Jurnal Pendidikan Matematika (JUPITEK) | December 2025 | Volume 8 Number 2 | Page. 119–129
ISSN: 2655-2841 (Print); 2655-6464 (Electronic)
DOI https://doi.org/10.30598/jupitekvol8iss2pp119-129

A Comparative Study of RME and PBL Models on Students' Problem-Solving Skills Based on Mathematical Communication

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Submitted: August 19,2025 *Revised: November 20, 2025* *Accepted: December 18, 2025*
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Abstract

This study aims to compare the effects of the Realistic Mathematics Education (RME) and Problem-Based Learning (PBL) models on junior high school students' problem-solving skills, viewed through the lens of mathematical communication. A quasi-experimental method employing a 2×2 factorial design (treatment by level) was implemented. The sample consisted of 32 seventh-grade students from a public junior high school in East Lombok, West Nusa Tenggara, divided into four groups based on instructional model and mathematical communication level (high vs. low). The research instrument was an essay-based test administered both before and after the intervention. Two-way ANOVA results revealed a statistically significant effect of the learning model on problem-solving skills ($F = 106.68$; $p < 0.001$), a significant effect of mathematical communication level ($F = 85.34$; $p < 0.001$), and a significant interaction between the two factors ($F = 13.00$; $p = 0.0012$). Dunnett's post hoc analysis indicated that students with both high and low levels of mathematical communication performed significantly better under the RME model than under PBL ($t = 3.56$ and $t = 3.74$, respectively; $t_{0.05} = 2.49$). These findings suggest that RME is more effective than PBL in enhancing students' problem-solving abilities, regardless of their level of mathematical communication, and is well-suited for implementation in diverse classroom settings.

Keywords: Mathematical communication; Problem-Based Learning (PBL); Problem-solving skills Realistic Mathematics Education (RME)

1. Introduction

Based on data obtained from the Programme for International Student Assessment (PISA) (OECD, 2023), the problem-solving skills of Indonesian students remains significantly low compared to other participating countries. PISA (OECD, 2023) recorded an average mathematics score of 366 points for Indonesian students, which is substantially below the OECD average score of 472 points. This figure reflects a substantial gap in mathematical competence between Indonesian students and their counterparts in more developed countries. Furthermore, only approximately 18% of Indonesian students achieved the minimum proficiency level (Level 2) in problem-solving assessments, indicating that the majority of students face difficulties in addressing mathematical problems that require the application of critical, analytical, and creative thinking skills. This perspective aligns with recent international evidence on learning loss and the need to strengthen higher-order thinking instruction in low-performing systems (UNESCO, 2023). Additionally, results from the Trends in International Mathematics and Science Study (TIMSS) further reinforce the picture of Indonesian students' low competence in mathematics and science. In the TIMSS assessment, Indonesian students ranked among the lower-performing countries, with many still classified at low proficiency levels in understanding fundamental concepts and problem-solving skills (IEA, 2024). These data indicate that the issue of problem-solving competence is not new, and it continues to pose a significant educational challenge that merits serious attention from various stakeholders (OECD, 2023)(IEA, 2024).

Beyond these international assessments, the results of the Minimum Competency Assessment (Asesmen Kompetensi Minimum, AKM) in 2023 provide further evidence regarding numeracy competence issues facing Indonesian students. The Rapor Pendidikan Indonesia [Indonesian Education Report Card] 2023 reveals that 59.37% of Junior High School (Sekolah Menengah Pertama, SMP) students still fall into the low category of numeracy skills (Kemendikbudristek, 2023). This condition reflects that more than half of the students are unable to apply problem-solving skills in contexts relevant to daily life or complex academic challenges. Conversely, only around 40.63% of students have attained proficiency from basic to advanced levels (Kemendikbudristek, 2023). These findings underscore the urgency of developing more contextualized learning methods that require active student engagement in critical thinking processes. The importance of this skill is supported by various educational literatures that emphasize the need to develop problem-solving learning approaches that challenge students to process information and make decisions independently and systematically (Guo et al., 2024). Collectively, these three evaluation sources—PISA, TIMSS, and AKM—highlight an urgent need to improve learning models to enhance the problem-solving skills of Indonesian students.

Empirical observations and studies suggest that one of the main causes of poor problem-solving skills among students is the dominance of conventional teaching methods in schools, including SMPs. Such teaching methods tend to rely heavily on passive lecture approaches and rote learning exercises that emphasize memorization of formulas and procedures without providing opportunities for students to deeply explore mathematical concepts critically. Previous research has revealed that these approaches make students less actively engaged and hinder their ability to connect learning materials with real-life contexts in their surroundings (Mangarin & Caballes, 2024; Saragih & Napitupulu, 2015). Furthermore, the extensive use of textbooks as the primary learning resource also poses a challenge due to often non-contextual content and exercises that do not relate to students' daily experiences (Saragih & Napitupulu, 2015). Teachers' inability to present materials contextually and appealingly results in low motivation and student engagement during learning, thus impeding the optimal development of problem-solving skills. Under such instructional conditions, students are not accustomed to thinking critically, creatively, or analytically when facing complex problems requiring comprehensive solutions.

This reality calls for a revolutionary shift in teaching paradigms by adopting more innovative approaches oriented toward developing problem-solving skills. Two learning models considered highly relevant and promising in this context are Realistic Mathematics Education (RME) and

Problem-Based Learning (PBL). Both approaches position students as active learners central to the educational process, engaging them in solving authentic, contextual problems. RME invites students to construct mathematical understanding based on real-life experiences close to their daily lives, thus facilitating a better grasp and application of abstract mathematical concepts (Genç et al., 2025; Gravemeijer, 1994). Meanwhile, PBL emphasizes stimulating students' critical and autonomous thinking by guiding them through systematic problem identification, analysis, and decision-making processes (Nicholus et al., 2023; Barrows & Tamblyn, 1980). Previous studies have demonstrated that the implementation of RME and PBL significantly enhances students' problem-solving abilities, and the combination of these models yields better outcomes compared to conventional methods (Putri et al., 2022; Nicholus et al., 2023).

Although numerous studies have highlighted improvements in problem-solving abilities through RME and PBL, a critical gap remains regarding the limited attention to the role of mathematical communication within the learning context. Mathematical communication refers to students' ability to express ideas, arguments, and solutions logically, clearly, and systematically, both orally and in writing. This aspect is vital in problem-solving processes because it involves deep cognitive and social interaction and serves to reinforce conceptual understanding of mathematics (Nguyen et al., 2025; Genç et al., 2025). Therefore, this study aims to address this gap by positioning mathematical communication as a moderating variable that influences the effectiveness of these two learning models in enhancing students' problem-solving skills.

This research is designed to compare the effects of the Realistic Mathematics Education (RME) and Problem-Based Learning (PBL) models on the problem-solving abilities of junior high school students, taking into account their levels of mathematical communication skills. The novelty of this study lies in the parallel implementation of RME and PBL in different classes and the focus on analyzing mathematical communication as a key factor within the learning process. This approach is expected to provide a more comprehensive empirical understanding of the effectiveness of each model in enhancing problem-solving skills through the lens of mathematical communication. Findings from this research are anticipated not only to contribute to the advancement of mathematical teaching theories and practices but also to serve as a reference for educators in optimizing contextual, interactive learning strategies that support the holistic development of students’ critical thinking skills.

2. Method

This study adopted a quantitative approach using a quasi-experimental method with a 2×2 treatment-by-level factorial design to investigate the effects of the Realistic Mathematics Education (RME) and Problem-Based Learning (PBL) models on junior high school students’ problem-solving abilities, with mathematical communication level serving as a moderating variable. The 2×2 treatment by-level design was selected as it enables simultaneous examination of the main effects of the instructional models and levels of mathematical communication, as well as their interaction on the dependent variable. This approach offers a more comprehensive analysis than a simple experimental design. The 2×2 treatment-by-level design can be seen in Table 1 below.

Table 1. 2×2 Treatment-by-Level Design

Mathematical Communication Level B	**RME Approach (A1)**	**PBL Model (A2)**
High (B1)	A1B1	A2B1
Low (B2)	A1B2	A2B2

The study population comprised all seventh-grade students at SMP uring the 2024/2025 academic year, totaling 93 students. The sample was selected using random sampling by choosing two classes, each receiving instruction through either the RME or PBL model. In each class, students are categorized into high and low mathematical communication ability groups based on the results of a preliminary communication test. To clarify contrasts and enhance the sensitivity of the analysis regarding the treatment effects moderated by mathematical communication ability, the 2x2 treatment-by-level design intentionally samples only from the extreme categories (high and low), excluding the moderate category. Selecting extreme groups reduces heterogeneity within each cell, thereby decreasing within-group variance and increasing the likelihood of detecting an interaction between treatment and mathematical communication ability. The moderate category tends to have mixed or unstable profiles, which may increase variability, obscure differences between groups, and complicate the interpretation of average effects within that cell. Therefore, focusing on the high and low categories enhances the internal validity and facilitates the interpretation of results concerning differences in the effectiveness of learning models for students with clearly distinct levels of mathematical communication ability.

Two instruments were used in the study: a problem-solving ability test and a mathematical communication test, both consisting of open-ended items. The problem-solving test included five questions designed to assess students' ability to understand, plan, solve, and evaluate mathematical problems. The mathematical communication test consisted of four items developed based on indicators from the National Council of Teachers of Mathematics (NCTM, 2000), which included the ability to express mathematical ideas orally and in writing, use mathematical representations, and explain and justify problem-solving strategies. Content validity for both instruments was assessed by two experts in mathematics education, yielding a Content Validity Ratio (CVR) of 1.00 well above the critical threshold of 0.62 indicating strong substantive validity. Empirical validity, tested using Pearson's product-moment correlation, produced coefficients ranging from 0.58 to 0.84, demonstrating moderate to high validity. Instrument reliability was assessed using Cronbach's alpha, yielding coefficients of 0.81 for the problem-solving test and 0.78 for the mathematical communication test. These results indicate that both instruments were highly reliable and suitable for use in the study.

Data collection was conducted in several phases. Initially, students completed a pre-test on mathematical communication to assess their baseline ability to express mathematical ideas and arguments in writing. This pre-test was also used to classify students into high, medium, and low communication levels. Following this, students participated in learning sessions based on the RME and PBL models, each delivered over four instructional meetings. After the intervention, students completed a post-test on problem-solving ability to assess their progress in addressing mathematical problems. The data obtained from both instruments served as the basis for subsequent analysis.

Data analysis began with prerequisite tests to ensure that the assumptions for ANOVA were satisfied. Normality was assessed using the Shapiro–Wilk test, while homogeneity of variances was examined using Levene's test. Once these assumptions were confirmed, both descriptive and inferential analyses were performed. Inferential statistics involved a two-way analysis of variance (2×2 ANOVA) to examine the interaction between the learning models and levels of mathematical communication on students' problem-solving abilities. When significant interaction effects were identified, a post hoc Dunnett's test was conducted to determine which instructional model was most effective within each communication category. All statistical tests were conducted at a 5% significance level ($\alpha = 0.05$).

3. Results and Discussion

3.1. Results

This study aims to investigate the comparative effects of the Realistic Mathematics Education (RME) and Problem-Based Learning (PBL) models on students' problem-solving skills taking into account their levels of mathematical communication skills A quasi-experimental design using a 2×2 treatment-by-level factorial model was implemented with seventh-grade students at SMP Negeri 1 Jerowaru. Participants were categorized into four treatment groups based on the instructional model and their level of mathematical communication: RME–High, RME–Low, PBL–High, and PBL–Low.

Table 2. Pre-Test Results of Students' Mathematical Communication Skills

Treatment Group	N	Min Score	Max Score	Mean	SD
RME	24	67	88	79	6
PBL	23	67	88	78	6

Based on the data presented in Table 2, the average pre-test scores for students' mathematical communication skills were relatively comparable between the RME and PBL groups. Subsequently, students in each treatment group were classified into three levels of mathematical communication ability high, medium, and low as shown in Tables 3 and 4.

Table 3. Categories of Mathematical Communication Skills in the RME Group

Category	N	Min	Max	Mean	SD
High	8	82	88	85	2
Medium	8	73	80	77	4
Low	8	67	75	72	3

Table 4. Categories of Mathematical Communication Skills in the PBL Group

Category	N	Min	Max	Mean	SD
High	8	82	88	85	2
Medium	7	76	78	78	1
Low	8	67	75	71	2

Tables 3 and 4 show the distribution of students' mathematical communication abilities across the high, medium, and low categories within the RME and PBL groups. The highest mean scores were observed in the high category (85), followed by the medium category (77–78), and the lowest in the low category (71–72). The score distributions within each category were relatively homogeneous. For subsequent analyses, only data from students in the high and low communication skill categories within each treatment group were included.

Following the implementation of the instructional treatments in each class, post-test results on students' problem-solving abilities were obtained, as presented in Table 5.

Table 5. Post-Test Results of Problem-Solving Ability

Treatment Group	N	Min	Max	Mean	SD
RME	24	68	91	79	8
PBL	23	58	82	70	9

Table 5 displays the students' problem-solving performance after the application of the respective instructional models. The average score for the RME group was 79, notably higher than that of the PBL group, which averaged 70. The RME group also demonstrated superior minimum and maximum scores, suggesting that the RME model was more effective in improving students' problem-solving abilities.

Subsequently, the post-test data were further categorized into four groups based on the instructional model and the students' levels of mathematical communication, as shown in Table 6.

Table 6. Mean Problem-Solving Scores by Group

Code	Model	Communication Level	N	Min	Max	Mean	SD
A1B1	RME	High	8	88	91	90	1
A1B2	RME	Low	8	68	72	70	1
A2B1	PBL	High	8	78	82	80	1
A2B2	PBL	Low	8	58	61	60	1

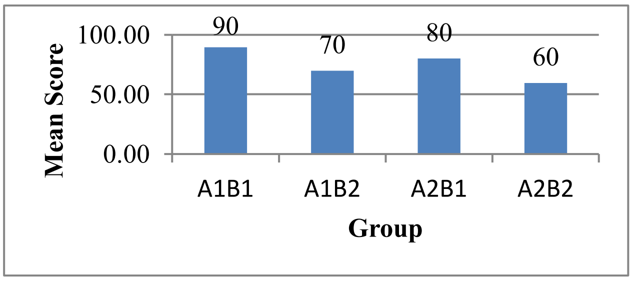

Figure 1. Mean Problem-Solving Scores by Group

Figure 1 presents a comparison of the average problem-solving scores across the four groups. The RME group with high mathematical communication skills (A1B1) recorded the highest mean score (90), followed by the PBL–High group (80), the RME–Low group (70), and the PBL–Low group (60). The graph demonstrates that the RME model outperformed the PBL model across both levels of mathematical communication, with the most pronounced advantage observed in the high-communication group.

Prior to hypothesis testing, preliminary assumption checks were conducted, including tests for normality and homogeneity of variance. The results of these tests are summarized in Table 7.

Table 7. Results of the Normality Test

Tests of Normality				
	Kelompok	Shapiro-Wilk		
		Statistic	df	Sig.
Nilai	A1B1	0.917	8	0.408
	A1B2	0.958	8	0.792
	A2B1	0.965	8	0.857
	A2B2	0.906	8	0.324

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tabel 8. Results of the Homogenity Test

Test of Homogeneity of Variance				
	Levene Statistic	df1	df2	Sig.
Based on Mean	0.268	3	28	0.848
Based on Median	0.359	3	28	0.783
Based on Median and with adjusted df	0.359	3	27.576	0.783
Based on trimmed mean	0.278	3	28	0.841

Based on Table 8, the normality test results show that the significance values for each group exceed 0.05, indicating that the data in all groups are normally distributed. Similarly, the homogeneity test yielded a significance value of 0.848, which is greater than 0.05, confirming that the assumption of homogeneity of variances is satisfied.

Subsequently, a two-way ANOVA was conducted to examine the effects of the learning model, mathematical communication skills, and their interaction on students' problem-solving abilities. The results are summarized in Table 9.

Table 9. Summary of Two-Way ANOVA Results

Source of Variation	SS	df	MS	F-Value	Description
Learning Model	3200.25	1	3200.25	106.68	Significant
Mathematical Communication	2560.50	1	2560.50	85.34	Significant
Interaction (Model × Communication)	390.00	1	390.00	13.00	Significant
Error	840.00	28	30.00	–	–

As shown in Table 9, the two-way ANOVA revealed a statistically significant difference between the RME and PBL learning models in relation to students' problem-solving abilities ($F = 106.68 > F_t = 4.20$, $p < 0.05$). This finding suggests that the RME model is more effective than the PBL model in enhancing students' problem-solving performance.

Moreover, mathematical communication skills also demonstrated a significant impact on students' learning outcomes, as indicated by an F-value of 85.34, which exceeds the critical value of 4.20. Students with high mathematical communication skills achieved higher average scores than those with lower communication abilities.

Importantly, a significant interaction effect was found between the learning model and mathematical communication skills on students' problem-solving abilities ($F = 13.00 > F_t = 4.20$). To further explore these group differences, a post hoc Dunnett test was conducted, as presented in Table 10.

Table 10. Dunnett Test Results

Comparison	t-value	t-critical (5%)	Description
A1B1 vs. A2B1	3.56	2.49	Significant
A1B2 vs. A2B2	3.74	2.49	Significant

The results of the Dunnett test reveal a statistically significant difference between the RME and PBL learning models among students with high mathematical communication skills. This is evidenced by a t-value of 3.56, which exceeds the critical value of 2.49, along with a mean score difference indicating a significant improvement in the RME group compared to the PBL group. Furthermore, the effect size measured by Cohen's ddd is 0.75, indicating a moderate to large effect, which strengthens the evidence that the RME model has a more substantial positive impact on problem-solving skills in this group

Similarly, for students with low mathematical communication skills, the observed t-value of 3.74 also surpasses the critical threshold of 2.49, confirming a significant difference. The mean score difference and a Cohen's ddd value of 0.82 in this group demonstrate a large effect, reaffirming the consistent superiority of the RME model. Therefore, based on both statistical significance and effect size measures, it can be concluded that the RME model outperforms the PBL model in enhancing students' problem-solving skills, regardless of their level of mathematical communication skills.

3.2. Discussion

The findings of this study demonstrate that the Realistic Mathematics Education (RME) model consistently outperforms Problem-Based Learning (PBL) for students with both high and low levels of mathematical communication skills. This superiority can be attributed to RME's contextual approach, which embeds mathematical problems in real-life scenarios, allowing students to relate abstract concepts to concrete situations and to develop problem-solving strategies progressively and systematically.

These results align with the study's original objectives: to investigate the effects of instructional models and mathematical communication levels on students' problem-solving abilities, as well as to examine the interaction between these variables. The analysis revealed that both the instructional model and communication skills significantly influence student performance, with their interaction playing a meaningful role in determining problem-solving success. Specifically, in the RME approach, mathematical communication emerges through visual representations such as bar charts or block diagrams created by students to illustrate fraction problems (e.g., "I divide the rectangle into 4 equal parts and shade 3 parts to represent 3/4"), which facilitates contextual understanding and step-by-step exploration—thus addressing how RME stimulates representational mathematical communication through realistic activities. In contrast, in the PBL model, mathematical communication focuses more on verbal group discussions to formulate solution hypotheses (e.g., "I think we divide the apple into 8 parts because there are 8 friends, then calculate how much each gets"), which explains why students communicate cooperatively yet prove less effective for those with low communication levels due to the lack of visual guidance. This in-depth description links numerical results ($F = 106.68$; $p < 0.001$) to the RME theoretical framework emphasizing development from concrete to abstract, thereby providing strong support for RME's superior adaptability, even for students with lower communication abilities.

This conclusion is supported by both primary theoretical references in Realistic Mathematics Education (RME) and a range of empirical studies. As primary sources, Hans Freudenthal (1973, 1991) posits that mathem atics constitutes a human activity intrinsically linked to reality, emphasizing the principle of guided reinvention through contextual problems to facilitate horizontal mathematization (from real-world contexts to symbolic representations) and vertical mathematization (within formal mathematical domains). Gravemeijer (1994) further delineates three core tenets of RME: guided reinvention and progressive mathematization, didactical phenomenology, and emergent modeling, which underpin enhanced problem-solving via visual representations and incremental exploration.

Empirically, Palinussa et al. (2021) demonstrated that RME significantly elevates students' problem-solving skills across diverse prior mathematical proficiency levels. Susanti and Rustam (2018) reported RME's superior efficacy over direct instruction in fostering mathematical reasoning. Similarly, Akosah et al. (2026) observed that RME not only bolsters problem-solving and literacy abilities but also strengthens overall mathematical competence. Studies by Dinglasan et al. (2023) likewise affirm that RME and hybrid RME-PBL approaches substantially improve conceptual understanding and problem-solving capacities. Mutmainah and Karlimah (2024) corroborated RME's role in supporting elementary students' engagement alongside problem-solving performance gains, while Sidik and Herman's (2023) systematic review substantiated RME's positive effects on mathematical communication and problem-solving at the elementary level

In addition, Marpaung et al. (2020) found that RME contributes to improved mathematical communication. A meta-analysis by Putri et al. (2022) also demonstrated that RME generally strengthens students' mathematical communication skills. These findings are further corroborated by an experimental study by Gunawan and Hadi (2024), which revealed that RME instruction combined with students' reasoning ability significantly improved conceptual and procedural understanding of mathematics.

However, the present findings are not entirely consistent with those of Ndia et al. (2025), who found that the effectiveness of PBL in enhancing mathematical communication skills is moderated by students' dispositional characteristics, with high-disposition students benefiting more from PBL while low-disposition students performed better under more structured, direct instruction. This discrepancy may explain why the PBL model was less effective in the current study's context, where most students possessed moderate to low levels of communication ability. The novelty of this research lies in its dual focus: not only comparing the effectiveness of two instructional models, but also analyzing how each interacts with students' mathematical communication skills. The findings suggest that RME remains effective and superior across all levels of communication ability, positioning it as an inclusive and adaptive instructional model.

The implications of these findings emphasize the importance for mathematics educators to adopt the Realistic Mathematics Education (RME) model, particularly in classrooms composed of students with diverse levels of mathematical communication skills. The RME model has proven effective in accommodating the varying cognitive characteristics of students, thereby enhancing problem-solving abilities more optimally. Conversely, if teachers choose to implement the Problem-Based Learning (PBL) model, it is essential to provide adequate training or scaffolding in mathematical communication prior to instruction. This necessity arises from the study's findings, which indicate that PBL is less effective than RME, possibly because PBL requires higher levels of communication skills for students to actively engage in problem-solving and collaborative processes. Contributing factors to this reduced effectiveness may include the lack of meaningful contextual support and limitations in the progressive modeling inherent in PBL. Therefore, integrating supportive strategies that facilitate the enhancement of mathematical communication is crucial to maximize the effectiveness of PBL implementation

4. Conclusion

The findings of this study reveal that the Realistic Mathematics Education (RME) model has a significant and positive effect on enhancing students' problem-solving skills. Compared to the Problem-Based Learning (PBL) model, RME shows superior effectiveness, as reflected by consistently higher post-test scores across varying levels of mathematical communication ability. This demonstrates the flexibility of the RME model in accommodating diverse cognitive profiles, benefiting students with both high and low communication skills.

Moreover, mathematical communication skills were found to play a crucial role in students' problem-solving performance. Students exhibiting higher levels of communication ability achieved better outcomes, which aligns with the emphasis placed by the National Council of Teachers of Mathematics (NCTM, 2000) on communication as an essential component of conceptual understanding. This underscores the dual function of mathematical communication: not only as a cognitive skill but also as a moderating variable that influences the success of instructional methods. The significant interaction between learning model and communication level further confirms that the effectiveness of instruction is closely linked to students' internal characteristics. As Malacapay (2024) highlighted, instructional success depends heavily on aligning teaching strategies with learners' cognitive profiles.

A primary contribution of this research is its integration of mathematical communication as a moderating factor in assessing instructional effectiveness, a dimension that has been relatively underexplored in previous studies. Theoretically, this study supports constructivist and contextual learning paradigms while providing practical insights for educators and curriculum developers to consider students' communicative competencies in the design of effective mathematics instruction.

However, certain limitations need to be acknowledged. The relatively small sample size and focus on a single educational level—seventh-grade junior high school students—may restrict the generalizability of the findings. Consequently, future research should expand the scope by including larger and more diverse samples spanning various educational levels. It is also recommended to investigate additional moderating variables, such as learning styles, student motivation, and mathematics anxiety, to deepen the understanding of the effectiveness of contextual-based instructional models across different learning contexts.

Furthermore, future studies are encouraged to explore other potential moderating factors, including learning motivation, creativity, and student engagement. Expanding similar experimental designs to elementary and senior high school levels could provide broader evidence of instructional model effectiveness. In addition, integrating the strengths of both the RME and PBL models may offer promising opportunities to develop a more effective and flexible hybrid instructional approach aimed at enhancing students' problem-solving skills

5. Acknowledgements

The author wishes to express profound gratitude to the Principal of SMP Negeri 1 Jerowaru, along with the dedicated teachers and administrative staff, for their kind permission and invaluable support in facilitating this research. Deep appreciation is also extended to the author's beloved family especially his wife and child for their unwavering prayers, encouragement, and moral support. This study was entirely self-funded by the author, without any external sponsorship, as a reflection of his personal commitment to the advancement of scientific knowledge.

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