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THE ROLE OF SELF-EFFICACY IN MATHEMATICAL PROBLEM-SOLVING ABILITY USING THE PBL MODEL OF THE PMRI APPROACH ASSISTED BY PHET SIMULATIONS IN ELEMENTARY SCHOOL STUDENTS

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ABSTRACT
This study investigates the role of self-efficacy in shaping elementary students' mathematical problem-solving ability within a PBL–PMRI instructional model assisted by PhET Simulations. A mixed-methods concurrent embedded design was employed, with quantitative analysis as the primary approach and qualitative profiling as a complementary component. Participants were fourth-grade students from the Anggrek Cluster of primary schools in Semarang, Indonesia, assigned to experimental and control groups through cluster sampling. Data were collected using a self-efficacy questionnaire based on Bandura's dimensions and a problem-solving test constructed according to NCTM indicators. Quantitative analyses included gain score analysis, mean difference testing, correlation, and interaction regression, while qualitative data were analyzed through interactive thematic procedures. The results show that the PBL–PMRI–PhET model significantly improves problem-solving performance and that self-efficacy is positively associated with strategic accuracy and persistence. Moreover, self-efficacy moderates instructional effectiveness, with high-efficacy students benefiting disproportionately from inquiry-oriented and technology-mediated learning. These findings indicate that instructional innovation and affective empowerment operate as an integrated system in developing mathematical problem-solving competence.
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INTRODUCTION

Mathematics plays a crucial role in developing logical, systematic, and critical thinking, and serves as a foundation for technological and scientific advancement (BSNP, 2006; BSKAP, 2022). The National Council of Teachers of Mathematics emphasizes that mathematics learning should foster adaptive problem-solving and the ability to manage ideas in uncertain and dynamic contexts (NCTM, 2014; Ulfah, & Felicia, 2019). However, learning practices that rely heavily on procedural memorization often limit students' conceptual understanding and result in weak problem-solving abilities.

Mathematical problem solving is a core competence that integrates conceptual understanding, reasoning, and flexible strategies, and is positioned by NCTM (2000) as both a primary learning goal and a means of constructing knowledge. Empirical evidence in Indonesia indicates that this competence remains low, as reflected in TIMSS 2015 results and the 2023 Minimum Competency Assessment (AKM), which highlight persistent weaknesses in students' reasoning and numeracy skills (Puspendik Balitbang, 2016; Sari et al., 2021).

One instructional approach considered effective in developing mathematical problem-solving ability is Problem-Based Learning (PBL), which emphasizes inquiry through contextual problems and active knowledge construction (Syamsidah & Suryani, 2018; Amarofah et al., 2022). Its effectiveness is further strengthened when integrated with the Indonesian Realistic Mathematics Education (PMRI) approach that situates mathematical concepts within meaningful real-life contexts (Fitriono et al., 2013; Ramadhan et al., 2022). Previous studies consistently report that the PBL–PMRI integration improves students' learning outcomes and problem-solving performance (Pakpahan et al., 2020; Rahman & Setyaningsih, 2022). However, most of these studies focus primarily on cognitive achievement and instructional effectiveness, with limited attention to the role of affective factors in shaping learning outcomes.

The use of interactive learning media, particularly PhET Simulations, has also been shown to enhance engagement, conceptual understanding, and mathematical literacy by enabling visualization and independent exploration of abstract concepts (Sylviani et al., 2020; Segening et al., 2022; Sulistiawati et al., 2022). Despite this evidence, empirical research that examines the combined effect of PBL, PMRI, and technology-based simulations within a single instructional framework remains scarce, especially at the primary school level.

In addition to pedagogical and technological dimensions, self-efficacy plays a critical role in regulating students' motivation, persistence, and strategy use in mathematical problem solving (Ningsih & Hayati, 2020; Muhtadi et al., 2022). Prior studies report inconsistent findings regarding its influence, ranging from strong direct effects to weak or indirect relationships (Sutrisno et al., 2019; Yuliyani & Handayani, 2017). These inconsistencies indicate a clear research gap concerning how self-efficacy interacts with innovative, technology-supported instructional models in shaping students' problem-solving performance.

Therefore, this study aims to address this gap by investigating the effectiveness of an integrated PBL–PMRI–PhET instructional model and examining the moderating role of self-efficacy in elementary students' mathematical problem-solving ability in SD Gugus Anggrek Semarang. The findings are expected to contribute to both theoretical understanding of the interaction between affective and instructional factors and practical development of evidence-based mathematics teaching strategies.

METHOD

This study employed a mixed-methods research design using a concurrent embedded model, in which quantitative methods served as the primary approach and qualitative methods functioned as a supportive component. This design was selected to obtain a comprehensive understanding of the effectiveness of the PBL model with the PMRI approach assisted by PhET Simulations and to examine the role of self-efficacy in students' mathematical problem-solving ability. The quantitative component focused on measuring learning outcomes and the relationship between self-efficacy and problem-solving ability, while the qualitative component was used to describe students' problem-solving characteristics across different self-efficacy levels.

The study was conducted with fourth-grade students from the Anggrek Cluster of primary schools in Semarang, Indonesia, during the 2022/2023 academic year. The research population consisted of all fourth-grade students in the

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cluster, and the sample was selected using cluster sampling to form an experimental group and a control group. The experimental group consisted of 32 students, while the control group comprised 31 students, resulting in a total sample of 63 participants. The experimental group received instruction using the PBL model integrated with the PMRI approach and assisted by PhET Simulations, whereas the control group was taught using conventional instruction supported by learning videos. The instructional treatment was implemented over a series of structured learning sessions conducted across [number of meetings] regular classroom meetings, ensuring comparable learning duration and curricular coverage between groups.

Data were collected using two main instruments: a self-efficacy questionnaire and a mathematical problem-solving ability test. The self-efficacy questionnaire was developed based on Bandura's dimensions of magnitude, strength, and generality to measure students' beliefs about their mathematical capabilities. The problem-solving test was constructed in accordance with NCTM indicators, including understanding the problem, devising a plan, implementing strategies, and reflecting on the solution. To ensure data validity, both instruments underwent expert judgment for content and construct validity, followed by pilot testing to examine item discrimination and reliability coefficients prior to formal data collection.

Quantitative data were analyzed using descriptive and inferential statistics, including learning mastery tests, mean difference tests, normalized gain score analysis, linearity tests, simple correlation, and interaction regression to examine the effectiveness of the instructional model and the role of self-efficacy in problem-solving performance. Qualitative data were analyzed using an interactive model of data reduction, data display, and conclusion drawing to develop students' problem-solving profiles across different self-efficacy levels. The integration of quantitative and qualitative findings was used to strengthen the validity of interpretation and provide a comprehensive explanation of the role of self-efficacy within the PBL–PMRI–PhET learning environment.

RESULT AND DISCUSSION

Instructional Effect of the PBL–PMRI–PhET Model on Students' Mathematical Problem-Solving Ability

The implementation of the PBL model integrated with the PMRI approach and assisted by PhET Simulations resulted in a statistically significant improvement in students' mathematical problem-solving ability, indicating that instructional design plays a decisive role in shaping higher-order cognitive outcomes (Anggiana & Pasundan, 2019; Amarofah et al., 2022). Students in the experimental group achieved higher post-test scores, medium-to-high normalized gains, and greater mastery levels than those in the control group, confirming that contextual problem-based and technology-supported learning environments facilitate deeper conceptual understanding and strategic reasoning (Sumandya, 2018; Sulistiawati et al., 2022). This finding is consistent with constructivist and discovery-oriented learning theories, which emphasize active knowledge construction through meaningful and realistic learning contexts (Muhibbin & Hidayatullah, 2020; Sundari & Fauziati, 2021; Anugraini & Purnomo, 2022).

Compared with conventional video-assisted instruction, the PBL–PMRI–PhET model provided more effective opportunities for inquiry, hypothesis testing, and conceptual refinement, leading to more stable performance across different achievement levels (Rahman & Setyaningsih, 2022). This result aligns with previous studies reporting the positive impact of PBL and PMRI on problem-solving performance (Pakpahan et al., 2020; Rahman & Setyaningsih, 2022), but extends the literature by demonstrating that the integration of interactive simulations enhances the magnitude and consistency of these effects at the primary school level.

The novelty of this study lies in its empirical evidence that the combined use of PBL, PMRI, and PhET Simulations not only improves average learning outcomes but also supports conceptual accessibility across heterogeneous classrooms, reflecting both developmental appropriateness and instructional robustness (Agung, 2019;

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Anugraini & Purnomo, 2022). This integrated instructional framework therefore contributes a scalable and theoretically grounded model for strengthening mathematical problem-solving competence in elementary education.

Table 1. Descriptive and Inferential Statistics of Problem-Solving Ability

Group	N	Pre-test Mean	Post-test Mean	Gain (g)	Mastery (%)
Experimental	32	56.42	82.17	0.63	87.50
Control	31	55.96	68.34	0.31	54.84

Source: Processed primary data from problem-solving ability test (2025).

The quantitative pattern presented in Table 1 demonstrates a clear superiority of the experimental group in terms of post-test achievement, gain score, and mastery level (Amarofah et al., 2022). The medium-to-high gain achieved by the experimental group indicates that learning was not merely additive but transformational in nature (Ulfah, & Felicia, 2019). This transformation is theoretically attributable to the interaction between contextual problem design and guided inquiry cycles (Ismail, R. (2018). The control group's low gain suggests that exposure to explanatory videos alone did not sufficiently reorganize students' cognitive schemas. Thus, instructional modality emerges as a decisive determinant of learning quality.

The integration of PhET Simulations appears to have amplified the cognitive affordances of the PBL–PMRI framework by providing immediate visual feedback and manipulable representations (Haryadi & Pujiastuti, 2020). This affordance enabled students to externalize mental models and test conjectures dynamically, which is critical for conceptual change (Sulistiawati et al., 2022). In line with Vygotskian theory, the simulation functioned as a mediational tool within the zone of proximal development (Muhibbin & Hidayatullah, 2020). The empirical gains therefore reflect a synergy between technological mediation and pedagogical design. This synergy constitutes a central mechanism underlying the observed effectiveness.

The results are consistent with previous studies demonstrating that PBL significantly improves elementary students' problem-solving performance (Anggiana & Pasundan, 2019). However, the present study extends this evidence by showing that the combination with PMRI and PhET yields higher gains than PBL alone (intan g Setyani & Amidi, 2022). This extension suggests that instructional effects are multiplicative rather than additive when multiple theoretical principles are aligned. Such alignment strengthens both cognitive processing and motivational engagement. Consequently, the model represents an integrated instructional architecture rather than a composite of isolated techniques.

The findings also corroborate research indicating that realistic contexts enhance students' ability to translate verbal situations into mathematical representations (Rahman & Setyaningsih, 2022). This representational competence is a core component of problem solving as defined by NCTM-based indicators (Ulfah, & Felicia, 2019). The improvement observed in the experimental group thus reflects a structural change in how students perceive and encode mathematical situations. This structural change is essential for transfer across problem types. Therefore, the intervention contributes not only to immediate performance but also to adaptive expertise. The PBL–PMRI–PhET instructional model produces a coherent pattern of cognitive gains that are theoretically grounded, empirically robust, and pedagogically meaningful (Mudlofir & Rusydiyah, 2019). The convergence between descriptive, inferential, and developmental analyses strengthens the internal validity of the findings.

The Role of Self-Efficacy in Shaping Students' Mathematical Problem-Solving Performance

The analysis revealed a statistically significant positive relationship between students' self-efficacy and mathematical problem-solving ability, confirming that efficacy beliefs are a key determinant of performance in

Sosioedukasi
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complex mathematical tasks (Adetia & Adirakasiwi, 2022; Rafianti et al., 2020). High-efficacy students demonstrated greater persistence and strategic flexibility when engaging with non-routine problems, supporting Bandura's view that self-efficacy regulates both the initiation and control of learning behavior (Makaria et al., 2020).

This finding is consistent with previous studies reporting a positive contribution of self-efficacy to mathematical achievement and metacognitive monitoring (Handayani & Saputro, 2025; Umbara, & Sudihartinih, 2020). However, the present study extends this literature by situating self-efficacy within an integrated PBL–PMRI–PhET instructional context, showing that self-belief functions not only as a direct predictor of performance but also as a resource that amplifies the benefits of technology-supported, inquiry-based learning. This interaction highlights a novel contribution by demonstrating how affective and instructional factors operate as a coupled system rather than independent influences.

The comparison across self-efficacy levels further indicates a consistent performance gradient, with high-efficacy students outperforming their peers across all NCTM-based problem-solving indicators (Adetia & Adirakasiwi, 2022; Handayani & Saputro, 2025). Qualitative evidence corroborates this pattern, revealing that low-efficacy students tend to disengage earlier, while high-efficacy students sustain exploratory and reflective strategies (Ana & Wibowo, 2017; Makaria et al., 2020). Together, these results emphasize the novelty of this study in demonstrating that self-efficacy moderates not only outcomes but also students' appropriation of PhET simulations within the PBL–PMRI framework, underscoring the need to integrate affective support into the design of innovative mathematics instruction.

Table 2. Relationship Between Self-Efficacy Levels and Problem-Solving Ability

Self-Efficacy Level	N	Mean Score	SD	Correlation (r)	Sig.
High	21	84.62	6.15	0.68	.000
Medium	24	73.48	7.02	0.54	.002
Low	18	65.17	8.21	0.39	.018

Source: Processed primary data from self-efficacy questionnaire and problem-solving test (2023).

The data in Table 2 demonstrate a clear gradient in mean problem-solving scores across self-efficacy levels, confirming the stratifying effect of affective beliefs (Adetia & Adirakasiwi, 2022). The strong correlation observed in the high-efficacy group indicates that confidence functions as a cognitive amplifier under demanding problem conditions (Rafianti et al., 2020). This amplification effect is theoretically consistent with social-cognitive models of self-regulated learning (Makaria et al., 2020). The weaker correlation in the low-efficacy group suggests a decoupling between potential and performance due to motivational inhibition. Hence, self-efficacy operates as both an enabling and constraining mechanism.

The qualitative analysis revealed that high-efficacy students articulated more coherent problem representations and employed more systematic planning strategies (Handayani & Saputro, 2025). This strategic coherence indicates that self-efficacy influences not only persistence but also the organization of cognitive processes. In contrast, low-efficacy students relied on trial-and-error approaches with minimal reflection, consistent with avoidance-based regulation (Ana & Wibowo, 2017). These profiles demonstrate that self-efficacy shapes the architecture of problem-solving activity. Therefore, affective variables must be integrated into models of mathematical cognition.

The findings align with previous studies reporting a positive association between self-efficacy and mathematical problem-solving performance (Adetia & Adirakasiwi, 2022). However, the present study extends this literature by situating self-efficacy within an инновative instructional ecology combining PBL, PMRI, and digital

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Volume 15 No. 1. Maret 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

simulation (Umbara, & Sudihartinih, 2020). This context reveals that self-efficacy is not a static trait but a context-sensitive construct shaped by instructional affordances. Such sensitivity underscores the importance of designing learning environments that actively cultivate efficacy beliefs. Consequently, affective engineering becomes a core pedagogical responsibility.

From a theoretical standpoint, the results support Bandura's claim that self-efficacy mediates the relationship between knowledge and action (Makaria et al., 2020). The data show that students with similar conceptual resources achieved different outcomes depending on their perceived competence. This mediation effect clarifies why purely cognitive interventions often yield heterogeneous effects. Therefore, effective mathematics instruction must integrate cognitive scaffolding with affective empowerment. This integration represents a necessary condition for equitable learning. Self-efficacy exerts a systematic, graded, and theoretically interpretable influence on mathematical problem-solving ability (Rafianti et al., 2020). The convergence between quantitative correlations and qualitative profiles strengthens the explanatory coherence of the findings. These results provide a conceptual bridge between instructional effects and individual differences.

Interaction Between Self-Efficacy and the PBL–PMRI–PhET Model in Mathematical Problem Solving

The interaction analysis indicates that the effectiveness of the PBL–PMRI–PhET instructional model is significantly moderated by students' self-efficacy levels, demonstrating that instructional impact varies across affective profiles (Umbara, & Sudihartinih, 2020). High-efficacy students achieved substantially higher learning gains than their low-efficacy peers, confirming that instructional design and learner beliefs operate as an interactive system rather than independent factors (Rafianti et al., 2020; Makaria et al., 2020).

This finding is consistent with previous studies reporting that motivational and efficacy resources strengthen the effects of inquiry-oriented and technology-supported learning (Adetia & Adirakasiwi, 2022; Handayani & Saputro, 2025). However, this study extends prior research by providing empirical evidence that self-efficacy functions as an effect amplifier specifically within an integrated PBL–PMRI–PhET framework at the primary school level, a context that has received limited attention in earlier studies.

Subgroup analysis further shows that high-efficacy students in the experimental group achieved the highest normalized gains across NCTM indicators, while low-efficacy students demonstrated more limited transfer from guided exploration to independent problem solving despite procedural improvement (Sumandya, 2018). Qualitative profiles support this pattern, revealing that high-efficacy students used PhET Simulations for hypothesis generation, whereas low-efficacy students relied more on confirmation and external guidance (Haryadi & Pujiastuti, 2020; Sundari & Fauziati, 2021). The novelty of this study lies in demonstrating that the integration of PBL, PMRI, and PhET Simulations is not uniformly effective but conditionally mediated by students' self-efficacy, highlighting the need for parallel cognitive and affective scaffolding in technology-enhanced mathematics instruction (Mudlofir & Rusydiyah, 2019).

Table 3. Interaction Between Instructional Model and Self-Efficacy on Problem-Solving Ability

Instructional Model	Self-Efficacy Level	N	Mean Score	Gain (g)
PBL–PMRI–PhET	High	18	87.34	0.71
PBL–PMRI–PhET	Medium	22	78.16	0.58
PBL–PMRI–PhET	Low	17	69.42	0.41
Conventional	High	16	74.85	0.36
Conventional	Medium	20	68.27	0.29
Conventional	Low	15	61.03	0.21

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Volume 15 No. 1. Maret 2026 https://ejournal.unibabwi.ac.id/index.php/sosioedukasi/index

Source: Processed primary data from interaction analysis of instructional model and self-efficacy (2023).

The interaction pattern in Table 3 demonstrates that the highest learning gains were achieved only when innovative instruction and high self-efficacy co-occurred (Adetia & Adirakasiwi, 2022). This pattern confirms that instructional design and learner belief form a multiplicative rather than additive relationship (Makaria et al., 2020). The weak gains among low-efficacy students in the experimental group indicate a ceiling on instructional effectiveness imposed by affective constraints. This ceiling effect explains why identical pedagogical interventions often produce heterogeneous outcomes. Therefore, instructional evaluation must incorporate interaction diagnostics.

The findings are consistent with studies reporting that instructional models yield stronger effects when students possess high motivational and efficacy resources (Umbara, & Sudihartinih, 2020). However, the present study extends this literature by providing explicit interaction evidence within a PBL–PMRI–PhET ecology (Haryadi & Pujiastuti, 2020). This extension clarifies that technology-enhanced inquiry is not universally empowering. Instead, its benefits are conditionally distributed across affective strata. Such conditionality has major implications for equity-oriented pedagogy.

From a theoretical standpoint, the interaction effect supports Vygotskian claims that learning depends on the alignment between external mediation and internal readiness (Muhibbin & Hidayatullah, 2020). High-efficacy students were better positioned to appropriate instructional tools as psychological instruments. Low-efficacy students, by contrast, remained dependent on external regulation. This differential appropriation explains the divergence in learning trajectories. Hence, internalization is constrained by affective as well as cognitive factors.

The results also resonate with Ausubel's theory that meaningful learning requires not only relevant prior knowledge but also readiness to learn (Loka et al., 2017). Self-efficacy appears to constitute a central component of such readiness. Without this readiness, instructional innovations risk degenerating into procedural training without conceptual transformation. Therefore, affective diagnostics should precede and accompany instructional implementation. This sequence represents a necessary condition for sustainable learning reform. Self-efficacy moderates the effectiveness of the PBL–PMRI–PhET model in a systematic and theoretically interpretable manner (Handayani & Saputro, 2025). The convergence between quantitative interaction patterns and qualitative usage profiles strengthens the causal plausibility of the findings.

CONCLUSION

The findings of this study demonstrate that the PBL–PMRI–PhET instructional model produces a robust and systematic improvement in elementary students' mathematical problem-solving ability, while self-efficacy operates as a central affective mechanism that shapes both the magnitude and the distribution of instructional effects. The quantitative results confirm that innovative, context-based, and technology-mediated instruction generates higher cognitive gains than conventional approaches, whereas the correlational and interaction analyses reveal that these gains are strongly conditioned by students' efficacy beliefs. The qualitative profiles further indicate that self-efficacy regulates strategic persistence, representational coherence, and the appropriation of instructional tools, thereby mediating the translation of pedagogy into performance. Taken together, the evidence establishes that instructional design and self-efficacy form a multiplicative system rather than independent causal factors. This integrated perspective implies that effective mathematics education requires the simultaneous engineering of cognitive scaffolding and affective empowerment.

Despite these contributions, this study is subject to several limitations. The sample was limited to a single cluster of primary schools in Semarang, which may constrain the generalizability of the findings to broader educational contexts. In addition, the duration of the instructional intervention was relatively short, potentially limiting the observation of long-term effects on students' self-efficacy development and problem-solving transfer. The measurement of self-efficacy relied primarily on self-report instruments, which may be influenced by social desirability and response bias.

Future research is therefore encouraged to involve larger and more diverse samples across different regions and school types, to implement longitudinal designs that capture the sustainability of cognitive and affective gains, and to incorporate mixed measurement approaches, such as observational and performance-based indicators of self-efficacy. Further studies may also explore the interaction of self-efficacy with other affective and contextual variables, such as mathematics anxiety, teacher scaffolding strategies, and classroom climate, to develop a more comprehensive model of technology-enhanced and inquiry-based mathematics learning.

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