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The Effectiveness of the STEM Integrated PBL Model on Science Collaboration and Problem-Solving Skills

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Abstract

This study aimed to examine the effect of the Problem-Based Learning (PBL) model integrated with STEM on students' collaboration and problem-solving skills. It employed a quasi-experimental method using a pretest-posttest control group design. The population included all seventh-grade students of SMP Negeri 1 Plupuh in the 2024/2025 academic year. The sample was selected through cluster random sampling, with Class VII C designated as the experimental group and Class VII D as the control group. Data were collected through tests, observations, and documentation. The data were analyzed using an independent t-test with a significance level of 0.05. The analysis revealed that the STEM-integrated PBL model had a significant effect on students' problem-solving skills, with a significance value of 0.028 (< 0.05), because this learning provides a holistic, real, collaborative learning experience and encourages higher-level thinking. While the collaboration skills showed a significance value of 0.011 (< 0.05) because the learning process emphasizes group work in solving real problems, thus encouraging interaction, shared responsibility, productive communication, and positive interdependence between group members. These findings indicate there is an effect of implementing Problem Based Learning (PBL) integrated with Science, Technology, Engineering, and Mathematics (STEM) on students' collaboration and problem-solving skill. Problem Based Learning (PBL) integrated STEM allows students to broaden their horizons, discuss and collaborate in problem solving, encourage students to refine their knowledge through discussion, communicate in groups and respect each other when there are differences of opinion, critically assess group processes and work, provide feedback, and agree on the best solution, which directly improves various aspects of collaboration and develops competencies to address the complex challenges of their future.

How to Cite

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INTRODUCTION

Problems in the 21st century are increasingly complex, especially concerning survival and education. Education is undergoing a significant transformation in response to global dynamics and technological developments in the 21st century. The role of educators is crucial in developing 21st-century skills through relevant learning in schools. These skills, known as the 4Cs (Communication, Collaboration, Critical Thinking and Problem-solving, and Creativity and Innovation), are essential for individuals to adapt to the current era (Agaoglu, 2020). 21st century skills have not been fully achieved including critical thinking problem solving, communication and teamwork (Hanssens, Langle, & Van Soon, 2023).

The nature of Sciences is intrinsically linked to empowering students' collaboration and problem-solving skills, which are vital components of 21st century skills.The urgency of this research collaboration skills are necessary for group members to work together effectively to achieve common goals. Collaboration skills encompass five aspects: positive interdependence, promotive interaction, individual accountability, interpersonal and small-group skills, and group processing. It is important to instill the values of collaboration in students from an early age to train them in activities that foster individual collaborative skills. Project-based learning requires teamwork and communication skills through group work, so students must collaborate over long periods of time to solve problems and produce a final product (Cortázar et al., 2021).

Collaboration skills are fundamental to effective collaborative learning, career success, and responsible citizenship (Huang & Ochoa, 2025). As a result, students may prefer to work individually or simply share the work, thus missing out on opportunities to learn from each other (Wu, Corr & Rau, 2019). Students need to practice collaboration skills as a 21st century skill. Collaborative skills emphasize cooperative relationships between students and their peers (Gonen & Korkmaz, 2022). With collaboration skills, students can communicate in groups and respect each other when there are differences of opinion (Kongul & Yildirim, 2021). Students tend to remain silent during group discussions or group work, resulting in suboptimal collaboration skills. Research (Lin, 2022) shows that low collaboration skills and a fear of asking questions result in low theoretical and practical learning outcomes for students in schools. Collaborative learning allows students to broaden their horizons, although they tend to spend more time on reflection and discussion in problem-solving (Luo, Wang, Liu, & Zhou, 2018). By applying the right learning model, collaboration skills can be developed through direct interaction between students and teachers and between students and tutors in groups (Razi & Zhou, 2022). Based on research by Alali (2024), the urgency of integrating project oriented Problem-Based Learning into STEM education is emphasized to enhance critical skills such as problem-solving, creative thinking, collaboration, and effective communication. By engaging in practical project-based activities, students not only apply their knowledge but also develop competencies to address complex challenges in their future endeavors.

Science learning is closely related to the development of problem-solving skills. The scientific method taught in science involves systematic problem-solving stages, from formulating a problem, proposing a hypothesis, conducting experiments, to drawing conclusions. This process challenges students to analyze problems using scientific knowledge to solve existing challenges. Problem-solving skills are defined as the ability to find the best solution to a problem or make a decision by considering various existing constraints. It can also be interpreted as a process of overcoming discrepancies between the existing condition and the desired condition (Siburian & Suryana, 2021). Problem-solving skills have five aspects: defining the problem, formulating the problem, generating solutions, solving the problem, and reviewing and evaluating.

Based on observations and interviews with a teacher at one of junior high school in Plupuh, Central Java, Indonesia, in November 2024, the collaboration skills of students in one of the seventh-grade classes were low, indicated by their lack of active participation in group activities. Students were more passive and lacked confidence in expressing their opinions. The observation results showed that the students' collaboration skills scores were low. The aspect of positive interdependence received a score of 69.05, promotive interaction scored 61.5, individual accountability scored 55.7, communication scored 50.2, and group work skills scored 50.5. Thus, the overall average score for students' collaboration skills was 57.39. On the other hand, in one of the seventh-grade classes, students' problem-solving skills were also low due to a monotonous learning process. The teacher-centered learning, dominated by conventional lecture methods, resulted in inactive students. This condition was exacerbated by the minimal implementation of practical activities, making the learning atmosphere passive, boring, and less engaging for students. This was indicated by the low pretest scores in the aspect of defining the problem (76.05), formulating the problem (70), generating solutions (23.51), solving the problem (22.08), and reviewing and evaluating (48.76). The average score for students' problem-solving skills was 48.08.

Problem-Based Learning (PBL) is a learning model that uses real-life problems as the basis for learning, encouraging students to learn independently and refine their knowledge through discussion. PBL is highly relevant when combined with the STEM (Science, Technology, Engineering, and Mathematics) disciplines as both emphasize solving problems based on real-life contexts (Awalin & Ismono, 2021). PBL supports active learning and student engagement (Rehman, et al, 2024). The application of STEM-integrated PBL can enhance students' collaboration and problem-solving skills by promoting teamwork, idea discussion, and practical application of knowledge. This integration creates a different and more meaningful learning experience by strengthening critical thinking and understanding of scientific and technological concepts (Budiyono et al., 2020).

The integration of Problem-Based Learning (PBL) with the four STEM disciplines Science, Technology, Engineering, and Mathematics can lead to an improvement in collaboration and problem-solving skills. This learning model directs students to solve real-world problems, while STEM provides the relevant scientific and technical context. Through this approach, students are encouraged to discuss, exchange ideas, and apply STEM concepts to find solutions, thereby strengthening their teamwork abilities. The integration of PBL-STEM makes learning more meaningful and applicable, equipping students with practical skills to face real-world problems. This is based on research regarding the effect of the Problem-Based Learning (PBL) model integrated with the Science Technology Engineering Mathematics (STEM) approach on 21st century skills. Based on research by Ayubi et al. (2025), the contribution of STEM-integrated PBL to collaboration skills was 9%, indicating a moderate level of effectiveness. The aforementioned background prompted the researcher's interest in conducting research in this area. Most researchers focus on only one indicator of 21st century skills. Therefore, the researcher is interested in investigating "The Effect of Problem-Based Learning (PBL) integrated with Science Technology Engineering Mathematics (STEM) on students' collaboration and problem-solving skills." The novelty of this research is the application of the STEM Integrated PBL accompanied by assessment of collaboration and problem-solving skills.

Research gap the application of the STEM Integrated PBL Model in science there is a significant paucity of studies examining the long-term effectiveness of STEM-integrated Project-Based Learning (PBL) models in science education. While PBL has been shown to be achievable and beneficial in certain contexts, research on its lasting impacts, such as long-term student achievement and skill development over time, remains inadequate. Furthermore, outcomes such as student engagement, motivation, and persistence are rarely measured in evaluations of integrated STEM initiatives, leaving conclusive evidence on these important aspects lacking (Sutiah, Supriyono, 2024). Teachers in some elementary and secondary schools expressed uncertainty and ambiguity what and how to assess collaboration skills (Frykedal & Chiriac, 2021). Furthermore, a study by Chiriac and Granström (2022) reported that assessment criteria or rules lacked transparency and concreteness. Furthermore, the lack of assessment tools to measure the collaborative performance of each group member can lead to student frustration about the transparency and uniformity of assessment.

The researcher will examine the psychomotor domain of students' collaboration skills and the cognitive domain of their problem-solving skills because there is a correlation where both variables support and reinforce each other. Building collaboration skills in the classroom can contribute to the development of students' problem-solving skills, as students who work in groups to solve problems learn to communicate, combine different perspectives, and develop better strategies.

METHOD

This study is a quantitative research employing a quasi-experimental method with a non-equivalent control group pretest-posttest design. The research was conducted at SMP N 1 Plupuh during the first semester of the 2024/2025 academic year. The population of this study consisted of 192 seventh-grade students from six classes. The sample was selected using cluster random sampling, which designated class VII D as the control group and class VII C as the experimental group. Data were collected through tests, observations, and documentation. The instruments used were test questions to measure problem-solving skills and observation sheet to measure collaboration skills. Data analysis was performed using an Independent Sample T-test and N-gain calculations, assisted by SPSS version 25 software.

RESULT AND DISCUSSION

Result normality test

The normality test is conducted to determine whether the data follows a normal distribution. Normality was tested using the Kolmogorov-Smirnov test, with the analysis performed using SPSS version 25 software. Data are considered to have a normal distribution if the significance value is greater than 0.05, whereas if the significance value is less than 0.05, the data are considered not to be normally distributed. The normality test results data can be seen in Table 1 and 2.

Based on Tables 1 and 2, the collaboration skills data for the control group, with a significance value of 0.097 > 0.05, is considered to have a normal distribution. Similarly, the experimental group's data, with a significance value of 0.094 > 0.05, is also considered normally distributed. For the students' problem-solving skills data, the control group's pretest result, with a significance of 0.060 > 0.05, indicates a normal distribution, and the posttest result, with a significance of 0.074 > 0.05, is also normally distributed. For the experimental group, the pretest data, with a significance of 0.074 > 0.05, is normally distributed, while the posttest data, with a significance of 0.080 > 0.05, is also considered normally distributed. Based on this testing, it can be concluded that all samples originate from a population with a normal distribution.

Table 1. Normality test of control class

Variable	Sig	Explanation
Pretest problem solving	0.060	normally distributed
Posttest problem solving	0.074	normally distributed
Collaboration	0.097	normally distributed

Table 2. Normality test of experiment class

Variable	Sig	Explanation
Pretest problem solving	0.074	normally distributed
Posttest problem solving	0.080	normally distributed
Collaboration	0.094	normally distributed

Result homogeneity test

The homogeneity test is used to determine if the data is homogeneous. This test utilizes Levene's test with the assistance of SPSS version 25 software. The criterion is that if the significance level is > 0.05, the data is considered homogeneous, and vice versa. The homogeneity test results data can be seen in Table 3.

Table 3. Result homogeneity test

Variable	Sig	Explanation
Pretest problem solving	0.074	homogeneous
Posttest problem solving	0.080	homogeneous
Collaboration	0.094	homogeneous

Based on the results in Table 3, the collaboration skills data, with a significance value of 0.077 > 0.05, is considered homogeneous. For the problem-solving data, the pretest significance value of 0.086 > 0.05 indicates the data is homogeneous, and the posttest significance value of 0.082 > 0.05 also indicates the data is homogeneous. These test results demonstrate that all samples used are from a population with a homogeneous variance.

Result N-gain test

The N-Gain, or "normalized gain," test is widely used to assess the effectiveness of a learning intervention. This method provides a solid basis for evaluating how much a learning activity contributes to increase students' understanding. N-gain test results data can be seen in Table 4.

Table 4. Result of N-Gain score

Class	Score	Explanation
Control	0.37	Medium
Experiment	0.43	Medium

Based on Table 4, the N-Gain scores from the pretest-posttest results indicate that the control group's score of 0.37 ($0.30 \leq 0.37 < 0.70$) falls into the medium category. Similarly, the experimental group's N-Gain score of 0.43 ($0.30 \leq 0.43 < 0.70$) is also categorized as medium.

Result hypothesis test

Hypothesis testing was conducted using the Independent Sample T-test to compare the mean scores of two independent sample groups. The purpose of this test is to determine whether there is a statistically significant difference between the two groups. The hypothesis testing was performed with the assistance of SPSS software, using a significance level of 5%. The decision criteria for the hypothesis test are as follows: if the significance value is < 0.05, then H0 is rejected and H1 is accepted; if the significance value is > 0.05, then H0 is accepted and H1 is rejected. The data from the independent sample t-test in Table 5.

Table 5. Result of hypothesis test

Variable	Sig	Explanation
Problem-solving	0.028	H1 is accepted
Collaboration	0.01	H1 is accepted

Based on Tables 5, the application of the Problem Based Learning (PBL) model integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach demonstrates a significant influence on students' collaboration and problem-solving skills. In the first hypothesis test, a significance value of 0.01 was obtained, which is less than 0.05. Consequently, H0 was rejected and H1 was accepted, indicating a significant effect of the STEM-integrated PBL model on collaboration skills. Meanwhile, the second hypothesis test yielded a significance value of 0.028 < 0.05, which also resulted in the rejection of H0 and acceptance of H1. Therefore, it is concluded that the model significantly affects students' problem-solving skills.

Collaboration skills

The results of the data analysis, assisted by SPSS version 25 software, indicate that the application of the Problem Based Learning (PBL) model integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach has a positive influence on students' collaboration skills. This is evident from the observer's assessment of student activities in group work, which shows an improvement in collaboration skills compared to the application of PBL model without STEM integration. The average scores of students' collaboration skills in Figure 1.

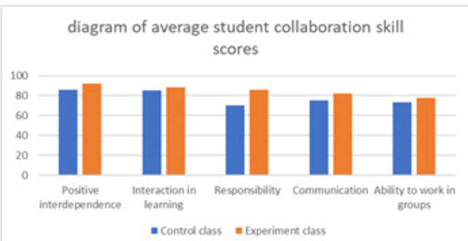


Figure 1. Diagram of average results of collaboration skills scores

The application of Problem Based Learning (PBL) in the classroom has been shown to encourage students to solve problems collaboratively, thereby creating a more meaningful learning experience In this study, the PBL model used was integrated with STEM and followed the learning syntax according to Arends (2012), which consists of the following phases: orienting students to the problem, organizing students for study, assisting independent and group investigation, developing and presenting artifacts, and analyzing and evaluating the problem-solving process.

In the orientation and student organization phase, the teacher facilitated the random formation of groups and introduced a problem based on the natural phenomenon of temperature change as the learning context. STEM activities in this phase included defining the problem and research, where students were prompted to discuss initial solutions and develop an experimental plan. Collaboration began to form through initial communication and positive interdependence, in line with the collaboration skills indicators by Johnson (1991).

The group investigation phase emphasized the use of technology as part of the STEM approach. Students used digital devices to access information, design solutions, and actively exchange ideas within their groups. STEM activities at this stage included imagining and planning, which allowed students to formulate an experimental design and build productive communication within the group. This aligns with research by Hollman et al (2019) show that students who participate in collaborative, problem-based STEM activities can improve their critical and analytical thinking skills in solving real-world problems, as well as their cooperative learning and communication skills.

In the phase of developing and presenting artifacts, the involvement of Engineering and Mathematics aspects was highly prominent. Students designed and tested a simple device in the form of a homemade thermometer, then conducted evaluations and improvements (redesign) based on the trial results. This activity reflects the STEM stages: create, test and evaluate, redesign, and communicate. The presentation of their work fostered coordination, communication, and group reflection. The score for communication skills, as an indicator of collaboration, increased from 75.15 to 82.15 (Rahmawati & Ridwan, 2021).

In the 'analyzing and evaluating' syntax, students and the teacher collaboratively reflect on the process that has been undertaken. In the analysis stage, students are encouraged to collectively break down the problem, discuss, and delegate tasks, which demands active communication and effective cooperation among group members. Subsequently, the evaluation stage trains students to critically assess the group's process and work, provide feedback, and agree on a collective solution, which directly enhances various aspects of collaboration. Research indicates that the application of PBL syntax, which includes the analysis and evaluation of the problem-solving process, can significantly improve students' collaboration skills. This is consistent with the research by Bessas, et al (2024).

Problem-solving skills

Based on the results of data analysis assisted by SPSS version 25 software, it was found that the application of the Problem-Based Learning (PBL) model integrated with Science, Technology, Engineering, and Mathematics (STEM) has a positive influence on students' problem-solving skills. This is demonstrated by the comparison of pretest-posttest scores, which showed a higher increase compared to the application of the PBL model without STEM integration. The average scores of students' problem-solving skills are presented in Figure 2. The Problem Based Learning (PBL) model integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach has been proven effective in systematically enhancing students' problem-solving skills through syntax phases that align with the indicators of this ability.

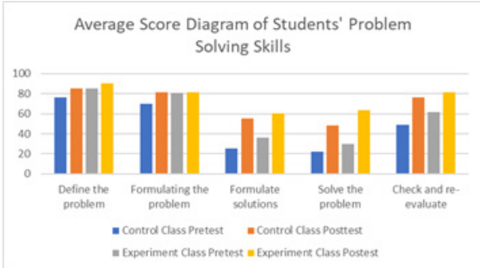
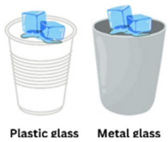


Figure 2. Average score diagram of student's problem solving skills

In the phase of orienting students to the problem, participants were divided into six groups and were required to identify and define a contextual problem based on the phenomenon of temperature change, which reflects the involvement of the Science discipline. The STEM activity of 'defining the problem' encourages students to identify facts and important variables, aligning with the problem-solving skill indicator of "identifying the problem." This finding is consistent Wieselmann, et al. (2025) that ntegrated STEM instruction, especially when paired with PBL, leads to improved student knowledge and skills, including creativity, communication, collaboration, and problem-solving. Examples of student answers can be seen in Table 6.

Table 6. Example of student answers on the aspect of formulating problems

Question	Look at the following picture!  Sinta conducted her first experiment by placing ice cubes in two containers. After 10 minutes, the ice in metal container melted faster, even though the ice cubes were the same size and room temperature was the same. Based on this information, explain the main problem discussed and provide rationale.!	
Answer indicators and rubrics	**Indicator**	**Score**
	1 Students are able to identify the main problem.	1: If 1 indicator appears.
	2 Students are able to explain background the cause of problem.	2: If 2 indicators appear.
	3 Students are able to identify information about the problem.	3: If 3 indicators appear.
	4 Students are able to distinguish between important and unimportant information.	4: If 4 indicators appear.
Example Answer	The main problem is the difference in the rate at which the ice melts in the two different containers. The underlying cause is the difference in container materials; metal conducts heat better than plastic, causing	(4 score)
	The difference in melting ice cubes is because the containers are different and metal containers melt faster.	(3 score)
	The main problem is the difference in melting speed and the difference in containers	(2 score)
	The difference in melting ice is because ice melts faster.	(1 score)

Based on Table 6 in the control group's pretest answers for the "identifying the problem" aspect, students were only able to state the problem without including the background causes or identifying information from the issue. The students' posttest answers still followed the same pattern; they were only able to state the problem without including the other indicators of the "identifying the problem" aspect.

In the 'organizing students for study' phase, the learning process emphasizes group work to formulate the problem in a specific and focused manner through the STEM activity of 'research.' Students formulate key questions as a basis for investigation, which corresponds to the "formulating the problem" indicator. Huang, et al. (2022) explain that the PBL-STEM model enhances problem formulation skills through an interdisciplinary approach based on real-world contexts. This is supported by an increase in the pretest-posttest scores from 80.6 to 81.3. Examples of student answers can be seen in Figure 7.

Table 7. Example of student answers on the aspect of formulating problems

Question	Look at the following picture!  Sinta conducted the third experiment by pouring hot water into a ceramic cup and a metal cup. After 20 minutes, the temperature of the water in the cup decreased, but this decrease was slower than the temperature of the hot water placed in the metal container. a. Based on this information, determine the problem formulation and formulate questions based on the problem formulation! b. What was the purpose of the third experiment conducted by Sinta and what factors caused the temperature to decrease?	
Answer indicators and rubrics	**Indicator**	**Score**
	1 Students are able to formulate the main problem.	1: If 1 indicator appears.
	2 Students are able to explain the goals they want to achieve.	2: If 2 indicators appear.
	3 Students are able to formulate questions or hypotheses.	3: If 3 indicators appear.
	4 Students are able to detail the factors related to the problem.	4: If 4 indicators appear.
Example Answer	The main problem is the difference in the rate of temperature drop of water placed in a ceramic cup and a metal container in cold room conditions. The relevant question is: "Why does the temperature of the water in the metal container drop more quickly than in the ceramic cup?"	(4 score)
	The main problem is the difference in the speed of temperature reduction in water placed in a ceramic cup and a metal container.	(3 score)
	Difference in temperature drop, why is the water temperature drop not the same?	(2 score)
	Difference in temperature drop	(1 score)

Based on Table 7, in the control group's pretest answers for the 'formulating the problem' aspect, students were still unable to meet the indicators for this aspect; they only provided a problem statement, while the hypothesis was largely unstated. The students' posttest answers were similar, with most only mentioning the problem statement and failing to fulfill the question's indicators comprehensively.

The next phase, 'assisting independent and group investigation,' focuses on the "developing solutions" indicator. The STEM activities involved are 'imagining' and 'planning,' where students utilize technology to access information and design innovative solutions to the temperature change problem. This process emphasizes data collection and the productive use of digital devices, while also developing applicable ideas based on STEM principles. Hayuana et al. (2023) state that this approach enhances students' ability to develop systematic and evidence-based solutions, as demonstrated by the score increase from 30.16 to 60.07. Examples of student answers can be seen in Figure 5.

Table 8. Example of student answers on the aspect of compiling solutions

Question	During the dry season in 2023, the ambient temperature in Surakarta reached 410°C, the highest recorded during that period. Bayu wanted to make a simple thermometer because the thermometer at home was broken. He had an old bottle, colored water, a straw, and plasticine. a. Based on these conditions, create an appropriate solution and systematically organize the steps to make the device! b. Can the tool made by Bayu be used to measure temperature, and analyze the obstacles that might arise and how to overcome them so that the solution is effective!		
Answer indicators and rubrics	**Indicator**	**Score**	
	1 Students are able to identify the main problem.	1: If 1 indicator appears.	
	2 Students are able to explain background the cause of problem.	2: If 2 indicators appear.	
	3 Students are able to identify information about the problem.	3: If 3 indicators appear.	
	4 Students are able to distinguish between important and unimportant information.	4: If 4 indicators appear.	
Example Answer	A solution that can be implemented is to make a simple thermometer. The steps are to prepare the tools and materials and then assemble them. This way, the tool can be used to measure temperature. The resistance that occurs is due to the changing scale.		(4 score)
	The solution is to make a thermometer from simple materials. To make it, prepare a used bottle, a used straw, and plasticine. The resistance of the liquid on the scale does not rise.		(3 score)
	Looking for materials, put a straw in the bottle cap, put colored water in it, then cover it using plasticine.		(2 score)
	Making a thermometer from a straw		(1 score)

Based on Table 8, in the control group's pretest answers for the 'formulating the problem' aspect, students were still unable to meet the indicators for this aspect; they only provided a problem statement, while the hypothesis was largely unstated. The students' posttest answers were similar, with most only mentioning the problem statement and failing to fulfill the question's indicators comprehensively. In the 'developing and presenting artifacts' phase, students solve the problem by implementing the designed solutions and creating a prototype, such as a simple thermometer. The Engineering and Mathematics disciplnes play a role in the design, calculation, and testing process of the prototype through the STEM stages: create, test and evaluate, redesign, and communicate. The problem-solving indicator involved is "solving the problem," with a score increase from 30 to 63.57. PBL-STEM encourages the implementation of science and mathematics concepts in real-world contexts, as well as the reinforcement of 21st century skills such as solution-oriented thinking and collaboration (Pratiwi et al., 2024). Examples of student in Figure 6.

Table 9. Example of student answers on problem-solving aspects

Question	Based on a thermometer made by Bayu a. Explain how Bayu applies the tool as a solution in measuring temperature and explain the steps that must be taken! b. How to evaluate whether the tool is working properly, and provide alternative solutions if the tool is not working properly!		
Answer indicators and rubrics	**Indicator**	**Score**	
	1 Students are able to apply solutions based on problems.	1: If 1 indicator appears.	
	2 Students are able to carry out the stages of solution.	2: If 2 indicators appear.	
	3 Students are able to evaluate the results of the solution.	3: If 3 indicators appear.	
	4 Students are able to provide alternative solutions.	4: If 4 indicators appear.	
Example Answer	If the thermometer is broken, Bayu can use a simple thermometer. To do this, place bottle in liquid whose temperature you want to measure, then observe the rise in water level in straw, indicating temperature reading. To evaluate, check the results and repeat the steps.		(4 score)
	If thermometer is broken, you can use a simple thermometer. To test temperature, place the bottle in the liquid you want to measure and then observe the rise in the water level in straw, which indicates the temperature reading. To evaluate the reading, check the results.		(3 score)
	To measure temperature, dip the diary bottle and look at the scale.		(2 score)
	View notes.		(1 score)

Based on Table 9, in the control group's pretest answers for the 'developing solutions' aspect, students were able to formulate a solution related to the presented problem and provide reasoning for the solution they offered. The posttest answers remained similar, with students only able to state the solution and its reasoning; they had not yet met the question's indicator of identifying potential obstacles that might arise from the proposed solution. The final phase, 'analyzing and evaluating the problem-solving process,' involves critical reflection on the effectiveness of the solution and the process undertaken. Students evaluate data validity, the success of the method, and opportunities for improvement, corresponding to the "evaluating the solution" indicator. The PBL-STEM approach facilitates students' reflective and evaluative skills regarding their work. The improvement in this indicator is reflected in the pretest-posttest scores, which increased from 61.75 to 81.63. Examples of student answers can be seen in Table 10.

Table 10. Example of student answers on evaluation and re-checking aspects

Question	Based on a thermometer made by Bayu a. Based on the thermometer Bayu made, the measurement results fluctuate after use. Under these circumstances, what should Bayu do to ensure the thermometer remains accurate? b. Identify the possible factors that cause the thermometer to be inaccurate and provide suggestions so that the next experiment will be accurate!		
Answer indicators and rubrics	**Indicator**	**Score**	
	1 Students are able to examine the steps taken in solving a problem.	1: If 1 indicator appears.	
	2 Students are able to evaluate the results of the implemented solution.	2: If 2 indicators appear.	
	3 Students are able to identify possible errors that affect the results.	3: If 3 indicators appear.	
	4 Students are able to provide recommendations or improvements.	4: If 4 indicators appear.	
Example Answer	Bayu must measure carefully and repeat the steps. The thermometer may be inaccurate due to a loose straw hole or an incorrect scale.		(4 score)
	Bayu must measure carefully. If it is still not accurate, Bayu can repeat the manufacturing steps by paying attention to the tools and materials used.		(3 score)
	Perform carefully and repeat the experiment.		(2 score)
	Try again.		(1 score)

Based on Table 10, in the control group's pretest answers for the 'solving the problem' aspect, students were able to apply the solution and evaluate the problem-solving process presented in the question. In the posttest answers, students had not yet met all the indicators for this aspect; they were unable to provide alternative solutions when the first offered solution was unsuccessful.

The integration of the STEM approach using the Problem Based Learning (PBL) model challenges students to be solution-oriented, creative, and innovative in applying science, technology, engineering, and mathematics concepts to solve real-world problems (Sumartati, 2020). The learning syntax within PBL-STEM comprehensively guides students in developing the indicators of problem-solving skills, from defining and formulating problems, developing and implementing solutions, to critically evaluating the process and results. This approach not only develops higher-order thinking skills but also equips students with the practical skills needed to face the multidisciplinary challenges of the 21st century. Research by Altun and Çakır (2022) supports this finding, proving that the application of STEM-integrated PBL significantly improves students' perceptions and problem-solving skills. Through collaborative, problem-based learning activities, students are directed to analyze issues from various perspectives, design and test solutions, and systematically reflect on the process. This fosters the development of logical, analytical, and systematic thinking habits for confronting complex and contextual problems. The implementation of a STEM-integrated project-based learning (PBL) model immerses students in authentic, real-world problems and hands-on design challenges, deepening their understanding of the discipline's core concepts and bridging the gap between theoretical knowledge and practical application. This approach encourages student-centered and cooperative learning, making students active participants in their education and developing essential 21st-century skills such as creativity, critical thinking, problem-solving, communication, and collaboration

(Bessas et al., 2024; Hu, Yeh & Chen, 2020; Sterna, et al, 2019). In addition to deepening students' understanding of the core ideas of the discipline and essential 21st-century skills such as creativity, critical thinking, problem-solving, communication, and collaboration, students can be enhanced by engaging students in authentic real-world problems and hands-on design challenges through this approach (Shahali et al., 2017; Mystakidis & Christopoulos, 2022). Communication skills can be strengthened by implementing the PBL model because students work in teams to address open-ended problems, present findings, and engage in real-world writing assignments, which enhances their ability to communicate ideas clearly and effectively (Stern et al., 2019). The application of STEM-integrated Project-Based Learning (PBL) models in science learning has been shown to improve students' conceptual understanding, discipline-specific knowledge, STEM skills, and dispositions. Multiple studies and meta-analyses have reported positive impacts on student achievement, attitudes, interests, and motivation, with the strongest impacts observed at the elementary level. Integrated STEM education also improves higher-order thinking skills, technological literacy, creativity, communication, and collaboration, making students better problem solvers, innovators, and inventors (Deehan et al., 2025; Thibaut et al., 2018; Wieselmann et al., 2025; Shernoff et al., 2017). PBL STEM supports the development of critical thinking, communication, and creativity, which are essential for success in a rapidly changing society. This model encourages students to use multimodal representations to create, communicate, and apply knowledge across STEM disciplines. It also fosters teamwork, resilience, adaptability, and self-evaluation, preparing students for collaborative work environments and the demands of the 21st-century workplace (Altan et al., 2025; Abdurrahman et al., 2023). The PBL model with a STEM approach has a positive impact on collaborative skills in chemistry learning, making learning more meaningful and optimizing collaborative skills (Ayubi, et al, 2025). Students' social and emotional development, including improving communication skills, teamwork, leadership, and tolerance, can be enhanced by collaborative skills (Hinyard, Toomey, Eliot, & Breitbach, 2018; Saldo & Walag, 2020). Communication skills develop through group work and collaboration, where students can discover and understand perspectives different from their own and explore diverse ideas from group members, leading to a more comprehensive understanding (Le, Janssen, & Wubbels, 2018; Masuda, Marimoto, Matsuodani, & Tsuda, 2016).

CONCLUSION

Based on the results of the research and data analysis conducted, it can be concluded that the application of the Problem Based Learning (PBL) model integrated with Science, Technology, Engineering, and Mathematics (STEM) has a significant effect on improving the collaboration and problem-solving skills of seventh-grade students at SMP N 1 Plupuh. This is evident from the Independent Sample T-test, which yielded significance values of $0.01 < 0.05$ and $0.028 < 0.05$, respectively. Based on the tests conducted, these results indicate that H0 is rejected and H1 is accepted, confirming that there is an effect of implementing Problem Based Learning (PBL) integrated with Science, Technology, Engineering, and Mathematics (STEM) on students' collaboration and problem-solving skill. Problem Based Learning (PBL) integrated STEM allows students to broaden their horizons, discuss and collaborate in problem solving, encourage students to refine their knowledge through discussion, communicate in groups and respect each other when there are differences of opinion, critically assess group processes and work, provide feedback, and agree on the best solution, which directly improves various aspects of collaboration and develops competencies to address the complex challenges of their future.

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