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Project-Based Learning in the Independent Curriculum: Improving Secondary Students' Mathematical Problem-Solving Skills

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ABSTRACT

This study aims to examine the effectiveness of Project-Based Learning (PjBL) in the context of the Independent Curriculum to improve mathematics problem-solving skills in junior high school (SMP) students. The Independent Curriculum emphasizes independent and contextual learning, encouraging the application of methods that can develop students' critical and creative thinking skills. The research method uses a mixed-methods approach with a quasi-experimental design and qualitative deepening. A total of 70 junior high school students from two classes were selected purposively; one class as an experimental group that followed PjBL-based mathematics learning, and one control class with conventional learning methods. Quantitative data was collected through math problem-solving tests before and after the intervention, while qualitative data was obtained from classroom interviews and observations to explore student motivation and engagement. Statistical analysis showed a significant improvement in problem-solving ability in the experimental group compared to the control group. In addition, qualitative results revealed that PjBL increases students' learning motivation, active engagement, and collaborative ability in solving complex mathematical problems. This study confirms that the integration of PjBL in the Independent Curriculum is effective in improving mathematical problem-solving skills holistically. The study presents practical implications and recommendations for the development of innovative and contextual mathematics learning in secondary schools.

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1. INTRODUCTION

Mathematics education at the junior high school (SMP) level holds a crucial role in developing students' higher-order thinking skills—particularly critical thinking, creativity, and problem-solving abilities. These competencies serve as a foundation not only for mastering mathematical concepts but also for addressing real-life challenges in a rapidly evolving scientific and technological world (Sari &

Juandi, 2023; Pratiwi & Widjajanti, 2020). Mathematical problem-solving is considered the "core of mathematics learning," reflecting students' ability to reason logically, formulate strategies, and apply concepts to non-routine situations. However, empirical studies consistently reveal that many Indonesian junior high school students still struggle with these competencies, resulting in low learning motivation, fragmented understanding, and unsatisfactory academic performance. This issue underscores the urgency of transforming instructional approaches to be more engaging, contextual, and student-centered.

Over the last decade, there has been a paradigm shift in mathematics instruction—from teacher-centered, rote-based methods toward constructivist, inquiry-driven learning models that promote student autonomy and contextual understanding (Hoidn & Reusser, 2020; Sharma, 2024). Traditional approaches often emphasize procedural fluency over conceptual depth, leading to passive learning behaviors and limited transfer of knowledge. In contrast, contemporary frameworks emphasize learning by doing and situational engagement. Among these, Project-Based Learning (PjBL) has emerged as one of the most promising pedagogical innovations. PjBL encourages students to work collaboratively on authentic projects that integrate cognitive, affective, and psychomotor domains, thereby linking abstract mathematical theory to tangible real-world problems (Karan & Brown, 2022). This aligns with global trends in education that emphasize 21st-century skills such as creativity, collaboration, communication, and critical thinking (Williamson, 2023; Nayak et al., 2024).

Project-Based Learning (PjBL) is theoretically grounded in constructivist and experiential learning theories, which assert that knowledge is best constructed through meaningful experiences rather than passive transmission (Siregar, 2024). Within mathematics education, PjBL situates students as active problem solvers who design, implement, and evaluate projects requiring the application of mathematical reasoning to real-life contexts (Almulla, 2020; Prayekti, 2025). This approach transforms mathematics from a series of abstract procedures into an investigative process of discovery and reflection. Unlike conventional teaching, which tends to fragment learning into isolated concepts, PjBL integrates multiple skills—quantitative analysis, reasoning, and communication—into a coherent and authentic learning experience (Sabat, 2024; Lisnasari et al., 2025; Fanani, 2024).

From a cognitive standpoint, PjBL fosters deep learning through iterative processes of inquiry, hypothesis formulation, data collection, and reflection. When students confront authentic problems, they are compelled to analyze situations critically, apply relevant formulas, and justify their reasoning. This cyclical process enhances metacognitive awareness and self-regulated learning, enabling students to monitor their thinking and adapt strategies when faced with complex problems (Rehman et al., 2025). Moreover, the collaborative nature of PjBL promotes social constructivism—students learn from peer interactions, exchange perspectives, and develop communication skills essential for future academic and professional contexts. Such collaboration not only improves cognitive outcomes but also nurtures socio-emotional competencies such as empathy, teamwork, and resilience (Hussein, 2021; Rohmaniyah & Asih, 2024).

At a deeper pedagogical level, mathematical problem-solving through PjBL extends beyond computation to include critical inquiry, modeling, and creative reasoning. Students are encouraged to identify problems, generate alternative solutions, and evaluate their outcomes through evidence-based reasoning. This aligns with the mathematical proficiency framework proposed by the National Council of Teachers of Mathematics (NCTM), which emphasizes five interrelated strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. Through project-based activities, students develop all five strands holistically, thereby achieving a more balanced form of mathematical literacy that is essential in the 21st century.

The implementation of PjBL is particularly relevant in Indonesia's educational reform under the Kurikulum Merdeka (Independent Curriculum), which promotes learner autonomy, differentiated instruction, and contextualized learning. This curriculum provides educators with flexibility to design lessons that cater to students' individual needs, integrate interdisciplinary knowledge, and foster authentic engagement with the surrounding environment. The Ministry of Education, Culture, Research, and Technology Kemendikbudristek, 2021 explicitly encourages innovative pedagogies such

as PjBL as part of the Profil Pelajar Pancasila framework, which envisions students who are creative, collaborative, and independent learners. However, despite the theoretical alignment between PjBL and the Kurikulum Merdeka, empirical research exploring the model's specific impact on mathematics problem-solving skills within the Indonesian junior high school context remains limited.

This study addresses this research gap by systematically examining the effectiveness of Project-Based Learning in enhancing students' mathematical problem-solving skills within the framework of Kurikulum Merdeka. In addition, the study explores how PjBL influences student motivation, engagement, and perceptions toward mathematics learning. By employing a mixed-methods approach—combining quantitative analysis of learning outcomes with qualitative insights into student experiences—this research seeks to contribute to both theoretical development and pedagogical practice. The findings are expected to inform educators, policymakers, and curriculum developers in designing sustainable, culturally grounded, and contextually relevant mathematics learning models for Indonesian schools in the 21st century.

2. METHODS

2.1. Research Design

This study employed a mixed-methods approach with a quasi-experimental design integrated into a sequential explanatory design framework. The quantitative phase aimed to measure the effect of Project-Based Learning (PjBL) on students' mathematical problem-solving abilities, while the qualitative phase provided in-depth insights into student motivation, engagement, and classroom dynamics that could not be fully captured through numerical data (Azzam & Jones, 2025).

The sequential explanatory design was selected because it combines the strengths of quantitative rigor and qualitative depth—allowing initial statistical findings to be further interpreted through participants' lived experiences. This design aligns with the philosophy of pragmatism in mixed-methods research, emphasizing the complementarity of methods to gain a comprehensive understanding of educational phenomena. The quasi-experimental element (non-randomized control group pretest–posttest) was chosen due to practical constraints in school-based settings, where randomization could disrupt ongoing learning processes. Nonetheless, matching procedures were employed to ensure baseline equivalence between groups, thereby maintaining internal validity.

2.2. Research Subjects and Samples

The study involved 70 junior high school students (average age = 13.2 years; 52% male and 48% female) from two parallel classes in a state secondary school in Indonesia that had fully implemented the Kurikulum Merdeka. Both classes were selected purposively based on administrative and logistical considerations, ensuring that the academic achievement profiles were relatively similar.

Prior to group assignment, a matching process was performed using students' mathematics scores from the previous semester to minimize pre-existing disparities in academic ability. Subsequently, one class (n = 35) was designated as the experimental group and received PjBL-based mathematics instruction, while the other (n = 35) served as the control group, taught using traditional teacher-centered methods (expository and drill-based instruction). Ethical considerations were fully observed, including informed consent from students and guardians, anonymity of responses, and voluntary participation. The study protocol received formal approval from the school's academic committee.

2.3. Instruments and Data Collection

Quantitative data were collected through a mathematics problem-solving skill test administered before and after the learning intervention. The test was developed based on Polya's four indicators of problem-solving skills, including problem identification, strategy formulation, solution implementation, and evaluation of results. The instrument underwent a content validation process by three validators: two mathematics education lecturers with doctoral qualifications and one senior mathematics teacher with over ten years of teaching experience (Cambaya & Tan, 2022). Content validity was assessed using the Content Validity Index (CVI), which indicated that all items met the

minimum relevance threshold. Reliability testing was carried out using Cronbach's Alpha, which yielded a coefficient of 0.82, demonstrating good internal consistency.

Qualitative data were collected through in-depth interviews with selected students and teachers involved in the learning process, as well as classroom observations during the implementation of PjBL. The interviews aimed to explore aspects of learning motivation, active student involvement, collaborative experiences, and obstacles encountered during instruction. Observations were conducted using structured observation sheets to systematically document the dynamics of student interaction and participation.

2.4. Implementation Procedure

The learning intervention was implemented over one academic semester (approximately 14 weeks) with two mathematics sessions per week, each lasting 90 minutes. Both groups were taught by the same mathematics teacher to ensure instructional consistency. The learning content and objectives were aligned with the Kurikulum Merdeka, which emphasizes student-centered, contextual, and competency-based learning. The experimental group received instruction using the Project-Based Learning (PjBL) model, while the control group followed conventional lecture-based and practice-oriented learning. All classroom activities were systematically monitored and documented through field notes, structured observation sheets, and video recordings to ensure fidelity of implementation.

The implementation of PjBL followed six essential stages adapted from Guo et al., (2020) and Kemendikbudristek (2021), including orientation and problem formulation, planning and design, project implementation, product development, presentation and peer evaluation, and reflection. At the orientation stage, students were introduced to real-world problems related to mathematics topics and guided to formulate driving questions. During the planning and design phase, students collaborated in small groups to develop project plans, assign roles, and determine strategies for data collection and analysis. In the implementation phase, students engaged in inquiry-based activities to construct solutions or mathematical models. The product development stage involved producing tangible outputs such as geometric models or data visualizations that represented the application of mathematical concepts. These outputs were then presented in the peer evaluation stage, followed by reflection sessions in which students discussed their learning experiences, challenges, and problem-solving strategies. Each project cycle lasted two to three consecutive meetings to provide sufficient time for exploration, collaboration, and synthesis. Throughout the process, the teacher acted as a facilitator, providing scaffolding in the form of guidance and feedback while maintaining students' autonomy, in accordance with Vygotsky's zone of proximal development (ZPD) framework (Zolfaghari & Rashidi, 2023).

The projects were designed to connect mathematics concepts with real-life contexts in line with the Kurikulum Merdeka's emphasis on contextual and inquiry-based learning. One of the projects involved constructing three-dimensional geometric models, such as cubes, prisms, and pyramids, from recyclable materials to explore formulas for surface area and volume. Another project required students to conduct a statistical survey on school-related habits—such as study duration and preferred learning styles—and present their findings through infographics. These projects encouraged interdisciplinary integration, combining mathematics with digital literacy, environmental awareness, and communication skills, consistent with the 21st-century learning competencies promoted by OECD (2020).

Project outcomes were assessed using an analytic rubric encompassing five aspects: conceptual understanding, problem-solving strategy, creativity, collaboration, and reflective thinking. Each criterion was rated on a four-point Likert scale (1–4) with clear performance descriptors to ensure assessment consistency. Evaluation was based not only on the final product but also on the process of learning and teamwork, reflecting the authentic assessment principles of the Kurikulum Merdeka (Kusdarini, 2025). To ensure reliability, inter-rater consistency was established between the teacher and the researcher, producing a Cohen's kappa coefficient of 0.86, indicating high agreement.

During implementation, researchers conducted systematic classroom observations to capture students' engagement, collaboration, and participation. Reflective journals were collected weekly from both teachers and students to document learning experiences and challenges. Coordination meetings were held periodically with the mathematics teacher to review progress and ensure adherence to PjBL principles. Short video clips were also analyzed to confirm procedural fidelity and to triangulate data from multiple sources.

Pedagogically, the implementation of PjBL in this study was grounded in the constructivist learning theory, which posits that knowledge is actively constructed through experience rather than passively transmitted (Mitry, 2021; Amiri, 2025). By engaging students in authentic, project-based learning activities, the intervention aimed to strengthen not only procedural fluency but also conceptual understanding, metacognitive awareness, and independent learning skills. This approach aligns with the broader objectives of Indonesia's Kurikulum Merdeka and the global framework of mathematical literacy outlined by OECD (2018), which emphasize creativity, collaboration, and critical thinking as essential competencies for 21st-century learners.

2.5. Data Analysis

Quantitative data analysis was conducted using a t-test statistical test for paired and unpaired samples to test the significant difference between pretest and posttest results in both groups. Tests of normality and homogeneity of variance are also performed before hypothesis testing to ensure statistical assumptions are met. Qualitative data were analyzed using thematic analysis methods, which included interview transcription, data coding, theme grouping, and narrative interpretation. The validity of qualitative data is strengthened through triangulation of data sources (students and teachers), member checking, and discussions between researchers (peer debriefing).

3. FINDINGS AND DISCUSSION

3.1. Quantitative Results

Table 1. Comparison of Pretest and Posttest Scores of Mathematical Problem-Solving Ability in the Experimental Group and

Group	N	Mean Pretest	Mean Posttest	Mean Difference	t (df)	p-value
Experiment	35	58,4	79,6	21,2	9,23 (34)	< 0.001
Control	35	57,9	63,2	5,3	2,11 (34)	0,043

Note: N = number of participants, t = t-test scores for pretest-posttest in groups

Table 2. Comparison of Posttest Scores of Mathematical Problem-Solving Ability between the Experimental and Control Groups

Group	N	Mean Posttest	Standard Deviation	t (df)	p-value
Experiment	35	79,6	6,5	6,48 (68)	< 0.001
Control	35	63,2	7,8	-	-

Note: Cohen's d = 1.55 (large effect)

Statistical analysis conducted in this study shows that the application of Project-Based Learning (PjBL) in the context of the *Kurikulum Merdeka* has a significant influence on improving mathematics problem-solving skills in junior high school (SMP) students. Through the t-test for the difference in mean scores between pretest and posttest scores, it was found that the experimental group that received a PjBL-based learning intervention experienced a very significant increase in scores, with an average pretest score of 58.4 increasing to 79.6 in the posttest ($t(34) = 9.23$; $p < 0.001$). This shows that the PjBL

learning model is able to effectively improve students' ability to solve mathematical problems compared to the initial condition before the intervention.

In contrast, the control group that followed conventional learning experienced only a relatively small increase, although statistically significant nonetheless, with a pretest mean score of 57.9 and an increase to 63.2 on the posttest ($t(34) = 2.11$; $p = 0.043$). This difference in improvement was much lower compared to the experimental group, which shows the limitations of conventional learning methods in developing optimal math problem-solving skills. In addition, the independent samples t-test comparing posttest scores between the experimental and control groups showed a statistically significant difference, with the experimental group scoring higher ($M = 79.6$, $SD = 6.5$) than the control group ($M = 63.2$, $SD = 7.8$), $t(68) = 6.48$, $p < 0.001$. The effect size, measured using Cohen's d, was 1.55, indicating a large effect (Cohen, 1988). This confirms that project-based learning provides a significant advantage in improving students' mathematical problem-solving skills compared to conventional instruction.

The significant increase experienced by the experimental group reflects the development of students' cognitive aspects at various stages of problem-solving skills, starting from the stage of problem identification, strategy formulation, solution implementation, to evaluation of the final result. This is in accordance with the mathematical problem-solving model put forward by Polya, which emphasizes the importance of each stage in building analytical and critical thinking skills. Through PjBL, students are not only faced with practice of ordinary problems, but are encouraged to integrate mathematical knowledge in the context of real projects that demand the application and exploration of concepts in depth. Thus, the learning process becomes more meaningful and relevant for students.

This finding is in line with the results of previous research which confirms that PjBL is effective in deepening the understanding of mathematical concepts and honing high-level thinking skills, especially critical and creative thinking (Syahbanda, 2025). Bell stated that PjBL provides space for students to actively and independently process in finding solutions, which strengthens the transfer of knowledge to new situations (Afzal & Tumpa, 2025; Belwal et al., 2021). Thomas adds that involvement in real projects allows students to build a firmer understanding and increase their intrinsic motivation towards learning. Therefore, the increase in scores in the experimental group is not just an increase in numbers, but an indicator of the development of holistic and in-depth mathematical competence.

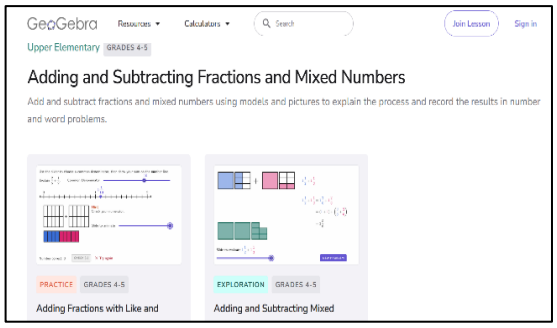
Overall, the results of this statistical analysis show that PjBL is a very relevant and effective learning strategy within the framework of the Kurikulum Merdeka to equip junior high school students with mathematical problem-solving skills that are essential for academic success and daily life. With the right implementation and adequate resource support, PjBL has the potential to become a superior learning approach that is able to answer the challenges of mathematics education in the modern era.

3.2. Qualitative Results

The analysis of qualitative data obtained from in-depth interviews and classroom observations provides a very rich and realistic picture of the implementation of Project-Based Learning (PjBL) in improving the mathematical problem-solving skills of junior high school students. A total of 12 students and 2 mathematics teachers were selected as qualitative informants. The students were chosen purposively to represent different levels of academic achievement (high, medium, and low) as well as gender balance, ensuring diverse perspectives on the implementation of PjBL. The two teachers were those directly involved in teaching the experimental and control groups. This selection was intended to capture both student learning experiences and teacher observations during the intervention (Cambaya & Tan, 2022).

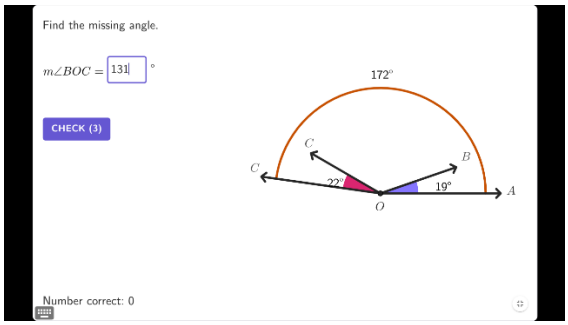
The majority of students stated that Project-Based Learning (PjBL) made mathematics more enjoyable and meaningful, transforming the process from mechanical memorization into an exploratory activity that required critical thinking and collaboration. As one student noted, *"When we learn like this, I feel more challenged. Plus, we work together with friends and discuss a lot, so many ideas come up"*, (Interview, code B1 – August 24, 2024). This reflects a shift toward more active and participatory learning, where students become the main drivers of the learning process rather than passive recipients.

Students also highlighted the role of learning tools such as 3D models and digital applications like GeoGebra in helping them visualize abstract mathematical concepts more clearly. One student explained, *"GeoGebra is very helpful. I can see directly the shape of the building, change the size, and see the effect on the corners and sides. So it's not just a theory, but it can really be seen and tried"*, (Interview, code B2 – August 24, 2024). Teachers likewise confirmed that integrating GeoGebra enriched the learning process and enhanced students' confidence and classroom interactivity.



Source: GeoGebra application, created by researchers (2024)

Figure 1. GeoGebra Page for Adding and Subtracting Fractions and Mixed Numbers



Source: GeoGebra application, created by researchers (2024)

Figure 2. Illustration of Central Angle and Inscribed Angle Measurement in a Circle on the GeoGebra page

Many students reported greater metacognitive awareness, recognizing which strategies were effective in solving problems and which needed improvement through structured reflection. One of the students revealed, *"After working on the project, we were asked to write a reflection about what we had learned and what was still difficult. So, i can know the way I think and learn all along"*, (Interview, code B3 – August 24, 2024). Teachers emphasized that such reflection activities are essential for helping students focus not only on outcomes but also on the processes and strategies used, which is the essence of meaningful learning. This aligns with the literature highlighting the role of metacognition in fostering critical thinking and deep problem-solving (Bhardwaj et al., 2025; Mabaso, 2024).

Despite its benefits, PjBL presented challenges such as extended time requirements and unequal participation due to differences in students' initial abilities. As one teacher explained, *"Even though PjBL is good, not all students can adapt immediately. Teachers must be sensitive and smart in dividing tasks so that all students can be active and learn according to their abilities"*, (Interview, code A1 – August 24, 2024). These challenges highlight the need for effective classroom management and differentiated support to ensure that all students benefit equally from project-based learning.

Teachers emphasized the need for special training to help educators manage PjBL classes effectively and utilize contextual learning resources such as digital media, reflection worksheets, and process flow diagrams (Prasetiyo et al., 2023; Joswick et al., 2023). Tools like GeoGebra were also seen as valuable in enriching learning and providing real-time feedback. Overall, the qualitative findings show that PjBL, supported by innovative media, enhances students' motivation, collaboration, and metacognitive skills, aligning with the Kurikulum Merdeka's emphasis on independent and contextual learning.

3.3. Discussion

The findings of this study reaffirm that Project-Based Learning (PjBL) serves not only as an instructional strategy but as a transformative pedagogical paradigm that redefines the nature of mathematics learning in the 21st century. Within the framework of the Kurikulum Merdeka, PjBL bridges the gap between conceptual knowledge and authentic application by engaging students in inquiry, experimentation, and collaborative construction of meaning. This alignment between cognitive and experiential learning echoes the constructivist view of knowledge as an active process of meaning-

making rather than passive reception (Kemendikbud, 2021). Through contextual projects, students not only acquire mathematical reasoning but also develop transferable skills, communication, teamwork, and self-regulated learning, that extend beyond the classroom and prepare them for complex real-world problem-solving (National Council of Teachers of Mathematics, 2020).

Moreover, the implementation of PjBL fosters metacognitive development, as students are required to plan, monitor, and evaluate their learning strategies systematically. This reflective dimension of learning enhances their ability to manage ambiguity and adapt their approaches—abilities that are critical in higher-order reasoning and lifelong learning (Williamson, 2023).

The findings also resonate with global educational goals such as those articulated in the OECD Education 2030 framework, emphasizing the cultivation of agency, creativity, and resilience through authentic, student-centered learning environments (Aldabbus, 2018). Despite its promise, the study also underlines several structural and pedagogical challenges that may hinder the consistent application of PjBL in Indonesian classrooms. Limited instructional time, insufficient teacher training, and the scarcity of learning resources remain central barriers. In practice, teachers often struggle to balance the depth of project exploration with curriculum coverage requirements. This tension underscores the need for institutional flexibility and curriculum policies that accommodate deeper learning approaches. Furthermore, the variation in students' background knowledge and collaboration skills calls for differentiated scaffolding to ensure equitable participation within group-based projects (Rodrigues, 2020).

From a pedagogical innovation standpoint, the success of PjBL hinges on the teacher's role as a facilitator rather than a transmitter of knowledge. Effective facilitation demands not only mastery of mathematical content but also pedagogical creativity to design meaningful, interdisciplinary projects that connect mathematics with real-life contexts such as environmental awareness, technology, and social issues (Elijah, 2024). Integrating digital tools, such as interactive simulations, data visualization software, and collaborative online platforms, could further enhance engagement and extend the reach of project-based learning into hybrid or blended learning environments.

Theoretically, this research strengthens the argument that mathematics education should evolve from rote procedural training toward inquiry-driven learning ecosystems that cultivate mathematical literacy, the ability to formulate, employ, and interpret mathematics in diverse contexts (Taja-on et al., 2025). Empirically, it provides localized evidence that supports global pedagogical trends while acknowledging Indonesia's unique educational landscape under the Kurikulum Merdeka. Thus, this study contributes to the growing body of literature positioning PjBL as a bridge between policy aspirations and classroom realities.

In conclusion, the study reinforces that adopting PjBL within the Kurikulum Merdeka framework can transform mathematics education into a more engaging, equitable, and future-oriented experience. For sustainability, ongoing professional development, resource provision, and policy alignment are essential to institutionalize PjBL practices at scale. Future research should further explore longitudinal effects of PjBL on students' cognitive and affective outcomes, as well as its integration with digital pedagogy and assessment innovation to fully harness its transformative potential.

4. CONCLUSION

This research shows that Project-Based Learning (PjBL) applied in the context of the *Kurikulum Merdeka* is effective in improving mathematical problem-solving skills in junior high school students. PjBL not only deepens the mastery of mathematical concepts significantly, but also develops 21st century competencies such as critical thinking, creativity, and collaboration skills that are needed in today's world of education.

In addition to these successes, this study also identified challenges in the implementation of PjBL, such as the need for longer time and differences in students' initial abilities that affect group dynamics. Therefore, support in the form of systematic teacher training and the provision of contextual and innovative learning resources are needed so that this method can be implemented optimally and sustainably.

Overall, PjBL in the *Kurikulum Merdeka* is a strategic and relevant learning model to improve the quality of mathematics learning at the junior high school level. This research provides an empirical basis for the development of innovative learning practices that are oriented towards developing students' skills in a holistic and contextual manner.

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