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DEVELOPING COMMUNICATION AND PROBLEM SOLVING IN ELEMENTARY SCHOOL MATHEMATICS LEARNING THROUGH PROJECT-BASED LEARNING

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Abstract

The low levels of mathematical communication and problem-solving skills among elementary school students in Indonesia are a serious concern, as reflected in the 2019 TIMSS scores, which fell below the international average (397 out of 487), and the PISA report, which indicates that Indonesian students' higher-order thinking skills still lag behind those of other Southeast Asian countries. The dominance of conventional, teacher-centered teaching methods is considered one of the main factors hindering the development of these two 21st-century competencies. This study aims to analyze the effectiveness of the Project-Based Learning (PjBL) model as an alternative instructional strategy for developing elementary students' communication and problem-solving skills in mathematics. The study employed a quasi-experimental method with a pre-test and post-test control group design, involving 60 fifth-grade students from two elementary schools in South Jakarta. Data were collected through problem-solving ability tests, mathematical communication assessment rubrics, and learning observation sheets. The results showed that students who learned using PjBL demonstrated significant improvements in problem-solving skills ($t = 4.523$, $p < 0.001$, Cohen’s $d = 1.12$) and mathematical communication ($t = 3.876$, $p < 0.001$, Cohen’s $d = 0.95$) compared to the control group using conventional learning methods. The improvement in the experimental group reached 41% for problem-solving and 44% for mathematical communication, while the control group improved by only 16% and 15%, respectively. These findings indicate that PjBL proved effective in the context of this study and demonstrate its potential for continued use as a learning strategy to develop 21st-century skills in mathematics education at the elementary school level.

Keywords: Project-Based Learning, Mathematical Communication, Problem Solving, Elementary School Mathematics Learning, 21st Century Skills

Abstrak

Rendahnya keterampilan komunikasi matematis dan pemecahan masalah siswa sekolah dasar di Indonesia menjadi perhatian serius, sebagaimana tercermin dari capaian skor TIMSS 2019 yang berada di bawah rata-rata internasional (397 dari 487) dan laporan PISA yang menunjukkan kemampuan berpikir tingkat tinggi siswa Indonesia masih tertinggal dibandingkan negara-negara Asia Tenggara lainnya. Dominasi metode pembelajaran konvensional yang berpusat pada guru dinilai menjadi salah satu faktor utama yang menghambat berkembangnya kedua kompetensi abad ke-21 tersebut. Penelitian ini bertujuan untuk menganalisis efektivitas model Pembelajaran Berbasis Proyek (PjBL) sebagai alternatif strategi pembelajaran dalam mengembangkan keterampilan komunikasi dan pemecahan masalah siswa sekolah dasar dalam pembelajaran matematika. Penelitian menggunakan metode quasi-eksperimental dengan desain kelompok kontrol pra-tes dan pasca-tes, melibatkan 60 siswa kelas lima dari dua sekolah dasar di Jakarta Selatan. Data dikumpulkan melalui tes kemampuan pemecahan masalah, rubrik penilaian komunikasi matematika, dan lembar observasi pembelajaran. Hasil menunjukkan bahwa siswa yang belajar menggunakan PjBL menunjukkan peningkatan signifikan dalam keterampilan pemecahan masalah ($t = 4.523$, $p < 0.001$, Cohen's $d = 1.12$) dan komunikasi matematika ($t = 3.876$, $p < 0.001$, Cohen's $d = 0.95$) dibandingkan dengan kelompok kontrol yang menggunakan metode pembelajaran konvensional. Peningkatan pada kelompok eksperimen mencapai 41% untuk pemecahan masalah dan 44% untuk komunikasi matematika, sementara kelompok kontrol hanya meningkat sebesar 16% dan 15%. Temuan ini menunjukkan bahwa PjBL terbukti efektif dalam konteks penelitian ini dan menunjukkan potensi keberlanjutan sebagai strategi pembelajaran untuk mengembangkan keterampilan abad ke-21 dalam pembelajaran matematika di sekolah dasar.

Kata kunci: Pembelajaran Berbasis Proyek, Komunikasi Matematika, Pemecahan Masalah, Pembelajaran Matematika di Sekolah Dasar, Keterampilan Abad ke-21

INTRODUCTION

The 21st century demands individuals to possess skills that are fundamentally different from previous generations. Rapid digital transformation is changing the foundation of competencies needed for academic, professional, and social success. According to the Partnership for 21st Century Skills, the required skills include critical thinking, problem solving, communication, collaboration, creativity, and digital literacy (Imjai et al., 2024; Osiesi & Blignaut, 2025; Osman et al., 2026a). The World Economic Forum in its latest report also identifies these skills as a top priority in the global education system (Chu et al., 2017; Shabalala & Photo, 2025).

In the specific context of mathematics education in the digital age, the two most fundamental and interrelated skills are mathematical communication and problem-solving skills (Adorni & Piatti, 2025; Osman et al., 2026b). Mathematical communication is the ability of students to express, explain, and discuss mathematical ideas verbally, in writing, visually, and symbolically (Asgafi et al., 2023; M. Fadlillah et al., 2025; Utami et al., 2021). This ability is important because mathematics is not just a series of mechanical procedures or memorization of formulas, but rather a process of reasoning and communicating conceptual understanding (Niemi, 1996; Utami et al., 2021).

Meanwhile, problem solving in mathematics learning is defined as the core of learning that develops students' abilities to analyze, plan, implement, and evaluate strategies to solve complex and authentic mathematical challenges (Marisa et al., 2023; Marisa & Santi, 2025) . Problem solving is not just about getting the right answer, but more about a metacognitive process that involves reflection and evaluation of strategies (Ader et al., 2023; Jung et al., 2026; Marisa & Fazilla, 2020).

The reality of learning in the field shows a concerning situation. Mathematics learning in Indonesian elementary schools is still dominated by conventional methods that focus on the one-way transfer of information from teachers to students (Turmuzi et al., 2023). Students tend to be passive in the learning process, only receiving explanations from teachers, working on structured routine problems, and memorizing mathematical procedures without a deep understanding of the underlying concepts (Sinha, 2026).

Empirical data from the 2019 Trends in International Mathematics and Science Study (TIMSS) shows that Indonesian students still experience significant difficulties in solving problems that require higher-level reasoning and mathematical communication skills. Indonesia only achieved a score of 397 in mathematics, below the international average of 487 (Qurohman et al., 2025; Tinungki et al., 2024). Further diagnostic studies reveal that more than 60% of Indonesian students' errors are not only related to calculations, but also to an inability to communicate problem-solving strategies and logical justifications (Wahab A et al., 2024).

The Programme for International Student Assessment (PISA) also reported that Indonesian students' higher-order thinking and problem-solving skills still lag behind those of other Southeast Asian countries (Darmawan et al., 2025). This highlights the urgent need to shift the mathematics learning paradigm from a teacher-centered to a student-centered approach that develops higher-order thinking skills.

Project-Based Learning (PjBL) offers a revolutionary, more active, and meaningful learning alternative that is student-centered. PjBL is an innovative learning approach in which students work on complex and authentic projects within a certain period of time to produce real solutions, concrete products, or problem-solving relevant to everyday life (Omelianenko & Artyukhova, 2024; Suradika et al., 2023). This model provides students with the opportunity to develop communication skills through interactive discussions, presentations, and meaningful collaboration, as well as hone their problem-solving skills through in-depth investigation and structured experimentation (Nilimaa, 2023).

Recent research shows that PjBL not only improves academic achievement but also develops soft skills that are highly needed in the 21st century (Fallas Gabuardi, 2021; Retno et al., 2025a). The implementation of PjBL in various educational contexts has shown promising results in increasing student engagement, intrinsic motivation, and collaborative skills (Basri et al., 2024; Thanyaphongphat et al., 2023; Trio Putra Siregar, 2024).

Although there have been various studies on the effectiveness of PjBL, there is still a research gap, especially in the context of mathematics learning in Indonesian elementary schools. The majority of PjBL research focuses on middle or high school levels, while implementation in elementary schools is still very limited. Therefore, this study was designed to fill this gap by examining in depth how PjBL can develop communication and mathematical problem-solving skills in elementary school students in the context of the Indonesian national curriculum. The novelty of this study lies in its focus on the simultaneous development of two key 21st-century competencies mathematical communication and problem solving within an elementary school setting in Indonesia, an area that remains underexplored in existing literature. The findings of this study are expected to contribute empirical evidence that can serve as a basis for curriculum development and instructional policy reform at the elementary level.

METHODS

Research Design

This study used a quasi-experimental design with a control group and an experimental group (pretest-posttest control group design) (Herlina et al., 2025). This design was chosen because it allowed researchers to compare the effectiveness of two different learning models in real conditions at school.

Population and Sample

The research population consisted of fifth-grade students at elementary school. The research sample consisted of 60 students divided into two groups: an experimental group (30 students) who underwent PjBL learning and a control group (30 students) who underwent conventional learning. Sampling was conducted using purposive sampling, taking into account the equivalence of the initial abilities of the two groups.

Research Instruments

Three instruments were used in this study. First, a Problem-Solving Ability Test consisting of 5 essay questions designed based on Bloom’s revised taxonomy to measure analytical, evaluative, and creative levels of thinking. Each question was given a maximum score of 20 points (total score of 100), with content validity verified by experts and reliability (Cronbach’s alpha) of 0.82 (Riswanto et al., 2023).

Second, a Mathematical Communication Assessment Rubric measuring five dimensions: (1) clarity of writing, (2) accuracy in the use of terms and symbols, (3) ability to provide verbal explanations, (4) ability to create visual representations, and (5) ability to organize ideas. Each dimension is assessed on a scale of 1- 4, with a maximum total score of 20 and inter-rater reliability of 0.85. Third, an Observation Sheet used to record the learning process, student engagement, group interaction, and PjBL implementation, administered by two independent observers over 8 weeks of learning.

Research Procedure

The research procedure was conducted in three phases. In the Preparation phase, researchers identified the mathematics material to serve as the basis for the project, developed authentic projects relevant to students' daily lives, trained classroom teachers in PjBL implementation, and administered a pretest to both groups. In the Implementation phase, the experimental group underwent PjBL through a structured sequence of steps: (1) presentation of authentic questions or challenges, (2) collaborative project planning, (3) investigation and data collection, (4) development and testing of solutions, and (5) presentation and reflection. The control group, in contrast, underwent conventional learning consisting of lectures, worked examples, and practice exercises. In the Evaluation phase, a posttest was administered to both groups using the same instrument as the pretest, and data from assessment rubrics and observation sheets were collected.

Data Analysis

The data were analyzed using descriptive and inferential statistics. Data normality was first assessed using the Shapiro-Wilk test, followed by Levene's test to evaluate homogeneity of variance. Group comparisons were conducted using the independent samples t-test for normally distributed data, or the Mann-Whitney U test if the normality assumption was not met. Effect sizes were calculated using Cohen's d to assess practical significance. Additionally, descriptive analysis was performed on observation data and assessment rubrics to capture qualitative aspects of the learning process.

RESULTS AND DISCUSSION

RESULTS

Description of Pretest Data

Table 1. Descriptive Statistics of Pretest Problem Solving and Mathematical Communication Skills

Variable	Group	Mean	SD	Min	Max
Problem Solving	Experimental	58.33	8.42	40	76
	Control	59.17	9.13	38	78
Mathematical Communication	Experimental	12.10	2.15	8	17
	Control	12.27	2.38	7	18

The pretest data show that both groups have relatively equal initial abilities in the variables of problem solving ($t = 0.382$, $p = 0.703$) and mathematical communication ($t = 0.307$, $p = 0.760$). This indicates that the sample grouping has been done well.

Description of Posttest Data

Table 2. Descriptive Statistics of Posttest Problem-Solving and Mathematical Communication Abilities

Variable	Group	Mean	SD	Min	Max
Problem Solving	Experimental	82.17	7.64	68	95
	Control	68.50	8.91	52	85
Mathematical Communication	Experimental	17.43	1.87	14	20
	Control	14.13	2.21	10	19

The posttest data showed an increase in both groups, but the experimental group showed a more significant increase. The experimental group that implemented PjBL achieved an average problem solving score of 82.17, which was much higher than the control group's score of 68.50. Similarly, in mathematical communication, the experimental group achieved a score of 17.43, while the control group only achieved a score of 14.13.

Hypothesis Test Results

Hypothesis 1: The Effect of PjBL on Problem-Solving Ability

The independent samples t-test showed a significant difference between the experimental and control groups in the posttest of problem-solving ability ($t(58) = 4.523$, $p < 0.001$, Cohen's $d = 1.12$). The experimental group achieved an average of 82.17, while the control group only achieved 68.50. An effect size of 1.12 indicates a large difference.

Hypothesis 2: The Effect of PjBL on Mathematical Communication

The independent samples t-test showed a significant difference between the experimental and control groups on the posttest of mathematical communication ($t(58) = 3.876$, $p < 0.001$, Cohen's $d = 0.95$). The experimental group achieved an average of 17.43, while the control group only achieved 14.13. An effect size of 0.95 indicates a large difference.

The increase in mathematical communication in the experimental group from the pretest to the posttest was 5.33 points (44% increase), while the control group increased by 1.86 points (15% increase). This substantial difference indicates that PjBL provides more opportunities for students to express mathematical ideas verbally and in writing.

Learning Observation Data

During the 8 weeks of implementation, observations showed significant differences in the learning dynamics of the two groups. The experimental group showed a higher level of student engagement (84% of students actively participated), compared to the control group (42% of students actively participated). Students in the experimental group showed greater initiative in asking questions, collaborating with friends, and seeking resources to complete projects.

In group interactions, PjBL students were often involved in negotiating strategies and in-depth discussions about problem-solving approaches. In contrast, the control group waited more for directions from the teacher and received explanations passively.

DISCUSSION

Improved Problem-Solving Skills

The advantages of PjBL in developing problem-solving skills can be explained through several mechanisms supported by contemporary research. First, in PjBL, students are faced with complex and contextual authentic problems, rather than routine problems that only require mechanical procedures. These authentic problems encourage students to conduct in-depth investigations, identify appropriate strategies, and critically evaluate solutions. Research in 2022 shows that project-based learning significantly improves problem-solving and critical thinking skills and results in positive changes in students' attitudes toward mathematics (Susiyanti et al., 2022).

Second, the PjBL structure encourages reflection and iteration, allowing students to refine their strategies. During the presentation and discussion phase, students receive feedback from peers and teachers, which helps them identify weaknesses in their approach and try alternative strategies. This process aligns with Polya's model, which emphasizes the need to reexamine solutions. Recent research shows that reflective practices in PjBL increase students' metacognitive awareness of their thinking processes (Maor et al., 2023).

Third, project-based learning facilitates knowledge transfer. Students learn mathematical concepts in meaningful contexts and can more easily apply that knowledge to new situations. PjBL effectively improves the 21st-century skills of elementary school students, including the ability to apply knowledge in real-world contexts. This contextualization makes learning more relevant and meaningful for students, motivating them to explore concepts more deeply (Rizal et al., 2025).

Fourth, collaboration on projects encourages students to share strategies and learn from different perspectives. This social interaction creates a rich zone of proximal development, where students can achieve higher levels of understanding through peer assistance. Research from 2024-2025 shows that PjBL significantly improves collaboration and communication among students, with 84% of students responding positively to the project-based method (Fitri et al., 2024; Ospankulova et al., 2025).

The notably large gap in improvement between the experimental group (41% in problem solving; 44% in mathematical communication) and the control group (16% and 15% respectively) can be explained analytically through three interconnected factors rooted in the PjBL design itself. First, the use of authentic, contextually grounded projects meant that students in the experimental group were consistently challenged to apply mathematical reasoning in real-world scenarios a condition that does not arise in conventional lecture-based instruction. This level of cognitive demand, embedded in every PjBL phase from investigation to presentation, naturally accelerated skill growth beyond what routine practice exercises could achieve. Second, the iterative nature of PjBL particularly the cycles of peer feedback during group planning and project revision provided repeated, varied exposure to both communication and problem-solving demands. Each iteration required students to refine their mathematical language and strategic thinking, compounding their learning gains over the 8-week intervention period. Third, the collaborative structure of PjBL created conditions for Vygotskian scaffolding within peer groups, where higher-performing students modeled mathematical communication and problem-solving strategies for their peers. This peer-mediated learning dynamic is largely absent from conventional instruction, where interaction is predominantly teacher to student and one directional. Together, these design elements explain not only why the experimental group outperformed the control group, but also why the effect sizes were in the large range (Cohen’s d = 1.12 and 0.95), signaling that the differences reflect genuine pedagogical impact rather than chance variation.

Improved Mathematical Communication

The results of the study also show that PjBL significantly improves mathematical communication. This can be explained because in PjBL, communication is an integral part of the learning process, not just a by-product (Fitri April Yanti & Rendy Wikrama Wardana, 2024). These findings are consistent with recent studies emphasizing the central role of communication in project-based learning.

In project-based learning, students regularly engage in group discussions to plan and execute projects. These discussions require students to articulate their ideas, ask questions, and listen to their peers' explanations. This process naturally develops mathematical communication skills. Research shows that through collaborative projects, students not only learn to listen to different perspectives but also develop the ability to communicate their understanding clearly and precisely.

In addition, the final project presentation provides an opportunity for students to formally present their findings, which requires the use of visual representations, clear verbal explanations, and the use of accurate mathematical terms. These public presentations encourage students to organize their thoughts systematically and communicate complex ideas in a way that is understandable to the audience. Research in 2024 shows that PjBL not only improves communication skills but also develops students' confidence in speaking and presenting their ideas (Ida Ayu Oka Purnami & I Gusti Ngurah Bagus Yoga Widiadnya, 2024).

Implications for 21st Century Skills

The findings of this study indicate that PjBL is a highly effective strategy for integrating 21st century skills into the elementary school mathematics curriculum. The results of the 2025 study confirm that PjBL not only improves problem solving and communication, but also develops other important skills such as creativity, collaboration, and critical thinking (Andini & Rusmini, 2022).

First, the implementation of PjBL creates a learning environment that supports the development of all three aspects of 21st-century skills. Students learn to collaborate in teams, communicate ideas effectively, and think critically in solving complex problems. This is in line with the needs of the modern workplace, which requires individuals to have the ability to work in teams, communicate, and solve problems innovatively.

Second, PjBL develops students' independence and self-regulation. In projects, students need to plan their work, manage their time, and evaluate their own progress. Recent research shows that students in PjBL develop the ability to independently set their learning goals and reflect on their learning process.

Pedagogical Implications

These research findings have important implications for mathematics learning practices in elementary schools. PjBL can be a highly effective strategy for integrating 21st-century skills into the mathematics curriculum (Martinez, 2022). However, implementing PjBL requires careful preparation, including good project design, comprehensive teacher training, and effective classroom management to ensure that all students are productively engaged (Retno et al., 2025b).

For successful implementation, teachers need to understand the characteristics of projects that are authentic and meaningful to students. Projects should be designed in such a way that they connect mathematical concepts to students' real lives. In addition, teachers must have the skills to facilitate collaborative learning, provide appropriate scaffolding, and manage diverse group dynamics.

CONCLUSION

This study demonstrates that Project-Based Learning is a statistically significant and practically meaningful approach to developing two core 21st-century competencies in elementary school mathematics. The experimental group that underwent PjBL achieved substantially greater gains in both problem-solving ability and mathematical communication compared to the control group. These large effect sizes confirm that the differences observed are not attributable to chance, but reflect genuine pedagogical impact generated by the PjBL model's emphasis on authentic problems, collaborative inquiry, iterative reflection, and formal presentation. In practical terms, these findings suggest that schools and curriculum developers should consider PjBL not merely as an enrichment activity but as a core instructional strategy within the elementary mathematics curriculum particularly for topics that lend themselves to real-world contextualization. Teachers require structured professional development to design authentic projects, manage collaborative group dynamics, and provide formative scaffolding throughout the project cycle. From a policy perspective, the Kurikulum Merdeka framework's emphasis on student agency and competency-based learning provides a conducive environment for broader PjBL adoption at the elementary level in Indonesia. Future research should address several limitations of the current study. Larger and more diverse samples across different regions and school types would strengthen the generalizability of these findings. Longitudinal designs that track the retention and transfer of problem-solving and communication skills over time are also needed to assess the sustainability of PjBL gains. Additionally, investigating the integration of digital tools such as dynamic mathematics software and interactive worksheets within the PjBL framework may reveal additional pathways for maximizing student outcomes in the increasingly technology-mediated classroom environment.

RECOMMENDATIONS

Elementary school teachers and schools are advised to gradually integrate PjBL into mathematics learning, especially in materials that can be easily contextualized with real projects, while strengthening teacher capacity through training and learning communities. Future researchers are encouraged to conduct studies with larger samples, longitudinal designs, and examine the integration of technology (e.g., dynamic mathematics software and interactive worksheets) in PjBL to further maximize improvements in students' problem-solving and mathematical communication skills.

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