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Problem-Based Learning in Elementary Mathematics: Enhancing Mathematical Self-Efficacy and Communication Skills

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Abstract: This study investigated the use of Problem-Based Learning (PBL) in elementary mathematics, with particular attention to students' mathematical self-efficacy and mathematical communication skills. A quantitative quasi-experimental study was carried out using a pretest–posttest control group design. The participants were 45 fifth-grade students from two elementary schools during the 2024/2025 academic year, including 22 students assigned to the experimental group and 23 to the control group. Students in the experimental group participated in four PBL lessons on whole-number arithmetic operations, while those in the control group received conventional mathematics instruction. Mathematical self-efficacy was assessed through a 20-item questionnaire, and mathematical communication skills were measured using a 10-item test. The data were examined using analysis of covariance (ANCOVA) after the required assumptions had been assessed. The analysis revealed a significant between-group difference in mathematical self-efficacy after controlling for the pretest score, $F(1,42) = 24{,}100$; $p < 0{,}001$; partial $\eta^2 = 0{,}365$. The adjusted posttest means were 61,13 for the PBL group and 55,70 for the control group. A significant difference was also found for mathematical communication skills, $F(1,42) = 8{,}835$; $p = 0{,}005$; partial $\eta^2 = 0{,}174$ with adjusted means of 30,28 and 27,69 for the PBL and control groups, respectively. The results suggest that, within this study, PBL was associated with higher adjusted scores in both mathematical self-efficacy and mathematical communication.

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INTRODUCTION

Mathematics instruction in elementary school lays a crucial foundation for students' future academic development, as mathematical knowledge and problem-solving skills are cumulative and become increasingly important as students progress through their education. Specifically, solving mathematical word problems requires students not only to perform mathematical operations but also to comprehend the problem situation, integrate verbal and mathematical information, select appropriate strategies, and evaluate the reasonableness of their answers (Lowrie, 2020; Vessonen et al., 2025). A recent systematic review and meta-analysis involving 115 reports and 20,456 elementary school students found a strong positive overall effect of mathematical word-problem-solving interventions ($g = 0.95$), highlighting the importance of providing effective instructional experiences during the elementary years (Vessonen et al., 2025). Given that elementary school students are still in the process of developing the cognitive abilities required to coordinate linguistic, representational, and mathematical information, instruction should provide opportunities for students to actively engage with meaningful problems, rather than merely practicing procedural calculations (Lowrie, 2020; Utami & Amir, 2024; Vessonen et al., 2025).

However, success in mathematics learning is not determined solely by students' cognitive abilities. Students' affective and motivational characteristics shape how they approach mathematical

tasks, respond to difficulties, and participate in learning activities (García et al., 2016; Karamarkovich & Rutherford, 2021). Emotional experiences are particularly relevant in mathematics, as students may feel curiosity, frustration, or uncertainty, or experience moments of insight while grappling with mathematical problems; these experiences can influence their participation and sense of mathematical agency (McLean et al., 2026). Therefore, mathematics instruction needs to create situations that encourage students to attempt challenging tasks, learn from mistakes, and build confidence in their ability to engage with mathematics (McLean et al., 2026). One affective construct highly relevant to these processes is mathematical self-efficacy—defined as students' belief in their ability to successfully complete mathematical tasks (Schunk & Pajares, 2002).

Mathematics self-efficacy is significant because students' efficacy beliefs are linked to their academic performance and can influence how they approach learning tasks, persist in the face of difficulties, and regulate their efforts (Schunk & Pajares, 2002; Talsma et al., 2018). A meta-analysis employing a cross-lagged design further demonstrates a reciprocal relationship between self-efficacy and academic performance; this indicates that efficacy beliefs are not merely a reflection of past achievements but can also contribute to future academic performance (Talsma et al., 2018). Recent research also emphasizes the importance of understanding how mathematics self-efficacy develops at the primary and secondary education levels, particularly through students' experiences regarding mastery, social interaction, persuasion, and psychological states (Bjerke et al., 2026). Therefore, in primary school mathematics instruction, learning conditions play a crucial role in strengthening students' confidence in understanding mathematical concepts and completing mathematics tasks. For instance, it has been found that a guided inquiry method combined with scaffolding significantly enhances the mathematics self-efficacy of fourth-grade students; these findings suggest that appropriately designed learning experiences can support students' confidence in learning mathematics (Vonitasari & Amir, 2025).

In addition to self-efficacy, mathematical communication is another important dimension of mathematics learning, as students need to communicate mathematical ideas to demonstrate their reasoning, explain strategies, and participate in mathematical discourse. Mathematical communication requires students to understand and use mathematical language, representations, symbols, and explanations when expressing mathematical ideas (Lowrie, 2020; Powell et al., 2017). Research on elementary students has shown that mathematical vocabulary is related to students' mathematics performance and is particularly relevant for understanding mathematical texts and communicating within mathematics classrooms (Powell et al., 2017). Classroom interaction can also provide opportunities for students to construct and communicate mathematical meaning through discussion and the negotiation of mathematical ideas (Sum & Kwon, 2020). These processes are especially important in problem solving because students need to move between verbal, visual, and mathematical information, perform appropriate operations, and evaluate their solutions (Vessonen et al., 2025). Thus, mathematical communication should extend beyond producing a correct numerical answer and include students' ability to express, represent, explain, interpret, and evaluate mathematical ideas.

Problem-Based Learning (PBL) provides a potentially appropriate instructional approach for developing these complementary dimensions of mathematics learning. PBL places problems at the center of learning and engages students in investigating problems, constructing knowledge, discussing possible solutions, and reflecting on their reasoning (Dochy et al., 2003). Such characteristics can provide opportunities for students to experience active engagement with mathematical problems while interacting with peers and receiving support from teachers. The collaborative and problem-oriented nature of PBL may also create conditions that encourage students to explain their reasoning, compare strategies, use mathematical representations, and communicate solutions. Previous research has reported positive effects of PBL on skill-related outcomes, while studies in mathematics have also linked PBL with students' active engagement in problem solving and self-regulatory processes (Dochy et al., 2003; Hidajat, 2023). Therefore, PBL has theoretical potential to address both the cognitive-communicative demands of mathematical problem solving and the affective demands associated with students' confidence and persistence when confronting mathematical challenges.

Empirical studies have provided initial support for these possibilities, although their research configurations differ. Problem-Based Learning assisted by interactive worksheets has been found to

improve mathematical communication skills among fifth-grade elementary school students (Karatas-Aydin & Isiksal-Bostan, 2023). In addition, Problem-Based Learning assisted by manipulative teaching aids has demonstrated positive effects on students' mathematical communication skills and self-efficacy in elementary mathematics (Herdini et al., 2019). This study involved fourth-grade students and used a concurrent embedded mixed-method design; the researchers reported that the PBL intervention was effective in improving mathematical communication skills and was accompanied by increases in self-efficacy across the dimensions of magnitude, strength, and generality. Research on mathematics self-efficacy in primary education has also demonstrated that instructional approaches can influence students' efficacy beliefs, although such studies have not necessarily focused on PBL or on mathematical communication as a parallel outcome (Vonitasari & Amir, 2025).

Despite the growing body of evidence on PBL in elementary mathematics education, an important substantive question remains regarding how PBL may simultaneously support students' beliefs about their mathematical capabilities and their ability to communicate mathematical ideas. These two outcomes represent complementary dimensions of students' engagement in mathematical activity. Mathematical self-efficacy concerns students' perceived capability to understand, approach, and persist in mathematical tasks, whereas mathematical communication reflects their ability to express, represent, explain, and evaluate mathematical ideas. In PBL, students are expected to engage in authentic mathematical problems, explore and select solution strategies, explain their reasoning, discuss ideas with peers, receive feedback, and revise their solutions. These learning processes can provide opportunities for successful task experiences, social modeling, feedback, and persistence, while simultaneously requiring students to make their mathematical thinking visible through oral, written, symbolic, and representational forms. Therefore, examining MSE and MCS simultaneously holds theoretical relevance because changes in students' confidence in performing mathematics tasks and their ability to communicate mathematical reasoning can occur during the same problem-solving process, yet reflect distinct learning outcomes. Previous studies have provided evidence regarding PBL and mathematical communication or have investigated learning approaches in relation to mathematics self-efficacy. For instance, Herdini et al. (2019) examined PBL, mathematical communication, and self-efficacy within the context of primary school mathematics; however, the study combined quantitative and qualitative methods, utilized manipulatives as part of the intervention, and assessed self-efficacy primarily through its specific dimensions and within a particular group of students. Thus, a substantive aspect requiring clarification is whether participation in PBL is associated with differences in both mathematics self-efficacy and mathematical communication skills when these outcomes are examined concurrently within the same primary school mathematics learning context. This study addresses this issue by examining these two complementary outcomes among fifth-grade students learning whole-number operations, employing a quasi-experimental quantitative design that includes a control group and pretest-posttest measurements.

Therefore, this study aims to examine whether fifth-grade students receiving PBL-based mathematics instruction demonstrate higher mathematical self-efficacy and mathematical communication skills compared to students receiving conventional mathematics instruction, after controlling for their respective pretest scores. The study focuses on arithmetic operations with whole numbers, requiring students to understand contextual problems, select appropriate strategies, represent their mathematical thinking, explain solution procedures, and evaluate solutions. While problem-solving and mathematical reasoning are integral processes within PBL, this study focuses on mathematical self-efficacy and mathematical communication because the identified learning needs relate not only to student engagement in mathematical tasks but also to their confidence in performing these tasks and their ability to clearly communicate their mathematical thinking to others. These two outcomes therefore capture complementary aspects of students' participation in problem-based mathematics learning: their perceived capability to engage with mathematical tasks and their demonstrated ability to communicate mathematical ideas.

The study is guided by the proposition that PBL may support mathematical self-efficacy by providing mastery experiences through problem solving, vicarious experiences through observation of peers, social persuasion through teacher and peer feedback, and opportunities to manage affective

experiences when confronting challenging problems. At the same time, these PBL processes provide repeated opportunities for students to communicate mathematical ideas through representations, mathematical language, explanations, presentations, and evaluation of solutions. Thus, rather than treating MSE and MCS as substitutes for problem solving or reasoning, the study examines them as complementary outcomes that reflect how students engage with and communicate mathematical thinking during PBL. Based on this theoretical rationale, the study examines two hypotheses:

1. H1: After controlling for pretest mathematical self-efficacy, fifth-grade students who receive PBL-based mathematics instruction will demonstrate significantly higher adjusted posttest mathematical self-efficacy than students who receive conventional mathematics instruction.
2. H2: After controlling for pretest mathematical communication skills, fifth-grade students who receive PBL-based mathematics instruction will demonstrate significantly higher adjusted posttest mathematical communication skills than students who receive conventional mathematics instruction.

METHOD

Research Design

This study employed a quantitative approach with a quasi-experimental design using a pretest–posttest control group design. The design was selected because the study involved existing fifth-grade classes and the students were not individually randomly assigned to the experimental and control groups as shows in Table 1. The study involved two groups: an experimental group that received mathematics instruction using the Problem-Based Learning (PBL) model and a control group that received conventional mathematics instruction. Both groups were administered pretests before the intervention and posttests after the intervention to measure changes in students' mathematical self-efficacy and mathematical communication skills. The intervention was conducted over four meetings focusing on whole-number arithmetic operations. The PBL intervention was structured around five stages: (1) orienting students to the problem, (2) organizing students for learning, (3) guiding individual or group investigation, (4) developing and presenting solutions, and (5) analyzing and evaluating the problem-solving process. These stages were consistently implemented across the four treatment meetings.

Table 1. The Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	C	O_4

Note: O_1 = experimental-group pretest; O_2 = experimental-group posttest; O_3 = control-group pretest; O_4 = control-group posttest; X = PBL intervention; C = conventional instruction.

Participants and Sampling

The study population consisted of 67 fifth-grade students from SDN Sidorejo 1 and SDN Sidorejo 2 during the 2024/2025 academic year. Participants were selected using a purposive sampling technique, with two existing fifth-grade classes selected as intact groups. Selection criteria required the classes to be at the fifth-grade level, follow the same mathematics curriculum, cover the same topic of integer arithmetic during the study period, and be willing to participate in the intervention. These two classes were selected from the respective schools because they represented the available fifth-grade classes within the study population and could participate under comparable learning conditions. The experimental group comprised 22 fifth-grade students from SDN Sidorejo 1, while the control group consisted of 23 fifth-grade students from SDN Sidorejo 2, resulting in a total sample of 45 students. The experimental group received mathematics instruction using the Problem-Based Learning (PBL) model, whereas the control group received conventional mathematics instruction. Assignment to experimental and control conditions was determined at the class level rather than through individual random assignment. Both groups were taught by the same teacher due to staffing limitations, as the teacher was assigned to instruct both fifth-grade classes. Using the same teacher for both groups helped maintain consistency regarding teacher-related factors throughout the intervention. Baseline comparability was assessed using students' pretest scores

prior to the intervention, and these scores were subsequently included as a covariate in the ANCOVA analysis.

Intervention Procedure

The intervention was conducted in the experimental group over four meetings, with the learning material focused on whole-number arithmetic operations and contextual word problems. The treatment was designed to provide students with opportunities to solve contextual problems, communicate mathematical ideas, explain strategies, and evaluate solutions. The four meetings (Table 2) were organized progressively. In the first meeting, students worked on addition and subtraction of whole numbers through contextual problems. In the second meeting, the focus was on multiplication and division. The third meeting addressed mixed operations involving whole numbers, while the fourth meeting integrated whole-number operations through more complex contextual problems and evaluation of mathematical solutions. During the PBL activities, students were encouraged to identify relevant information, determine appropriate mathematical operations, develop representations, formulate solution strategies, present their solutions, and evaluate the correctness of their reasoning. The learning activities were supported by problem-based worksheets (LKPD), group activities, solution presentations, and student reflection. The intervention also explicitly targeted students' mathematical communication skills. Across the four meetings, students practiced five aspects of mathematical communication: expressing mathematical ideas in writing, using mathematical representations, using mathematical language and symbols, explaining strategies and solution processes, and interpreting and evaluating mathematical ideas or solutions.

Table 2. PBL Learning Focus and Main Activities Across Four Meetings

Meeting	Learning Focus	Main PBL Activities
1	Addition and subtraction of whole numbers	Identifying information, determining operations, explaining solutions
2	Multiplication and division of whole numbers	Developing mathematical representations and explaining strategies
3	Mixed operations of whole numbers	Explaining sequential solution processes and mathematical reasoning
4	Integrated whole-number problem solving	Interpreting, evaluating, and correcting mathematical solutions

Research Instruments

Two instruments were used to collect research data: the Mathematics Self-Efficacy (MSE) scale and the Mathematics Communication Skills (MCS) test. Mathematics self-efficacy was operationally defined as students' perceptions of their ability to perform specific mathematical tasks, encompassing the understanding of mathematical concepts, mathematical problem-solving, the use of appropriate strategies, the handling of challenging mathematical tasks, and the checking and revising of their mathematical work. The MSE instrument was developed based on these five task-oriented indicators and consisted of 20 statements, with four items representing each indicator. The five indicators were: (1) understanding mathematical concepts, (2) solving mathematical problems, (3) using mathematical strategies, (4) handling difficult mathematical tasks, and (5) checking and revising mathematical work.

Each MSE item was rated on a four-point scale from 1 (very unsure) to 4 (very sure), with higher scores indicating stronger mathematics self-efficacy. The items were formulated as specific assessments of students' perceived ability to perform mathematical tasks, rather than as general attitudes toward mathematics. For instance, the items covered students' confidence in solving mathematical problems, selecting appropriate strategies, persisting when facing difficult problems, and checking and correcting their mathematical work.

Mathematics communication skills were measured using a written-response test consisting of 10 items. This instrument assessed students' abilities to express mathematical ideas in writing, use mathematical representations, employ mathematical language and symbols, explain strategies and solution processes, and interpret and evaluate mathematical ideas or solutions. The ten items were

distributed across five indicators, with two items for each indicator. Each test item is scored between 0 and 4 using an established scoring rubric, resulting in a maximum raw score of 40, which can then be converted to a 0–100 scale.

Validity and Reliability of the Instruments

The content validity of the MSE instrument was examined through an expert review involving three validators. These validators evaluated the relevance and appropriateness of the items in relation to five indicators of mathematical self-efficacy and the characteristics of fifth-grade mathematics learning. Following the expert review, the instrument was pilot-tested with 36 students. For empirical item analysis, corrected item-total correlations were calculated by correlating each item with the total score excluding that specific item. The corrected item-total correlation coefficients for the 20 MSE items ranged from 0,345 to 0,730, indicating a positive relationship between individual items and the overall construct measured by the scale. The internal consistency of the MSE scale was assessed using Cronbach's alpha coefficient. The 20-item scale yielded a Cronbach's alpha coefficient of 0,877, indicating high internal consistency; consequently, all 20 items were retained for the main study. As the pilot sample consisted of only 36 students, factor analysis was not performed. Thus, the measurement evidence reported for the MSE scale is based on expert review, corrected item-total correlations, and internal consistency, rather than on factor analysis.

The content validity of the MCS instrument was established through an expert assessment involving three validators: a mathematics expert, an educational assessment expert, and a language expert. Content validity was quantified using Aiken's V index. The coefficients for the various aspects assessed ranged from 0,75 to 1,00, with a mean coefficient of 0,90, indicating strong content validity. The MCS instrument consists of 10 items requiring written responses, each scored on a scale of 0 to 4 using a pre-established scoring rubric. The rubric details performance criteria for each score level and is applied consistently to all student responses. All responses were evaluated by a single rater. To minimize potential scoring bias, the rater was unaware of the students' assignment to either the experimental or control group during the assessment process. The same scoring rubric was applied to responses from both groups and at both measurement time points. The internal consistency of the MCS test was assessed using Cronbach's alpha, yielding a coefficient of 0,886 across the 10 items based on the responses of 36 students. As only one rater was involved, inter-rater reliability statistics—such as the intraclass correlation coefficient (ICC) or weighted kappa—could not be calculated. Consequently, this scoring procedure is acknowledged as a limitation of the study.

Data Collection Procedure

Data collection was conducted in three main stages. First, the MSE scale and MCS test were administered as a pretest to both the experimental and control groups to identify the students' initial levels of mathematical self-efficacy and mathematical communication skills. Second, the experimental group received a PBL intervention over four sessions, while the control group received conventional mathematics instruction covering the same topic: arithmetic operations with whole numbers. Third, following the intervention, both groups were administered the same measurement instruments as a posttest. The pretest and posttest results were then compared to determine differences in the students' mathematical self-efficacy and mathematical communication skills. For the MCS assessment, all written responses were scored using a predetermined 0–4 scale rubric by an evaluator who was unaware of the student group assignments.

Data Analysis

The collected data were analyzed quantitatively using descriptive and inferential statistics. Descriptive statistics were used to summarize students' pretest and posttest scores using mean values and standard deviations. Prior to conducting ANCOVA, relevant assumptions were checked. Normality was assessed using the Shapiro-Wilk test, homogeneity of variance was examined using Levene's test, and the linear relationship between the covariate and the dependent variable was assessed by examining the association between pretest and posttest scores. The assumption of homogeneity of regression slopes was evaluated by testing the interaction between pretest scores and learning groups. Residual behavior for each ANCOVA model was also examined to identify potential deviations from model

assumptions. Since this study employed a quasi-experimental pretest-posttest design using intact classes rather than individual random assignment, analysis of covariance (ANCOVA) was used to compare posttest results while controlling for the corresponding pretest scores. Two separate ANCOVA models were estimated: one for mathematical self-efficacy (MSE) and one for mathematical communication skills (MCS). In each model, the corresponding pretest score was included as a covariate, while the learning model (PBL versus conventional learning) was included as a fixed factor. The group × pretest interaction was examined before interpreting the main group effect to determine whether the assumption of homogeneous regression slopes was satisfied. For each ANCOVA model, the covariate effect and group effect were reported with degrees of freedom, mean square, F statistic, exact p-value, and partial eta squared (ηp^2) as the effect-size measure. Adjusted posttest means were also reported together with their standard errors and 95% confidence intervals where available. Statistical significance was evaluated at $\alpha = 0,05$.

RESULT AND DISCUSSION

Effect of Problem-Based Learning on Mathematical Self-Efficacy

The descriptive results showed an increase in mathematical self-efficacy in both groups following the instructional period, with a greater increase observed in the PBL class than in the conventional instruction class (Table 3). The PBL class also had a higher baseline MSE score than the conventional instruction class. Nevertheless, the data met the assumptions required for ANCOVA, including normality, homogeneity of variance, and homogeneity of regression slopes. After controlling for the pretest MSE score, the ANCOVA indicated a statistically significant difference in adjusted posttest mathematical self-efficacy between the two learning groups. The adjusted posttest MSE score was higher in the PBL class than in the conventional instruction class. The descriptive statistics and ANCOVA results are presented in Table 3. Overall, the findings indicate that, within this sample, students in the PBL class demonstrated higher adjusted posttest mathematical self-efficacy than students in the conventional instruction class after accounting for their initial MSE scores.

Table 3. Descriptive and ANCOVA Results for Mathematical Self-Efficacy

Statistic	PBL Class (n = 22)	Conventional Class (n = 23)
Pretest MSE, M (SD)	54,77 (4,84)	51,43 (5,82)
Posttest MSE, M (SD)	62,18 (4,44)	54,70 (5,15)
Mean change	7,41	3,26
Adjusted posttest MSE mean	61,13	55,70

Baseline standardized mean difference = 0,62.
ANCOVA: $F(1; 42) = 24,100$, $p < 0,001$, partial $\eta^2 = 0,365$.
Note. ANCOVA was conducted with pretest MSE score as the covariate. The adjusted means represent estimated posttest MSE scores after controlling for baseline MSE.

The improvement in MSE can be understood from the characteristics of PBL, which position students as active participants in solving meaningful mathematical problems rather than as recipients of predetermined procedures. Within the PBL process, students are required to understand the problem, identify relevant information, discuss possible strategies, work collaboratively, and evaluate the solutions they produce. Such experiences provide students with opportunities to experience successful task completion and to develop greater confidence in their ability to deal with mathematical tasks (Bicer, Aldemir, et al., 2024; Knox & Kontorovich, 2023). The importance of affective and motivational experiences in elementary mathematics learning has also been emphasized in recent research, which suggests that students' emotional experiences and sense of mathematical agency are closely connected to their engagement with mathematical problem solving (McLean et al., 2026).

The present finding is consistent with previous evidence indicating that self-efficacy is an important factor associated with students' mathematical learning and achievement. Self-efficacy develops through students' experiences of successfully performing academic tasks and through the social and instructional environments in which learning takes place (Knox & Kontorovich, 2023; Schunk & Pajares,

2002). Research on mathematics self-efficacy has likewise demonstrated its relevance to students' mathematical performance and learning-related behaviors (Doz et al., 2026; Waluya et al., 2022). The current results extend this perspective by showing that an instructional model emphasizing authentic problem-solving and active student participation can be associated with substantial improvements in mathematical self-efficacy among fifth-grade elementary students.

The magnitude of the effect is particularly noteworthy. The partial η^2 value of 0,365 indicates a large effect, suggesting that the difference between the experimental and control groups was not merely a small statistical difference. This finding is also compatible with evidence that instructional interventions can influence students' self-efficacy when they provide opportunities for active participation, challenge, feedback, and successful performance. Recent research on primary mathematics education has similarly reported positive effects of instructional interventions on students' mathematical self-efficacy, although the instructional approaches and contexts differed from the present study (He & Xin, 2025; Xu et al., 2026).

Importantly, the current finding should be distinguished from studies in which self-efficacy is primarily used to classify or explain differences among students. In the present study, mathematical self-efficacy was treated as a primary learning outcome. This distinction is relevant because previous research has demonstrated that PBL can create learning conditions associated with students' confidence and engagement, but the specific effect of PBL on mathematical self-efficacy remains dependent on the instructional context, learning materials, and student characteristics (Hidajat, 2023; Knox & Kontorovich, 2023).

A particularly relevant comparison can be made with previous elementary mathematics research examining PBL together with mathematical communication and self-efficacy. PBL assisted by manipulative teaching aids was previously reported to improve mathematical communication skills while also being associated with increases in students' self-efficacy across several dimensions (Bicer, Aleksani, et al., 2024; Herdini et al., 2019; Ochugboju & Díez-Palomar, 2025). The present study supports this general pattern but provides quantitative evidence using a pretest–posttest controlled design and treats mathematical self-efficacy as one of two parallel outcomes. Thus, the findings suggest that PBL may contribute not only to students' mathematical performance but also to their confidence in engaging with mathematical tasks.

Effect of Problem-Based Learning on Mathematical Communication Skills

The results in Table 4 also showed an increase in mathematical communication skills in both groups following the instructional period, with a greater increase observed in the PBL class than in the conventional instruction class. The PBL class also had a higher baseline MCS score than the conventional instruction class. After controlling for the pretest MCS score, the ANCOVA indicated a statistically significant difference in adjusted posttest mathematical communication skills between the two learning groups. The adjusted MCS post-test scores in the PBL class were higher than those in the conventional instruction class. Descriptive statistics and ANCOVA results are presented in Table 4. Overall, the findings indicate that, within this sample, students in the PBL class demonstrated higher levels of mathematical communication skills (MCS) on the adjusted post-test compared to students in the conventional instruction class, after accounting for their initial MCS scores.

Table 4. Descriptive and ANCOVA Results for Mathematical Communication Skills

Statistic	PBL Class (n = 22)	Conventional Class (n = 23)
Pretest MCS, M (SD)	27,77 (2,58)	25,83 (2,50)
Posttest MCS, M (SD)	30,91 (2,71)	27,09 (3,49)
Mean change	3,14	1,26
Adjusted posttest MCS mean	30,28	27,69

Baseline standardized mean difference = 0,76
ANCOVA: $F(1; 42) = 8,835$, $p = 0,005$, partial $\eta^2 = 0,174$.
Note. An ANCOVA analysis was conducted using pretest MCS scores as a covariate. The adjusted means represent estimated posttest MCS scores after controlling for baseline MCS values. The standardized

mean difference at the initial stage was calculated based on pretest mean scores and the pooled standard deviation.

The positive impact on MCS is closely linked to the problem-solving activities integrated into the PBL process. Mathematical communication requires students not only to obtain numerical answers but also to articulate mathematical ideas, select appropriate representations, use mathematical language and symbols, explain the procedures employed, and interpret or evaluate solutions. These demands are highly relevant to contextual mathematical problems, as students must navigate between verbal information and mathematical representations while simultaneously selecting and performing the appropriate mathematical operations. Research on elementary mathematical problem solving has emphasized that word problems require students to understand linguistic information, construct mental representations, perform mathematical operations, and evaluate the reasonableness of their answers (Setiyani et al., 2024; Stenberg Hartviksen & Haavold, 2025).

The PBL environment provides repeated opportunities for these communication processes to occur. When students work in groups to investigate a problem, they need to articulate what is known, determine what is being asked, explain their strategy, and justify their answer to peers. The presentation and evaluation stages further require students to communicate their reasoning and respond to alternative solutions. Consequently, mathematical communication becomes part of the problem-solving process rather than an additional activity performed after obtaining an answer (Bicer, Aleksani, et al., 2024; Salido & Dasari, 2019).

This finding is consistent with previous research showing that PBL can support mathematical communication skills in elementary mathematics. For example, one study examined PBL assisted by manipulative teaching aids and reported higher mathematical communication performance among elementary students receiving the PBL-based intervention than among students receiving conventional learning (Herdini et al., 2019). Their study assessed both written and oral mathematical communication, providing evidence that PBL can create opportunities for students to express and explain mathematical ideas during problem-based learning. The present findings are consistent with this evidence and extend it by showing a significant adjusted between-group difference in mathematical communication skills in a fifth-grade whole-number arithmetic context using a quantitative quasi-experimental pretest–posttest design.

The present study also provides a somewhat different emphasis from earlier research. Mathematical communication in this study was operationalized through written mathematical tasks requiring students to express mathematical ideas, use representations, apply mathematical language and symbols, explain strategies and procedures, and interpret or evaluate solutions (Ahn et al., 2024; Hoa et al., 2026). Therefore, the observed improvement cannot be interpreted merely as an improvement in students' ability to produce correct numerical answers. Rather, the learning activities required students to make their mathematical thinking visible through written communication.

The effect size obtained for MCS (partial $\eta^2 = 0{,}174$) indicates a large effect, although it was smaller than the effect obtained for MSE (partial $\eta^2 = 0{,}365$). One possible interpretation is that mathematical communication requires students to coordinate several processes simultaneously, including comprehension, representation, procedural reasoning, and written explanation. Consequently, enhancing these interconnected skills may require sustained opportunities for practice. Nevertheless, these significant results indicate that four PBL sessions were sufficient to produce a measurable difference between the experimental and control groups within this learning context.

Integrated Discussion: The Role of Problem-Based Learning in Developing Self-Efficacy and Mathematical Communication

Overall, the findings indicate that PBL has a significant impact on both mathematical self-efficacy and mathematical communication skills. This is important because these two outcomes represent complementary dimensions of mathematics learning. Mathematical self-efficacy relates to students' belief in their ability to successfully complete mathematical tasks, whereas mathematical communication relates to their ability to express, represent, explain, and evaluate mathematical ideas. The simultaneous improvement of these outcomes suggests that PBL may create a learning environment in which students

are not only more confident in engaging with mathematics but are also given opportunities to communicate their mathematical thinking (Gun & Bossé, 2025; Salido et al., 2020).

The relationship between these two outcomes can be understood through the nature of PBL activities. Students encounter problems that require them to work through uncertainty, select strategies, discuss their reasoning, and evaluate solutions. Successfully completing such activities may strengthen students' confidence in their mathematical capabilities. At the same time, explaining strategies and discussing solutions provides opportunities to practice mathematical communication. Thus, the affective and communicative dimensions of mathematics learning can develop within the same instructional process rather than being treated as separate learning targets (Ceballos et al., 2026).

This interpretation is supported by previous elementary research in which PBL assisted by manipulative teaching aids was found to be effective for mathematical communication while students' self-efficacy also increased during the intervention (Herdini et al., 2019). However, this study extends existing evidence by examining MSE and MCS as two parallel primary outcomes within a quantitative pretest-posttest control group design. This approach is significant because previous studies have often focused on mathematical communication as the primary outcome while using self-efficacy to characterize students, or have examined self-efficacy in isolation from mathematical communication.

The findings also have implications for elementary mathematics instruction. A mathematics classroom that emphasizes only correct answers may offer limited opportunities for students to build confidence and communicate their mathematical reasoning. In contrast, PBL requires students to engage with problems, discuss possible solutions, represent mathematical ideas, explain their reasoning, and evaluate the validity of solutions. Such learning experiences are consistent with broader evidence that problem-oriented and contextual mathematics learning encourages students to construct mathematical meaning through active engagement with meaningful problems. Research on elementary mathematics has also identified problem solving and PBL as prominent directions in contemporary mathematics education research.

Overall, the results indicate that PBL can function as an instructional approach that simultaneously supports affective and communicative dimensions of elementary mathematics learning. The larger effect observed for mathematical self-efficacy suggests that the intervention may have been particularly effective in strengthening students' confidence in engaging with mathematical problems, while the significant effect on mathematical communication indicates that the collaborative and explanatory nature of PBL also supported students' ability to communicate mathematical reasoning. These findings strengthen the argument for designing elementary mathematics instruction that integrates cognitive problem solving with opportunities for students to develop confidence and communicate their mathematical thinking.

Research Limitations

There are several limitations to consider when interpreting the findings of this study. First, the study involved 45 fifth-grade students from two elementary schools, which limits the extent to which the results can be generalized to other student populations or school contexts. Second, the study employed purposive sampling and utilized pre-existing classes rather than individual random assignment. Although pretest scores were included as a covariate in the ANCOVA analysis, unmeasured differences between classes or schools may still have influenced the results. Third, the intervention consisted of four instructional sessions focused on arithmetic operations with integers. Consequently, these findings do not indicate whether similar results would be obtained if the intervention were conducted over a longer duration or applied to other mathematical topics. Finally, mathematical communication skills were assessed through written tasks evaluated by a single rater, while mathematical self-efficacy was measured using a self-report questionnaire. Because only one rater evaluated the written responses, inter-rater reliability could not be determined. These limitations should be taken into account when interpreting the findings and when designing future research.

CONCLUSION

This study found that fifth-grade students who participated in Problem-Based Learning (PBL)

demonstrated higher adjusted posttest scores—in both mathematical self-efficacy and mathematical communication skills—compared to students who received conventional mathematics instruction. These findings indicate that PBL can bolster students' confidence in completing mathematical tasks and their ability to articulate and explain their mathematical reasoning in the context of integer operations. By engaging students in solving contextual problems, participating in discussions, and explaining mathematical strategies, PBL provides an opportunity to support both the affective and communicative dimensions of mathematics learning at the elementary school level.

Future research should examine PBL interventions over a longer duration, involve larger and more diverse samples across various schools and classrooms, and explore different mathematical topics. Subsequent studies could also combine written assessments with classroom observations and oral mathematical communication tasks to develop a more comprehensive understanding of students' mathematical self-efficacy and mathematical communication skills.

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AI USAGE STATEMENT

Generative AI tools were used to assist in the drafting and revision of the manuscript text, as well as to improve linguistic clarity, grammar, and readability. The authors have critically reviewed and evaluated the AI-assisted content and take full responsibility for the accuracy of the information, the originality of the work, the integrity of citations, the interpretation of findings, and the scientific conclusions presented in this manuscript.

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