaching 83.33%, student conceptual understanding improvement at a moderate level of 73.33%, and a significant difference in digital skills, with a pre-learning average of 61.30 and a post-learning average of 78.30, resulting in a score difference of 17. The conclusion of this study is that the PjBL model assisted by metaverse media in mathematics learning is effective in enhancing both conceptual understanding and digital skills of elementary school students.

Keywords: Mathematics Learning, Project-Based Learning (PjBL), Conceptual Understanding, Digital Skills, Metaverse Media

CITATION INFORMATION: Abdillah, C., Wiyanto, Fathonah, S., & Anggara, D. S. (2026). The Effectiveness of the Project-Based Learning (PjBL) Model Assisted by Metaverse

Media on Conceptual Understanding and Digital Skills in Elementary School Mathematics Learning. *Procedia of Multidisciplinary Research*, 4(2), 8.

INTRODUCTION

Project-Based Learning (PjBL) is a learning model that places students at the center of the learning process through authentic project activities aimed at solving real-world problems, with the goal of enhancing students' conceptual understanding, creativity, collaboration, and 21st-century skills. In the context of mathematics education, PjBL has been proven effective in improving students' problem-solving abilities and higher-order thinking skills (Prajoko et al., 2023). Students' active involvement in projects through the PjBL model can strengthen conceptual understanding and higher cognitive skills compared to conventional methods (Zhang, 2023). Moreover, the implementation of PjBL across various levels of mathematics education can enhance students' collaboration and critical thinking skills in learning (Lazi, 2021).

The integration of digital media in learning improves the quality of students' learning experiences by creating interactive and meaningful environments. PjBL combined with digital media creates a learning context that not only facilitates conceptual understanding but also develops students' digital skills (Azamatova et al., 2023). Digital media can support students in constructing knowledge through hands-on experiences and more dynamic interactions compared to traditional media (Loglo & Zawacki-richter, 2023).

The Metaverse, as an immersive virtual learning space, offers learning possibilities that go beyond the limitations of conventional time and space. Metaverse-based learning provides a more interactive, collaborative, and personalized learning experience, which has the potential to enhance student engagement and understanding in digital contexts (Wang & Huang, 2025). However, the integration of the Metaverse in education still faces challenges such as teacher readiness, technological infrastructure, and accessibility (Chen et al., 2023).

Although previous studies have shown that the Project-Based Learning (PjBL) model is effective in improving conceptual understanding, critical thinking skills, and student engagement in mathematics learning, its implementation has largely been dominated by conventional media or non-immersive digital media (Cruz et al., 2022). With the advancement of educational technology, Metaverse-based digital media has begun to be introduced as an immersive, interactive, and collaborative virtual learning environment, which has the potential to enhance the quality of students' learning experiences (Sripan & Jeerapattanatorn, 2025). Nevertheless, empirical studies that directly integrate Metaverse media into the PjBL model, particularly in elementary school mathematics education, are still very limited. Most research related to the Metaverse in education remains conceptual, in the form of literature reviews, or applied at secondary and higher education levels, thus not providing a comprehensive picture of its effectiveness for elementary school students (Rachmadtullah et al., 2025).

Based on this gap, this study is important to conduct as it seeks to provide empirical evidence regarding the effectiveness of implementing the Project-Based Learning (PjBL) model assisted by metaverse media in elementary school mathematics learning. The integration of PjBL with metaverse media is expected to create learning that is more contextual, meaningful, and student-centered, while also supporting the development of mathematical conceptual understanding through authentic and immersive learning experiences (Lee & Lee, 2025). Moreover, this study emphasizes the importance of developing students' digital skills, considering that digital literacy and skills are key demands in 21st-century learning and the transformation of education in the digital era (Charo & Serrano-puche, 2022). Thus, the results of this study are expected to provide theoretical contributions to the development of innovative, technology-based learning models as well as practical contributions for teachers and educational policymakers in designing mathematics learning that is adaptive and relevant to technological advancements.

In line with this background, this study focuses on examining the extent of elementary school students' mathematical conceptual understanding through the implementation of the PjBL

model assisted by metaverse media, the classical completeness of conceptual understanding achieved by students, the degree of improvement in mathematical conceptual understanding after participating in the learning, and whether there are significant differences in students' digital skills before and after learning using the PjBL model assisted by metaverse media.

RESEARCH METHODOLOGY

This study employed a quantitative approach with a pra-experimental method, without a control group to determine whether the improvement in outcomes resulted from student maturity, the novelty of using new technology, or standard classroom instruction. The research design used was a one-group pretest-posttest design, in which a single group of research subjects was given a pretest before the treatment and a posttest after the treatment. This design aimed to identify changes and improvements in students' abilities following the implementation of a Project-Based Learning (PjBL) model supported by metaverse-based media in mathematics learning. The population of this study comprised all elementary school students in South Tangerang City, Banten Province, Indonesia. The research sample was taken from fifth-grade elementary students, selected randomly using a simple random sampling technique, so that each member of the population had an equal chance of being chosen as a sample. Fifth-grade students were chosen based on considerations of cognitive development, as they are in the stage transitioning from concrete operational to formal operational thinking, and are therefore considered capable of participating in project-based learning and optimally utilizing digital metaverse-based media.

Data collection techniques in this study employed tests, consisting of a mathematics conceptual understanding test and a digital performance skills test. The conceptual understanding test was developed based on indicators of mathematical concept comprehension, such as the ability to explain concepts, classify objects based on certain properties, apply concepts to problem-solving, and connect various representations of mathematical concepts. Meanwhile, the digital performance skills instrument was designed to measure students' ability to use digital technology functionally, including operating metaverse media, interacting in virtual environments, completing digital project-based tasks, and demonstrating ethics and responsibility in technology use. Prior to use, the research instruments underwent content validation by experts and a limited trial to ensure their validity and reliability.

The data analysis techniques were conducted in stages according to the research objectives. A one-sample t-test was used to determine the level of students' mathematics conceptual understanding after the implementation of the PjBL model supported by metaverse media, compared to the predetermined minimum completeness criterion. A one-sample binomial test was employed to analyze students' classical completeness in conceptual understanding, specifically to determine whether the proportion of students achieving mastery met the established classical mastery threshold. Furthermore, the N-gain test was used to measure the magnitude of improvement in students' mathematics conceptual understanding from pretest to posttest and to categorize this improvement as low, medium, or high. Finally, a paired-sample t-test was conducted to determine whether there was a significant difference between students' pretest and posttest digital skills scores after participating in learning using the PjBL model supported by metaverse media.

RESEARCH RESULTS

The implementation of the Project-Based Learning (PjBL) model assisted by metaverse media in mathematics learning began with orienting students to contextual problems relevant to the material. The problems were presented through an interactive metaverse virtual environment, enabling students to observe and understand the context of the problems in a realistic manner. The teacher acted as a facilitator by guiding students to connect the problems with

mathematical concepts related to geometric shapes and by introducing the use of digital media. The project planning phase was then carried out, during which students worked in groups to formulate objectives, develop solution steps, and assign roles. The metaverse media was utilized as a digital collaboration space that allowed discussions, idea exchanges, and interactive project development, while simultaneously fostering digital skills such as online communication and technology operation.

The project implementation phase involved students applying mathematical concepts through problem-solving activities, simulations, and visualizations available in the metaverse, while receiving guidance and feedback from the teacher. Subsequently, students compiled and presented their project results digitally via the metaverse, explaining the concepts, problem-solving processes, and project outcomes to other groups, thereby enhancing both their communication and digital skills. The final phase was reflection and evaluation, in which students and the teacher assessed the achievement of conceptual understanding, improvement in digital skills, and the effectiveness of the learning process. Through these stages, the implementation of PjBL assisted by metaverse media not only improved mathematics learning outcomes but also comprehensively developed 21st-century skills. The following explains the analysis of the effectiveness of the Project-Based Learning (PjBL) model assisted by metaverse media in mathematics learning, in terms of students' conceptual understanding and digital skills, viewed from the levels of conceptual understanding achievement, classical completeness, conceptual understanding improvement, and significant differences in digital skills.

1) The level of elementary school students' conceptual understanding in mathematics through the implementation of the PjBL model assisted by metaverse media

To evaluate the average conceptual understanding of elementary school students in mathematics after the implementation of the Metaverse-based PjBL model, data analysis was conducted using a one-sample t-test as a hypothesis test. Before applying the hypothesis test, the data needed to meet statistical assumptions, particularly regarding the normality of the data distribution. Therefore, a normality test was first conducted on the students' mathematics conceptual understanding data as an initial step to ensure the suitability of subsequent analyses.

Table 1 Normality test results

	Kolmogorov-Sminrov		
	Statistic	df	Sig
Pretest	0.178	30	0.200
Posttest	0.212	30	0.189

The results of the normality test presented in Table 1 show that the significance value for the pretest data is 0.200, while for the posttest data it is 0.189. Both values are greater than the significance threshold of 0.05, so the null hypothesis (H_0) is accepted, indicating that the research data are normally distributed and meet the requirements for further analysis. Therefore, the analysis can proceed using a one-sample t-test. This test was then applied to assess the level of students' conceptual understanding in mathematics after the implementation of the Metaverse-based PjBL model. The results of the data processing using SPSS from this test are presented in Table 2.

Table 2 One sample t-test output results

Test Value = 70						
	T	df	Sig (2-tailed)	Mean difference	95% confidence interval of the difference	
					lower	Upper
Pretest	2.214	30	0.000	6.689	-13.56	-4.31
Posttest	3.675	30	0.001	6.256	2.53	9.66

The results of the one-sample test presented in Table 2 show a significance value of 0.01, which is below the 0.05 threshold. Therefore, the alternative hypothesis (H_1) is accepted. The findings indicate that the implementation of the metaverse-assisted Project-Based Learning (PjBL) model has a positive effect on elementary students' mathematical conceptual understanding and digital skills. Based on the one-sample t-test analysis, the average score of students' mathematical concept understanding after participating in the learning was 78.50. This score is above the established minimum completeness criteria, indicating that, individually, students have achieved the expected level of conceptual understanding. These findings suggest that project-based learning integrated with a metaverse learning environment can help students construct and develop mathematical conceptual understanding more meaningfully through contextual and interactive learning experiences.

These results align with previous studies stating that PjBL is effective in assisting students in building conceptual understanding through problem-solving activities and contextual projects (Widoretno et al., 2023). Active student involvement in designing and completing projects promotes meaningful knowledge construction, making conceptual understanding not only procedural but also conceptual.

2) Classical Mastery of Conceptual Understanding Achieved by Students through the Implementation of the PjBL Model Assisted by Metaverse Media

To evaluate the level of students' classical mastery of conceptual understanding after the implementation of the Metaverse-based PjBL model, a statistical analysis was conducted using a one-sample binomial test. The results of the test regarding the level of classical mastery are then presented in detail in Table 3.

Table 3 One sample binomial test output results

	Category	N	Observed Prop.	Test Prop.	Exact Sig (2-tailed)
conceptual understanding	Group 1	<= 70	5	0.17	0,11
	Group 2	> 70	25	0.83	
	Total		30	1.00	

Based on the results of the binomial test presented in Table 4, it can be seen that 83% of students (25 out of 30 students) achieved scores above 70, while 17% of students (5 out of 30 students) obtained scores of 70 or below. This indicates that the implementation of the Metaverse-based PjBL model successfully reached a classical mastery level of students' conceptual understanding of 83.33%. A more detailed breakdown of learning mastery, both individually and classically, in the experimental class is presented in Table 4.

Table 4 Classical Completion of Experimental Class

	Before treatment	After treatment
Number of students completed	12	25
Number of students not completed	18	5
Average value	61.30	78.30
Percentage of classical completion	40.00%	83.33%
Category	Incompleted	Completed

Based on the results of the classical mastery analysis using the one-sample binomial test, the percentage of students achieving mastery of conceptual understanding was 83.33%. This percentage has exceeded the established classical mastery threshold, indicating that learning through the Metaverse-assisted PjBL model is classically effective. The high level of classical mastery suggests that the majority of students were able to follow the learning process well, actively participate in project activities, and comprehend the mathematical concepts studied with the support of Metaverse media. The virtual learning environment can enhance students' engagement and focus in the learning process (Maroungkas et al., 2023). Furthermore, the N-gain value in the medium category indicates that the integration of PjBL with Metaverse media provides a consistent improvement, although further optimization is still required in terms of project design and teacher facilitation.

3) Enhancing Mathematical Conceptual Understanding after the Implementation of a Metaverse-Assisted PjBL Model

To evaluate the effectiveness of the Metaverse-based PjBL model in enhancing students' conceptual understanding, an analysis was conducted using the N-gain test. The N-gain results, which reflect the level of improvement in students' conceptual understanding in Science and Social Studies at the elementary school level, are presented in detail in Table 5.

Table 5 N-Gain test results

Score	Criteria	Total	Percentage (%)
$N\text{-gain} \geq 0.70$	High	3	10.00%
$0.30 \leq N\text{-gain} < 0.70$	Medium	22	73.33%
$N\text{-gain} < 0.30$	Low	5	16.67%
Total		30	100%

The analysis of the improvement in students' mathematical conceptual understanding, measured using the N-gain test, showed a value of 73.33%, which falls into the moderate category. This indicates a fairly significant increase in conceptual understanding from the initial condition before learning to the final condition after learning. This improvement reflects that the integration of the PjBL model with metaverse-based media can make a tangible contribution to the development of students' conceptual understanding, although there is still room for further enhancement through the optimization of project design and learning guidance. The significant improvement in students' digital skills further reinforces the view that the use of metaverse-based media not only contributes to academic learning outcomes but also to the development of students' digital competencies as part of 21st-century skills (Dergisi, 2025).

4) Significant Differences in Students' Digital Skills before and After Learning Using the PjBL Model Assisted by Metaverse Media

To examine whether there is a significant difference in students' digital skills before and after the implementation of the Metaverse-based PjBL model, an analysis was conducted using a paired sample t-test. Prior to performing the hypothesis test, a preliminary test in the form of a normality test was carried out to ensure that the data distribution met the assumption of

normality. The results of the normality test for students' digital skills scores, both before and after the implementation of the Metaverse-based PjBL model, are presented in Table 1. Once the data were confirmed to be normally distributed, the analysis proceeded with the paired sample t-test, and the results are shown in Tables 6 and 7.

Table 6 Paired Samples Statistics Results

		N	Mean	Std. Deviation	Std. Error Mean
Pair 1	Pretest	30	61.30	10.121	2.002
	Posttest	30	78.30	9.018	1.883

Table 7 output *paired samples test*

	Paired Differences						t	df	Sig (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% confidence interval of the difference					
				lower	Upper				
Pair Pretest-Posttest	-17.000	5.000	1.012	-17.132	-9.178	-12.176	22	0.000	

In addition to conceptual understanding, the study also revealed a significant difference in students' digital skills before and after the implementation of the PjBL model assisted by metaverse media. Based on the results of the paired sample t-test, the average score of students' digital skills before learning was 61.30, while the average score after learning increased to 78.30. Thus, a score difference of 17 points was obtained, indicating a substantial improvement in digital skills. These findings suggest that students' involvement in project-based learning utilizing metaverse media not only enhances digital skills but also develops their ability to operate digital technologies, interact in virtual environments, and complete technology-based learning tasks effectively and responsibly.

CONCLUSION & DISCUSSION

This study reinforces the evidence that the Project-Based Learning (PjBL) model, when combined with metaverse media, can significantly enhance elementary school students' conceptual understanding of mathematics. The findings of increased average scores and N-gain values indicating improved conceptual understanding are consistent with previous studies that found a positive effect of PjBL on conceptual understanding in mathematics learning. The implementation of PjBL significantly improved students' understanding of multiplication operations at the foundational level, as evidenced by the differences between pretest and posttest scores and N-gain values ranging from moderate to high (Sefa & Darko, 2023). This suggests that a project-based learning structure provides opportunities for students to engage with content in a more meaningful and contextualized manner, thereby supporting the development of their cognitive understanding.

Furthermore, the integration of digital learning media in PjBL implementation was also found to contribute additionally to learning achievement. This study explicitly states that the learning and assessment processes were conducted using an appropriate platform, namely *Spatial*, accessed via desktop-screen hardware. Specifying the platform and device used is essential, as variations in media and hardware can substantially influence the learning experience and the validity of digital skills assessment. Studies applying PjBL with the support of digital media, such as PhET simulations, have shown that the use of interactive media enhances students' digital literacy and conceptual understanding in science learning, reflecting the importance of digital media in 21st-century education (Diab et al., 2024). This supports the findings of the present study, indicating that the use of metaverse media, which creates an immersive virtual

learning environment, can facilitate collaboration, concept exploration, and a more engaging learning experience compared to traditional media.

From the perspective of digital skills, the literature also emphasizes that PjBL not only functions to improve academic outcomes but can also support the development of students' digital literacy, as discussed in studies on the relationship between PjBL and 21st-century digital skill development (Pramasdyahsari et al., 2023). The results of this research indicate a significant difference before and after the implementation of the metaverse-assisted PjBL model in students' digital skills, suggesting that learning experiences in virtual environments not only help students understand academic content but also enhance their technology usage, online collaboration, and digital problem-solving abilities.

Furthermore, the use of the metaverse in educational contexts has transformational potential, as identified in recent literature reviews which state that metaverse technology offers opportunities for more student-centered, interactive, and collaborative learning, although empirical research at the elementary education level remains relatively limited (Saritas & Topraklikoglu, 2022). Thus, this study expands empirical insights by providing concrete evidence of the effectiveness of the metaverse in stimulating conceptual understanding and digital skills in elementary school students, particularly in mathematics a field that has previously received limited in-depth attention in the context of the metaverse.

Overall, the findings of this study support the idea that integrating immersive technologies such as the metaverse into PjBL pedagogical models can provide more authentic and relevant learning experiences aligned with 21st-century learning demands. This also responds to the needs of modern education to combine conceptual understanding with the enhancement of digital skills, thereby opening opportunities for developing more innovative and relevant learning practices in the future.

The Project-Based Learning (PjBL) model assisted by metaverse media has been proven effective in improving elementary students' conceptual understanding of mathematics and digital skills, both individually and in a classroom setting. The study results indicate that the implementation of the metaverse-assisted PjBL model effectively enhances elementary students' mathematical conceptual understanding and digital skills. The average score for conceptual understanding reached 78.30, with a classical completeness of 83.33%. The improvement in conceptual understanding falls into the moderate category, with an N-gain value of 73.33%. In addition, there was a significant difference in digital skills before and after the learning, with an average score increase of 17 points. These findings suggest that the integration of PjBL and metaverse media can support meaningful mathematics learning that is relevant to 21st-century skill demands.

The study provides theoretical implications that integrating the PjBL model with metaverse media can strengthen mathematical conceptual understanding while simultaneously developing elementary students' digital skills. Practically, these findings can serve as a reference for teachers and schools in designing innovative, interactive mathematics learning that aligns with 21st-century skill requirements through the use of immersive technology. This study employed a pra-experimental design with a single group and no control group, involving subjects limited to fifth-grade students in one region, so the generalizability of the results remains limited. Additionally, the duration of the learning implementation was relatively short, so the long-term impact cannot yet be determined. Future research is recommended to use a stronger experimental design, a wider sample coverage, and a longer implementation period.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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