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Collaborative Learning Model of the PBL Type with a Scientific Approach to Improve Mathematical Problem-Solving Skills and Self-Regulated Learning of Students

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Abstract

21st-century education requires students to master mathematical problem-solving skills and self-regulated learning (SRL), but these skills remain a challenge for junior high school students in Indonesia. This study aims to examine the impact of implementing a Collaborative Learning Model of the PBL combined with a scientific approach (observing, questioning, reasoning/trying, communicating) on students' mathematical problem-solving skills and SRL. The study used a pre-experimental method with a One-Group Pretest–Posttest design on 31 seventh-grade students at a junior high school in Sleman Regency. Data on problem-solving skills were collected through a 5-item essay test with a maximum theoretical score of 50, while SRL was measured using a Likert scale questionnaire. Inferential analysis used the Wilcoxon signed-rank test for problem-solving skills (the assumption of normality was not met) and the paired sample t-test for SRL. The results showed a significant increase in problem-solving skills from 15.32 to 30.92 ($Z = -4.126$; $p < 0.001$; $r = 0.74$), with posttest achievement equivalent to 61.84% of the theoretical maximum score. SRL also increased significantly from 121.81 to 122.74 ($t(30) = -2.412$; $p = 0.022$; $dz = 0.43$), although the mean difference was relatively small compared to the scale range. These findings indicate changes in students' achievement after the intervention; however, the results should be interpreted cautiously due to the short intervention duration and the limitations of the one-group pretest–posttest design without a control group.

Keywords: Collaborative learning, Problem-Based Learning, Mathematical Problem Solving, Self-Regulated Learning, Scientific Approach

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INTRODUCTION

21st-century education requires students to have higher-order thinking skills, including critical thinking, creativity, problem solving, and self-regulated learning as important competencies to face global challenges (Asri et al. 2023; Rahman, 2019). In the context of mathematics education, problem-solving skills are a key cognitive skill that needs to be developed so that students are able to apply mathematical concepts meaningfully in various situations (Daimah & Suparni, 2023).

However, the reality in the field shows that junior high school students' mathematical problem-solving skills are still relatively low. Setiawati et al. (2017) reported that most junior high school students have difficulty understanding problems, determining solution strategies, and relating relevant mathematical concepts. This condition shows that problem-solving skills are still an important concern in mathematics learning, especially at the junior high school level.

In addition to problem-solving skills, self-regulated learning (SRL) is also an important skill in 21st-century mathematics learning. Zimmerman & Moylan (2009) explain that SRL involves the processes of planning, monitoring, and self-evaluation that enable students to manage their learning independently. SRL plays an important role in helping students set learning goals, choose appropriate strategies, and reflect on their learning outcomes (Arslantosun, 2021; Slisko, 2017). Rahmawati et al. (2023) emphasize that SRL plays a role in helping students manage the learning process independently, especially in the context of 21st-century learning demands. Thus, in mathematics learning, problem-solving and self-regulated learning are two important skills that need attention in efforts to improve the quality of student learning processes.

The development of problem-solving and SRL skills is influenced by the learning model used in the classroom. Widyaningsih et al. (2023) state that an inappropriate learning model can have an impact on low problem-solving skills in students. Collaborative learning is seen as an approach that encourages interaction and discussion among students in building a common understanding (Sharma, 2023). Meanwhile, Problem-Based Learning (PBL) places contextual problems as the focus of learning to encourage students to think and actively seek solutions (Masturi et al., 2020).

Previous studies have shown that integrating collaborative learning with Problem-Based Learning (PBL) can support students' mathematical problem-solving skills. Collaborative settings encourage interaction, discussion, and shared responsibility during problem solving (Hendarwati et al. 2021; Hidayatullah et al. 2020; Fitriyani et al. 2019). Such environments may also contribute to the development of self-regulated learning because students are encouraged to plan, monitor, and evaluate their learning while working with peers (Efendi et al. 2018; Kumyoung et al. 2023). However, problem-solving skills and SRL have not always been examined simultaneously in the same learning context.

Unlike many previous studies that examined collaborative learning or PBL separately, this study designed a collaborative PBL-based learning model by explicitly mapping the scientific approach to each phase of the learning process. The scientific approach, which includes observing, questioning, reasoning or trying, and communicating, is used as a framework for mathematics learning activities (Sudirman et al. 2017; Made et al. 2022; Nurzaman et al., 2022).

Despite extensive research on collaborative learning and Problem-Based Learning (PBL), several gaps remain. Previous studies report inconsistent effects of PBL and collaboration on mathematical problem-solving skills, particularly in geometry topics and short instructional durations. Moreover, self-regulated learning (SRL) is often examined separately from problem-solving outcomes, making it difficult to understand how both constructs develop simultaneously within the same instructional setting. Importantly, most prior studies implement collaborative learning and PBL as stand-alone approaches without explicitly mapping scientific approach steps to each phase of instruction.

Therefore, this study contributes by proposing a Collaborative PBL Model with a Scientific Approach (C-PBL-SA), in which observing, questioning, reasoning/trying, and communicating are systematically integrated into each phase of the PBL process. The hypothesis of this study is:

H_1: There is a difference in students' mathematical problem-solving abilities before and after the implementation of a Collaborative Learning Model of the PBL with a scientific approach.

H_2 : There is a difference in students' self-regulated learning before and after the implementation of a Collaborative Learning Model of the PBL with a scientific approach.

METHOD

Research Design

This study used a quantitative approach with a pre-experimental design of the One Group Pretest–Posttest Design type. One sample group was measured before the treatment (pretest) and after the treatment (posttest) to observe changes in problem-solving abilities and self-regulated learning.

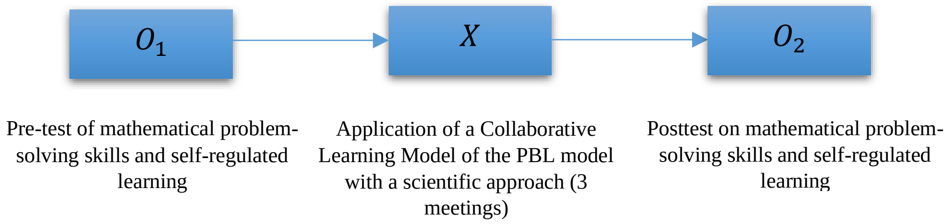

Figure 1 One-group pretest-posttest research design.

Threats to Validity and Mitigation

The one-group pretest–posttest design has limitations in terms of internal validity because it does not completely eliminate the effects of testing, student maturity, and historical factors. To minimize bias, assessments were conducted using consistent rubrics, the duration of the intervention was relatively short, and learning procedures were applied uniformly. Therefore, the results of this study are interpreted as preliminary evidence and are not claimed to be a strong causal relationship.

Research Intervention

The intervention applied a Collaborative PBL Model with a Scientific Approach (C-PBL-SA) in learning geometry topics (triangles and quadrilaterals). Instruction was conducted over three meetings, each lasting one class period. Students worked in small heterogeneous groups of four to five members based on initial ability. The instructional sequence followed four main phases: (1) problem orientation, (2) learning organization, (3) investigation and solution development, and (4) analysis and evaluation. At each phase, the scientific approach was explicitly embedded through observing, questioning, reasoning or trying, and communicating activities. Teachers acted as facilitators by guiding discussion, supporting collaboration, and ensuring that each phase of the C-PBL-SA model was implemented according to the lesson plan.

Table 1 Details of learning interventions

Meeting	Material	C-PBL-SA Phase	Main Student Activities	Scientific Approach
1	Triangle	Problem orientation and learning organization	Students work in groups to observe contextual problems, identify known information, and formulate questions.	Observing and questioning
2	Triangles and quadrilaterals	Investigation and solution development	Group discussions to develop problem-solving strategies and mathematical solutions	Reasoning/trying
3	Quadrilateral	Analysis and evaluation	Presentation of discussion results, reflection on the problem-solving process, and conclusion drawing	Communicating

Population and Samples

This study was conducted at a public junior high school in Sleman Regency, Special Region of Yogyakarta, from May to June 2025. The research subjects were 31 seventh-grade students aged 12–13 years, consisting of 16 female students and 15 male students. The sample class was selected using purposive sampling, considering the class's readiness and the suitability of the learning schedule. The students' initial abilities were heterogeneous and were assessed through pretest scores.

Instruments and Instrument Development

The data collection instruments used in this study consisted of a mathematical problem-solving ability test and a self-regulated learning questionnaire. The mathematical problem-solving ability test was used to collect data on students' ability to solve mathematical problems before and after the treatment. The mathematical problem-solving ability test was in the form of an essay test consisting of five questions with a maximum theoretical score of 50. The following is an example of a mathematical problem-solving item along with a summary of the scoring rubric.

Table 2 Sample Questions on Problem-Solving Skills

Sample Questions
Perhatikan layang-layang ABCD. Diketahui panjang diagonal AC = 10 cm dan diagonal BD = 6 cm. (a) Tentukan luas layang-layang ABCD. (b) Jelaskan alasan penggunaan rumus yang digunakan dalam penyelesaian soal tersebut.

Table 3 Summary of the problem-solving scoring rubric

Problem Solving Indicators	Assessment Description	Score
Understanding the Problem	Correctly state the known information and what is asked.	0-2
Planning a Strategy	Determine the correct formula or solution strategy.	0-3
Implementing the Strategy	Perform calculations and procedures correctly.	0-3
Evaluating the Solution	Explain the reasons for using the formula and check the results.	0-2
	Maximum Score	10

Self-Regulated Learning (SRL) Questionnaire: The questionnaire consists of 35 statements using a 5-point Likert scale to measure aspects of planning, self-monitoring, self-control, self-evaluation, and learning motivation.

Validity and Reliability

The content validity of the test and questionnaire instruments was determined through expert judgment and analyzed using Aiken's V coefficient. The results of the analysis showed that all items in the problem-solving ability test had a V value of 1.00, while the items in the self-regulated learning questionnaire had V values ranging from 0.667 to 1.00. Thus, all instruments were declared valid in terms of content.

The reliability of the instruments was tested using *Cronbach's Alpha*. The self-regulated learning questionnaire showed high reliability with an α coefficient of 0.80. Meanwhile, the mathematical problem-solving test had a reliability coefficient of $\alpha = 0.56$, which was in the adequate category. This reliability value is still acceptable in the context of this study, considering that the test used was in essay form with a limited number of items and different weightings for each item, which could potentially affect internal consistency. To minimize assessment bias, the scoring process was carried out consistently using the same scoring guidelines for all student answers.

Implementation Fidelity

Implementation fidelity was observed to ensure that the implementation of the C-PBL-SA model was carried out according to the design. Observations were conducted during three learning meetings using an implementation observation sheet filled out by the observer. The level of implementation was calculated as a percentage, with the criterion for implementation being achieved if it was in the high or very high category, a percentage of ≥ 60%.

The implementation observation sheet contained several key indicators, including: (1) the suitability of the PBL phase implementation with the learning plan, (2) the implementation of the scientific approach steps in each phase, (3) the active involvement of students in group discussions, (4) the distribution and implementation of collaborative roles in groups, and (5) the role of teachers as learning facilitators. Each indicator is assessed at each meeting to obtain an overview of the overall learning implementation.

The observation results show that the learning implementation is in the high category. Details of the implementation can be seen in the following table:

Table 4 Implementation fidelity

Meeting	Material	Teacher performance	Student performance
1	Triangle	93%	93%
2	Triangles and quadrilaterals	100%	100%
3	Quadrilateral	93%	93%
Average		95,3%	95,3%

Data Analysis Techniques

The collected data were analyzed using descriptive and inferential statistics.

Descriptive Analysis. This analysis was used to summarize the pretest and posttest scores of both variables by calculating the mean, standard deviation, and minimum and maximum scores.

Inferential Analysis. To test the research hypothesis, data on mathematical problem-solving ability was analyzed using the Wilcoxon signed-rank test because it did not meet the assumption of normality. Self-regulated learning data were analyzed using the paired sample t-test. The significance level used was $\alpha = 0.05$. Effect sizes were calculated to assess the strength of the differences that occurred, namely using the r coefficient for the Wilcoxon signed-rank test and Cohen's dz for the paired sample t-test.

RESULTS AND DISCUSSION

The results of the study show that there was a change in student learning achievement after the implementation of a **Collaborative Learning Model of the PBL** with a scientific approach to the subject matter of triangles and quadrilaterals. This change was assessed in terms of students' mathematical problem-solving abilities and self-regulated learning.

Problem Solving Skills

Descriptive statistics of students' mathematical problem-solving abilities before and after treatment are presented in Table 5.

Table 5 Achievement Results in Mathematical Problem Solving Skills

Variation	Collaborative Learning Model of the PBL	
	Pre-test	***Post-test***
Number of Students	31	31
Average Score	15,32	30,92
Standard Deviation	9,738	12,652
Maximum Observed Score	30	50
Minimum Observed Score	0	2
Maximum Theoretical Score	50	50

Based on Table 5, students' mathematical problem-solving abilities in the early stages of learning are still relatively low. The average pretest score of 15.32 out of a theoretical maximum score of 50 indicates that most students are not yet able to solve problems systematically. At this stage, students generally have difficulty identifying known and unknown information, choosing appropriate solution strategies, and relating relevant mathematical concepts. The standard deviation of 9.738 indicates that there is considerable variation in initial abilities among students, reflecting a class with heterogeneous abilities. After implementing a **Collaborative Learning Model of the PBL** with a scientific approach, the average score for students' problem-solving abilities increased to 30.92 with a standard deviation of 12.652. This increase in the average score indicates that students began to show progress in understanding problems, designing solution strategies, and evaluating the answers obtained. The increase in the maximum observation score from 30 on the pretest to 50 on the posttest also indicates that some students were able to achieve the maximum score on the instrument and complete the problem-solving questions more completely and logically. To determine the appropriate type of inferential test, a normality test was conducted on the mathematical problem-solving ability data as presented in Table 6.

Table 6 Testing the Normality of Mathematical Problem-Solving Ability

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
Pre	.180	31	.012	.796	31	.000
Post	.111	31	.200*	.964	31	.361

Based on Table 6, the normality test results show that the mathematical problem-solving ability data in the pretest is not normally distributed ($p < 0.05$), while the posttest data is normally distributed ($p > 0.05$). This condition indicates that the normality assumption for paired data is not fully met. Therefore, inferential analysis to test the difference between pretest and posttest scores was performed using the Wilcoxon signed-rank test. The results of the Wilcoxon signed-rank test are presented in Table 7.

Table 7 Wilcoxon signed-rank test Mathematical Problem Solving Ability

	Post – Pre
Z	-4.126[b]
Asymp. Sig. (2-tailed)	<.001

Based on Table 7, a significance value of $p < 0.05$ was obtained, so the null hypothesis (H_0) was rejected. This indicates that there is a significant difference between students' mathematical problem-solving abilities before and after the implementation of a Collaborative Learning Model of the PBL with a scientific approach. In addition to statistical significance, the magnitude of the difference was also examined through the effect size. Based on the Z value of −4.126 and the sample size (N = 31), an effect size of $r = 0.74$ was obtained, which is classified as large. Thus, the improvement in problem-solving ability is not only statistically significant but also substantively meaningful in the context of the class studied.

Self-regulated Learning

Descriptive statistics of students' self-regulated learning before and after treatment are presented in Table 8. Based on Table 8, the average self-regulated learning score of students on the pretest was 121.81, indicating that, in general, students had a moderate level of learning independence. However, this achievement showed that students' ability to regulate their learning process, especially in terms of planning, monitoring, and self-evaluation, had not developed optimally and still needed to be strengthened through appropriate learning strategies. After implementing a Collaborative Learning Model of the PBL with a scientific approach, the average self-regulated learning score increased to 122.74 with a standard deviation of 10.844. Although the increase in the average score was relatively small, this trend indicates an improvement in students' ability to actively engage in the learning process, manage learning responsibilities, and participate more independently in group discussions and task completion. To determine the appropriate type of inferential test, a normality test was conducted on the self-regulated learning data as presented in Table 9.

Table 8 Self-regulated Learning Achievement Results

Variation	Collaborative Learning Model of the PBL	
	Pre-test	***Post-test***
Number of Students	31	31
Average Score	121.81	122.74
Standard Deviation	11.519	10.844
Maximum Observed Score	149	149
Minimum Observed Score	98	100
Maximum Theoretical Score	175	175

Based on Table 9, the normality test results show that the self-regulated learning data in the pretest and posttest are normally distributed ($p > 0.05$). Therefore, inferential analysis to test the difference in scores was performed using a paired sample t-test. The results of the test are presented in Table 10.

Table 9 Testing the Normality of Self-regulated Learning

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**Df**	**Sig.**	**Statistic**	**Df**	**Sig.**
Pre	.110	31	.200*	.988	31	.974
Post	.088	31	.200*	.987	31	.961

Based on Table 10, a significance value of 0.022 (< 0.05) was obtained, so the null hypothesis (H_0) was rejected. This indicates that there is a significant difference between students' self-regulated learning before and after the implementation of the learning model. Although statistically significant, the mean difference of 0.93 is equivalent to approximately 0.53% of the theoretical maximum score (175), so the impact at the class level is practically small. However, the 95% confidence interval (−1.728 to −0.143) shows a consistent shift in some students, so this small change is still worth noting as an initial indication.

Table 10 Paired Sample t-Test for Self-regulated Learning

	Mean	Standard Deviation	Std Error Mean	95% Confidence interval of the Difference		T	Df	Sig. (2 tailed)
				Lower	**Upper**			
Pre Post	-0,935	2.159	.388	-1.728	-.143	-2.412	30	0.022

Recapitulation of Overall Pretest and Posttest Scores

To provide a comprehensive overview of changes in student learning outcomes, a summary of pretest and posttest scores for both variables is presented in Table 11. Based on Table 11, overall there was an increase in student learning achievement after the implementation of the learning model. The increase in problem-solving skills was more prominent than the increase in self-regulated learning, indicating that the impact of learning was more quickly observed in cognitive aspects than in affective and metacognitive aspects.

Table 11 Scores for the entire pretest and posttest

Variation	Problem solving		*Self-regulated learning*	
	Pretest	***Posttest***	***Pretest***	***Posttest***
Number of Students	31	31	31	31
Average Score	15,32	30,92	121.81	122.74
Standard Deviation	9,738	12,652	11.519	10.844
Maximum Observed Score	30	50	149	149
Minimum Observed Score	0	2	98	100
Maximum Theoretical Score	50	50	175	175

Discussion

The results of the study indicate that the application of a Collaborative Learning Model of the PBL with a scientific approach has a positive impact on students' mathematical problem-solving abilities and self-regulated learning (SRL).

In mathematical problem-solving skills, the students' average score increased significantly from 15.32 on the pretest to 30.92 on the posttest out of a theoretical maximum score of 50. The Wilcoxon signed-rank test results showed a Z value of -4.126 with $p < 0.001$, confirming that the difference in skills before and after the treatment was statistically significant. In addition, the increase in the maximum observation score from 30 on the pretest to 50 on the posttest indicates that some students were able to fully master the problem-solving ability indicators measured. These findings show that the learning applied was able to facilitate students in identifying problems, designing solution strategies, applying mathematical concepts, and evaluating the solutions obtained.

The results of this study are in line with Rahman (2019) view, which emphasizes that problem-solving skills are essential cognitive skills for the 21st-century that need to be developed through meaningful learning and student-centered activities. These findings are consistent with Budiyono (2021) and Estiva (2021), who conclude that problem-based learning encourages students to think critically and creatively through active engagement in contextual problem solving. International support also shows consistent results, with Santos-trigo (2024) emphasizing that mathematics learning focused on exploring strategies, reasoning, and reflecting on solutions can improve the ability to understand problems, design strategies, and evaluate solutions. Research by Yuhana & Fajari (2025) confirms that Problem-Based Learning has a significant positive impact on problem-solving skills through students' active engagement in higher-order thinking. These findings are reinforced by research by Torres-peña et al. (2025) and Sarakun & Seehamongkon (2025), as well as Ulya et al. (2024), which consistently show that active and innovative learning interventions have a positive effect on improving students' mathematical problem-solving abilities.

Despite a significant increase, the average posttest score of 30.92 indicates that students' problem-solving abilities are still around 62% of the theoretical maximum score. This indicates that, in practical terms, students' problem-solving abilities have not developed optimally. This finding is consistent with Setiawati et al. (2017), who reported that junior high school students' mathematical problem-solving abilities tend to be low and require continuous practice. The relatively large posttest standard deviation (12.652) also shows that the variation in students' abilities after treatment is still quite wide, so that not all students experience the same improvement.

Several factors are thought to limit the extent of improvement in problem-solving skills. First, the duration of the learning intervention, which lasted only three sessions, did not provide enough time for students to familiarize themselves with the stages of problem solving that require high-level reasoning. Rahman (2019) emphasizes that problem-solving skills develop through repeated practice and consistent learning experiences. This is reinforced by Ariani et al. (2020), who state that higher-order thinking skills, including mathematical problem solving, require a continuous learning process so that problem-solving strategies can be understood and applied optimally by students. Second, the characteristics of triangular and quadrilateral flat shapes require complex visualization and spatial reasoning skills, so students need more practice time to integrate concepts meaningfully. This is in line with Made et al. (2022) and Nurzaman et al. (2022) who state that improving mathematical problem-solving skills through a scientific approach requires a continuous learning process and cannot be achieved instantly.

The collaborative learning process applied in this study allows students to exchange ideas, clarify understanding, and develop solution strategies together. This condition supports Nashihah (2020) finding that group discussion and collaboration activities can help students express mathematical ideas more systematically and structurally. The findings of this study are also consistent with Sinaga et al. (2024), who reported that the application of PBL significantly improved mathematical problem-solving skills through increased learning activities and student confidence. In the context of this study, the increase in the average score from 15.32 to 30.92 shows that students' active involvement in group discussions and problem solving directly contributes to the improvement of problem-solving skills.

An integrated scientific approach to learning contributes to improving students' problem-solving skills. The observation and questioning stage helps students understand problems in a more structured way before determining a solution strategy. The reasoning and testing stage encourages students to relate relevant mathematical concepts in developing solutions, while the communication stage provides space for students to reflect on the process and results of problem solving. The role of this scientific approach is in line with Sudirman et al. (2017), who state that the scientific approach can improve students' problem-solving abilities as well as their reflective skills in mathematics learning.

Although the improvement in problem-solving skills was statistically significant with a large effect size, the posttest scores, which were in the range of 61.84% of the theoretical maximum score, indicated that the students' practical mastery was still not optimal. This suggests that the intervention had an initial positive impact but was not sufficient to produce full mastery in a short period of time.

In addition to problem-solving skills, the results also showed a significant increase in students' self-regulated learning (SRL) skills. The average SRL score increased from 121.81 on the pretest to 122.74 on the posttest on a maximum scale of 175. The results of the paired sample t-test showed a value of $t = -2.412$, $df = 30$, and $p = 0.022$, confirming that the difference was statistically significant. However, the score difference of 0.93 indicates that the increase in SRL was relatively small when viewed from the measurement scale range. The relatively small improvement in SRL may be attributed to the short duration of the intervention, as self-regulated learning typically develops through sustained and repeated instructional experiences rather than brief exposure.

This condition can be understood because SRL is a skill that develops gradually and is closely related to long-term learning habits. Zimmerman & Moylan (2009) and Higgins et al. (2021) emphasize that SRL involves the processes of planning, monitoring, and self-evaluation, which require repeated practice over a relatively long period of time. This finding is reinforced by Yanti et al. (2021), who show that the development of SRL in the context of blended learning occurs gradually through repeated cycles of self-regulation. Similarly, Rifki & Lutfi (2022) found that the use of innovative learning media can support the improvement of SRL, but its impact tends to be limited when applied in short learning durations.

In a broader context, research by Xu et al. (2023) shows that self-regulated learning is positively related to learning outcomes, but the effectiveness of the intervention is greatly influenced by the consistency and sustainability of the application of SRL strategies. In line with this, Balan & Jönsson (2025) emphasize that SRL interventions in mathematics learning generally only produce moderate initial improvements when the duration of learning is relatively short. In the context of this study, the short duration of the intervention did not provide sufficient time for students to develop stable independent learning habits, so that the observed improvement in SRL was still preliminary. This reinforces the view that the development of SRL through problem-based learning needs to be designed over a longer period of time in order to produce more meaningful educational changes.

Although the increase in the average SRL score was relatively small, the decrease in standard deviation from 11.519 to 10.844 indicates that the variation in students' SRL levels tended to be more evenly distributed after the treatment. This indicates that problem-based collaborative learning contributes to creating a learning environment that supports the development of student learning independence. This finding is in line with Istiningrum (2017) and Kurniyawati et al. (2019), who stated that problem-based learning can encourage the development of SRL because students are trained to take responsibility for their learning process. In addition, a conducive collaborative learning environment also plays an important role in strengthening SRL, as stated by Huang et al. (2022) and Kumyoung et al. (2023).

Another advantage of implementing a Collaborative Learning Model of the PBL is the strengthening of collaboration and division of labor skills within groups. During learning, students are trained to work together, divide tasks, and agree on problem-solving strategies collectively. This is in line with Ma'ruf & Mawardi (2023), who state that PBL can improve collaboration skills and effective work sharing within groups. Collaborative learning also allows students to integrate various sources of knowledge and learning experiences, making the learning process richer and more meaningful. In line with this, Sembiring (2024) emphasizes that the application of PBL not only improves academic learning outcomes but also fosters students' character, responsibility, and social skills. Thus, the learning model applied in this study not only has an impact on cognitive and metacognitive achievements but also equips students with social skills relevant to long-term learning.

However, the results of this study need to be interpreted with consideration of several limitations. The one-group pretest–posttest design without a control group limits the ability to compare the effectiveness of learning with other models. In addition, the reliability of the problem-solving ability test instrument, which was in the adequate category, as well as the short duration of the intervention and the implementation of the study in one school with a sample size of 31 students also limit the generalization of the results. These findings are in line with Efendi et al. (2018) and Masturi et al. (2020), which show that the development of problem-solving skills and SRL through PBL tends to be stronger when applied in longer learning durations and in broader learning contexts.

In line with this, several other studies report that the implementation of PBL has a positive effect on students' problem-solving skills and learning independence. Research by Asri & Maysarah (2024), Argianti & Andayani (2021), Chrisdiyanto & Hamdi (2023), and Kurniyawati et al. (2019) shows that PBL can encourage active student engagement and the development of higher-order thinking skills, although these studies were still conducted in specific learning contexts and durations. Therefore, the results of this study can be seen as an initial indication of the effectiveness of a collaborative PBL-based learning model in improving problem-solving skills and SRL, which still requires further testing through stronger research designs, longer learning durations, and broader subject coverage so that the findings obtained can be generalized more convincingly

CONCLUSION

Based on the results of research conducted in a seventh grade class at a junior high school in Sleman Regency, the application of a Collaborative Learning Model of the PBL with a scientific approach showed changes in students' mathematical problem-solving abilities and self-regulated learning (SRL). Mathematical problem-solving skills increased from an average of 15.32 to 30.92 out of a theoretical maximum score of 50 (61.84%) and differed significantly based on the Wilcoxon signed-rank test ($Z = -4.126$; $p < 0.001$) with a large effect size (r

= 0.74). Self-regulated learning also increased from 121.81 to 122.74 out of a maximum scale of 175 and differed significantly based on the paired sample t-test ($t(30) = -2.412$; $p = 0.022$; $dz = 0.43$), although the relative mean change was small. These findings provide preliminary evidence in the classroom context studied, but generalization and causal inference should be made with caution given the one-group pretest–posttest design without a control group, the short duration of the intervention, the adequate reliability of the problem-solving test ($\alpha = 0.56$), and the single-school context of the study.

RECOMMENDATION

First, junior high school mathematics teachers can consider applying a Collaborative Learning Model of the PBL with a scientific approach to train mathematical problem-solving skills through integrated activities of observing, questioning, reasoning/trying, and communicating in the PBL phase. To make the impact more meaningful educationally, implementation is recommended to be carried out over a longer period so that students have the opportunity to repeat exercises, reflect, and reinforce problem-solving strategies, especially in geometry. Second, to strengthen self-regulated learning, learning needs to be complemented with strategies that explicitly target SRL, such as setting learning goals, monitoring progress, structured reflection, and formative feedback that encourages student self-evaluation. Third, future researchers are advised to use stronger research designs (e.g., quasi-experiments with control groups), involve larger and more diverse samples, extend the duration of interventions, and improve the quality of problem-solving instruments by increasing the number of items, refining scoring rubrics, and reporting inter-rater reliability.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Risna Amelia	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Kuswari Hernawati	✓	✓		✓						✓		✓		
Jailani		✓		✓			✓			✓		✓		
Wahyu Setyaningrum										✓	✓	✓		

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration. The study was approved by the institutional authority of the school and the research ethics procedures of Yogyakarta State University.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, R.A., upon reasonable request. The data contain information that could compromise the privacy of research participants and are therefore not publicly available.

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