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The Effect of Problem Based Learning Model with STEAM Approach on Mathematical Critical Thinking Ability

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Abstract
This study aims to determine the effect of the problem-based learning model with the STEAM approach on students' critical thinking skills and their response to the model. Using a quantitative method with a quasi-experimental design, this study involved ninth-grade students with similar academic characteristics from a junior high school in Serang City. The sample consisted of 72 students from two classes: IX E as the experimental class that applied PBL-STEAM and IX A as the control class that used the collaborative model. The results showed that 1) students' critical thinking skills with the PBL-STEAM model were better than students who applied the collaborative model based on the experimental class posttest results with an average value of 83.33, superior to the control class, which was only 78.19. 2) Analysis of student response questionnaires showed that the application of the PBL-STEAM model received a positive response and was able to increase student knowledge of the material taught. 3) The PBL-STEAM model is effective in improving students' critical thinking skills so that it becomes one of the alternative learning models that can be applied by teachers in learning mathematics.

Keywords: critical thinking ability, problem-based learning, STEAM

Abstrak
Penelitian ini bertujuan untuk menentukan pengaruh model pembelajaran berbasis masalah (PBL) dengan pendekatan STEAM terhadap kemampuan berpikir kritis siswa dan respons mereka terhadap model tersebut. Dengan menggunakan metode kuantitatif dan desain quasi-eksperimental, penelitian ini melibatkan siswa kelas IX dengan karakteristik akademik yang serupa dari sekolah menengah pertama di Kota Serang. Sampel terdiri dari 72 siswa dari dua kelas: IX E sebagai kelas eksperimen yang menerapkan PBL-STEAM dan IX A sebagai kelas kontrol yang menggunakan model kolaboratif. Hasil penelitian menunjukkan bahwa 1) kemampuan berpikir kritis siswa dengan model PBL-STEAM lebih baik dibandingkan siswa yang menerapkan model kolaboratif berdasarkan hasil posttest kelas eksperimen dengan nilai rata-rata 83,33, lebih unggul daripada kelas kontrol yang hanya 78,19. 2) Analisis kuesioner tanggapan siswa menunjukkan bahwa penerapan model PBL-STEAM mendapat tanggapan positif dan mampu meningkatkan pengetahuan siswa tentang materi yang diajarkan. 3) Model PBL-STEAM efektif dalam meningkatkan kemampuan berpikir kritis siswa sehingga menjadi salah satu model pembelajaran alternatif yang dapat diterapkan oleh guru dalam pembelajaran matematika.

Kata Kunci: kemampuan berpikir kritis; problem-based learning; STEAM

1. INTRODUCTION

Mathematics is the main field of study that is taught continuously at all levels of study, from elementary school to university (Santosa et al., 2022). At the university level, mathematics requires high accuracy and the use of deductive thinking methods, drawing conclusions from general to specific premises. Meanwhile, at the school level, the focus is more on understanding basic concepts and formulas (Santosa et al., 2019). Learning mathematics is a complicated process because it involves many elements that must be processed simultaneously (Santosa et al., 2018). Therefore, when understanding an idea or solving a math problem, the stages of thinking are very important. These stages serve as balances and connectors that help students understand and solve the problem (Santosa & Filiz, 2025). Critical thinking becomes a fundamental element in this stage, guiding students to analyze the complexity of the problem, identify patterns, and formulate logical solution strategies (Pramudita et al., 2023).

Education today is intrinsically part of 21st-century learning that demands four competencies: creativity and innovation, critical thinking, communication, and collaboration (Hasanah et al., 2023). Critical thinking, as one of the four 21st-century skills, is an essential ability for students. This skill involves a systematic approach to analyzing information, solving problems, and choosing the best option (Hamzah et al., 2023). Critical thinking is also essential for building new ideas and developing new methods or products to analyze data based on facts, develop strong arguments based on evidence, and make rational decisions in complex situations (Sukmawati, 2020). A person can be said to think critically if he is able to explain simply, strengthen arguments with evidence, draw conclusions logically, provide deeper explanations, and plan steps to achieve goals (Hamzah et al., 2023).

The meaning of critical thinking in the context of mathematics learning is more than just how to solve problems but also includes a more thorough understanding. Critical thinking becomes the main foundation to capture more complex ideas and to develop problem-solving (Istiqomah & Indarini, 2021). In other words, critical thinking is at the core of mathematics learning. However, in fact, students tend to be passive in thinking. The PISA 2022 results indicated a significant gap between the performance of 15-year-old Indonesian students in science, math, and reading subjects and the OECD country average. In math particularly, most students in Indonesia, or around 82%, have not reached the basic proficiency level, far below international standards. In fact, very few students in Indonesia are able to solve high-level math problems that demand critical thinking and complex problem-solving skills (OCDE, 2023). Students' low skills in mathematics, which is the foundation for many fields of science, contribute to the overall low critical thinking skills. This indicates that students in Indonesia still face obstacles in utilizing their knowledge to examine information, test arguments, and solve complex problems (Girsang et al., 2022).

According to research by Arifianto dan Koeswanti (2022), students need to further develop their critical thinking skills. Students often have difficulty analyzing problems, formulating strong arguments, and lacking the initiative to find out more. The tendency to rely on friends during group discussions is also an indicator of students' low independent thinking skills. Another research study conducted by Supratman et al., (2021) found that the reason behind the low level of critical reasoning among students is because the majority of students are more comfortable with the mechanistic approach in solving math problems, so students rarely hone their critical and analytical thinking skills in solving mathematical problems. Some other factors that contribute to the lack of students' critical thinking skills are students' inability to use active learning to maximize their thinking potential, students' lack of understanding of the basics of mathematical arithmetic operations, and students' unfamiliarity with more complex types of problems (Nurfadillah et al., 2020. The interview results with a mathematics teacher at the school further supported this condition, indicating that students at this grade level generally demonstrate low critical thinking skills. They tend to rely on following procedural steps provided by the teacher, and when presented with problems that differ slightly from the given examples, they struggle to adapt their reasoning. Limited learning motivation, insufficient conceptual understanding, and inadequate learning facilities and resources are identified as contributing factors to this low level of critical thinking ability.

The negative perception that is still attached to learning mathematics is one of the triggers for students' low critical thinking skills. Math is often considered difficult and scary (Hadi et al., 2020). Another factor is that schools often encourage students to give standard answers and memorize information rather than encouraging them to analyze information in depth and draw conclusions (Hakiki et al., 2022). Therefore, students are accustomed to memorizing and answering questions according to what is exemplified. The limitation of students' critical thinking can also be caused by the implementation of inappropriate and monotonous learning models by teachers. Most teachers still apply lectures rather than discussion methods, which take a lot of time (Supratman et al., 2021). Therefore, it is important to change the learning model to be more student-centered so that they are encouraged to improve their critical thinking skills and be directly involved in learning activities (Amelia et al., 2022).

Problem-based learning is a learning model in which the teacher gives a problem to students as the focus of learning. Students do not just answer questions based on memory. They must be more proactive in identifying relevant knowledge and applying it to solve problems (Zahara et al., 2020). Through this model, students actively participate in solving problems directly to encourage students' critical thinking processes during learning. Meanwhile, the STEAM approach is a comprehensive learning approach that integrates science, technology, engineering, art, and math. By integrating these various disciplines, STEAM aims to develop relevant 21st-century skills, such as creativity, critical thinking, and collaboration skills (Budiyono et al., 2020).

The development of students' critical thinking can be effectively supported through the student-focused PBL-STEAM model, which encourages activeness and is in line with advances in educational technology in the era of the industrial revolution 4.0 (Asti & Andriyani, 2022). Iffiani's research also shows similar findings: PBL-STEAM can trigger students to participate directly in learning, motivate students to explore their skills in different ways, and improve their ability to think critically (Iffiani et al., 2024). Hartati (2023) research shows that PBL-STEAM not only encourages students to find solution to complex problems, but also trains them to connect concepts from mathematics, science, engineering, art, and technology. In line with this, Asti dan Andriyani (2022) emphasize that PBL-STEAM increases motivation, supports the strengthening of 21st-century skills, and creates a more creative, collaboration, and effective learning environment.

Although previous studies have indicated that STEAM-integrated PBL can enhance students' critical thinking skills, these studies were generally conducted in different subject contexts and educational levels, and most did not analyze the improvement of each critical thinking indicator in detail. In addition, prior studies tended to measure overall critical thinking outcomes without providing a comprehensive evaluation of students' responses during the learning process. This study provides novelty through a more rigorous quasi-experimental design implemented specifically on the topic of congruence in ninth-grade mathematics, accompanied by a detailed analysis of five critical thinking indicators and an extensive assessment of student responses across four dimensions: interest and engagement, attitudes, perceived benefits, and the integration of STEAM components. This comprehensive approach contributes new insights into how PBL-STEAM functions in shaping critical thinking development within the junior high school mathematics context.

2.RESEARCH METHOD

This study used quantitative methods with a quasi-experimental design of the nonequivalent pretest-posttest control group type. The school where this study was conducted is a public junior high school located in an urban area of Serang City, with a medium level of school resources. The student academic characteristics are heterogeneous, with most students having moderate prior mathematical ability based on teacher input and school assessment data. The school also implements the national curriculum and commonly uses collaborative and teacher-centered learning models. These characteristics allow the findings of this study to be applicable to schools with similar conditions, particularly public junior high schools in urban areas with moderate learning facilities and mixed-ability student populations.

The sampling technique in this study was carried out using simple random sampling based on the available classes. A total of two classes with 72 students were selected as the sample and then assigned as the experimental and control groups. Based on the mathematics teacher's recommendation, two classes with similar characteristics in terms of student ability and class size - Class IX A and IX E - were chosen as candidate samples. These two classes were then randomized using a simple random selection procedure, resulting in Class IX E being assigned as the experimental class and Class IX A as the control class. Class IX E received learning using the PBL-STEAM model, while Class IX A was taught using a collaborative learning model.

This study began with a pretest in two sample classes. It was followed by treatment during four meetings (PBL-STEAM for the experiment, collaborative for the control). After that, a post-test and questionnaire were conducted, and the results were then concluded with inferential data analysis to test the effect of the model. Data collection used critical thinking skills test instruments and student response questionnaires to the PBL-STEAM model. The data that has been collected will be analyzed descriptively and inferentially with the help of SPSS version 26. In the inferential analysis, the independent sample t-test is conducted to determine whether there is a significant difference in average or not between the posttest results of the control class and the experimental class.

3. RESULTS

This study aims to examine the critical thinking skills of students who get a problem-based learning model with a STEAM approach compared with students who get a collaborative learning model. This study also analyses how students respond to the application of the problem-based learning model with the STEAM approach. For data analysis purposes, this study utilized Ms. Excel and SPSS version 26. Data were collected through pretests and post-test in the form of description questions designed in accordance with the indicators of critical thinking skills, as well as student response questionnaires to the problem-based learning model with the STEAM approach.

Table 1. Descriptive Data of Critical Thinking Ability Pre-test

Class	N	Min	Max	Mean	Std. Dev
Experimental	36	40	75	56,94	9,583
Control	36	35	70	52,78	9,669

Based on Table 1, the mean pretest scores of the experimental 56,94 and control 52,78 classes show relatively similar initial critical thinking skills in the deficient category. Inferential statistical analysis will be conducted to confirm the absence of significant differences between these two mean pre-test scores.

Table 2. Descriptive Data of Critical Thinking Ability Post-test

Class	N	Min	Max	Mean	Std. Dev
Experimental	36	70	100	83,33	7,171
Control	36	65	95	78,19	7,285

Based on Table 2, the average post-test score of the experimental class of 83,33 and the control class of 78,19 showed a significant difference in the final critical thinking ability between the two classes, both of which were in the good category. Furthermore, inferential statistical analysis was carried out to prove the significance of the difference in the average post-test score.

Table 3. Results of the homogeneity Test of student

Levene Statistic	Remarks (Based on Mean)	df1	df2	Sig.
0,037	Pretest	1	72	0,847
0,021	Posttest	1	72	0,885

In this study, the Levene test was used to assess homogeneity between data groups. If Sig. (Significance) based on Based on Mean ≥ 0.05, then H_0 is rejected. The test results showed the pretest data had a Sig. of 0,847 and the post-test data had a value of Sig. 0,885. Both are ≥ 0.05, meaning H_0 is rejected, and the data is homogeneous.

3.1 Normality Test

The normality test for this study was conducted with a sample of 36 students. To see if the data is normally distributed, the Shapiro-Wilk test is carried out (Ahadi & Zain, 2023). The null hypothesis (H_0) is rejected if the significance (p-value) ≥ 0,05. The test results explained that the pretest data of the experimental class and control class had a significance value of 0,089 and 0,097, while the post-test data of the experimental class and control class had a significance value of 0,117 and 0,125. Both are ≥ 0,05, meaning the data is normally distributed.

3.3 Hypothesis Test

Hypothesis testing was carried out using the independent sample t-test (one party). This test is carried out with a statistical data processing application.

Table 4. Hypothesis Test Results

T-Test for Equality of Means			Description
t	df	$\frac{1}{2}$ *Sig. (2-tailed)*	
3,016	70	0,002	H_0 rejected

Based on table 3, the value of 1/2 Sig. (2-tailed) post-test data in the experimental class is 0,002 < 0.05, meaning that H_0 is rejected, and H_a is accepted. Thus, the final critical thinking ability of students who apply the PBL-STEAM learning model is better than students who apply the collaborative learning model.

3.4 Analysis of Each Indicator of Test and Questionnaire

Student post-test data in experimental and control classes will be analyzed based on critical thinking ability indicators. Data from student response questionnaires are also analyzed based on indicators. The results of the analysis will be shown in the following table.

Table 5. Percentage Results of Each Critical Thinking Ability Indicator

No	Indicator	Class	Percentages	Category
1	Checking arguments	Experimental	97%	Very high
		Control	92%	Very high
2	Compose a statement	Experimental	88%	Very high
		Control	85%	Very high
3	Identifying assumptions	Experimental	78%	Very high
		Control	63%	High
4	Identifying data	Experimental	69%	High
		Control	70%	High
5	Composing the answer	Experimental	83%	Very high
		Control	81%	Very high
	Average percentage	Experimental	83%	Very high
		Control	78%	Very high

Based on Table 4, the percentage of students' critical thinking skills in the experimental class was superior to that of the control class. Although only the "Identifying assumptions" indicator differed by one level (Very High vs. High), this superiority was concluded from a comparison of the overall average percentages (83% vs. 78%), which was supported by superior percentages in most indicators. Thus, although the data does not show a drastic categorical advantage, the numerical and statistical advantage in the final average and previous post-test results (83.33 vs. 78.19) demonstrates the effectiveness of the PBL - STEAM model.

Table 6. Student Interest and Engagement

No Item	Total Items	Score (-)/(+)	F	Total Average Score	Percentages
1, 2, 3, 4, 5, and 6	6	SS/STS (1)	0	0	0%
		S/TS (2)	14	28	4%
		TS/S (3)	160	480	71%
		STS/SS (4)	42	168	25%
Total			216	676	100%
Maximum Score				864	
Average percentage				78%	
Category				Very high	

Table 5 shows that the percentage of student interest and involvement reached 78% with very high criteria. This high level of student interest and engagement provides a positive response to the application of the PBL-STEAM model and creates a conducive learning atmosphere. Therefore, teachers can take advantage of this condition to implement student-centered PBL-STEAM learning.

Table 7. Student Attitude to Learning

No Item	Total Items	Score (-)/(+)	F	Total Average Score	Percentages
7, 8, 9, 10, 11, and 12	6	SS/STS (1)	0	0	0%
		S/TS (2)	8	16	2%
		TS/S (3)	162	486	71%
		STS/SS (4)	46	184	27%
Total			216	686	100%
Maximum Score			864		
Average percentage			79%		
Category			Very high		

Based on Table 6, 79% of students showed a very high attitude in PBL-STEAM learning, indicating an easy understanding of the material, enthusiasm for learning, active participation, independence in solving problems, and high curiosity about the material, so the attitude of students during PBL-STEAM learning is positive.

Table 8. Benefits of PBL-STEAM Model Implementation

No Item	Total Items	Score (-)/(+)	F	Total Average Score	Percentages
13, 14, 15, 16, 17, and 18	6	SS/STS (1)	0	0	0%
		S/TS (2)	1	1	0%
		TS/S (3)	167	167	72%
		STS/SS (4)	48	48	28%
Total			216	695	100%
Maximum Score			864		
Average percentage			80%		
Category			Very high		

Table 7 shows that 80% of students rated the benefits of applying the PBL-STEAM model very high, which has implications for improving material understanding, learning meaningfulness, and learning motivation, so this model is effective in achieving learning objectives.

Table 9. STEAM Components

No Item	Total Items	Score (-)/(+)	F	Total Average Score	Percentages
19, 20, 21, 22, 23, and 24	6	SS/STS (1)	0	0	0%
		S/TS (2)	19	38	5%
		TS/S (3)	107	321	45%
		STS/SS (4)	90	360	50%
Total			216	719	100%
Maximum Score			864		
Average percentage			83%		
Category			Very high		

Table 8 shows that 83% of students rated the STEAM component in learning as very high. This indicates that the utilization of STEAM components helps students understand the material and solve problems related to the lesson more easily. From the four questionnaire indicators, the average percentage of the questionnaire is 80.32% and is included in the good category. Thus, students' views on the PBL-STEAM learning model show a positive response.

4. DISCUSSION

The PBL-STEAM learning model combines problem-based learning with STEAM components. This model is in line with Lev Vygotsky's constructivist learning theory. This theory emphasizes that learning is not merely a process of passively receiving information from external sources, but rather an active process in which students are directly involved in constructing knowledge based on their own experiences(Salsabila & Muqowim, 2024).

The research procedure began with a pretest to measure initial critical thinking skills. The learning process with the PBL-STEAM model is carried out through 4 meetings. Students are given basic knowledge first related to congruence by utilizing technology, such as learning videos and PowerPoints. After that, students are given STEAM-oriented problems shown in Figure 1. Students are required to be actively involved in the problem-solving process, both individually and in groups. The purpose of giving STEAM-oriented problems is to encourage students to provide simple explanations, build basic skills, provide simple explanations, and be able to organize strategies and techniques. This can improve students' critical thinking skills.

Figure 1. STEAM-oriented problems

After learning is carried out for 4 meetings, at the last meeting (5th meeting), students are given a posttest to determine the final ability of students' critical thinking related to the material that has been taught. This test consists of 5 questions that must be done within 45 minutes and contains indicators of critical thinking skills. The last meeting was ended by filling out a student response questionnaire, as well as reflection and evaluation related to the learning that had been carried out for 5 meetings.

Students' posttest results were analyzed descriptively and inferentially; the analysis results showed that the critical thinking skills of the experimental class were better than the control class. Thus, students given the PBL-STEAM learning model have better critical thinking skills than students given the collaborative learning model. The results of this study are in line with the results of research conducted by Hartati et al. (2023), which stated that the STEAM-based PBL learning model is more effective in improving students' critical thinking skills than the conventional learning model, as seen from the results of the ANOVA test, which resulted in a significant value of 0,000, so it can be concluded that the sig value is <0,05.

The results of students' critical thinking skills in the experimental class for respondent S28 in the first indicator, namely checking the correctness of arguments, statements, and solution processes, have changed for the better, where respondents are able to check arguments, statements, and solution processes appropriately. In the second indicator, namely compiling statements accompanied by reasons, respondents have been able to compile statements accompanied by reasons properly and correctly, which previously in the pretest question, respondents had not been able to compile statements accompanied by reasons. In the third indicator, namely identifying assumptions, respondents were able to identify assumptions in the problem and provide the right solution. In the fourth indicator, namely identifying relevant and irrelevant data of a mathematical problem, the respondent can identify what data is needed to solve the given problem correctly. In the fifth indicator, namely solving math problems accompanied by reasons, respondents were able to solve the given problem accompanied by the reasons and make illustrations of the given problem, but there were still errors in the calculation process. Thus, in the fifth indicator, the respondent's final answer was not correct. This can be seen in Figure 2 and Figure 3

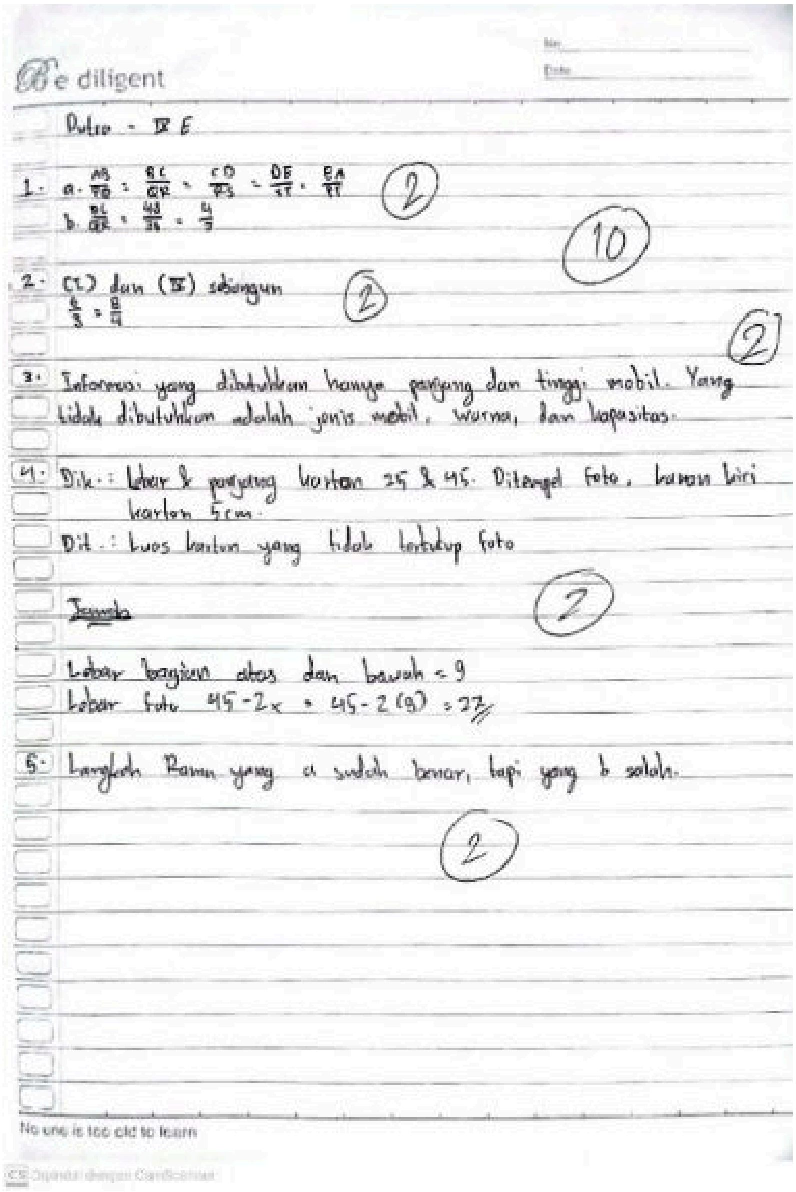

Figure 2. Experimental class pretest answers

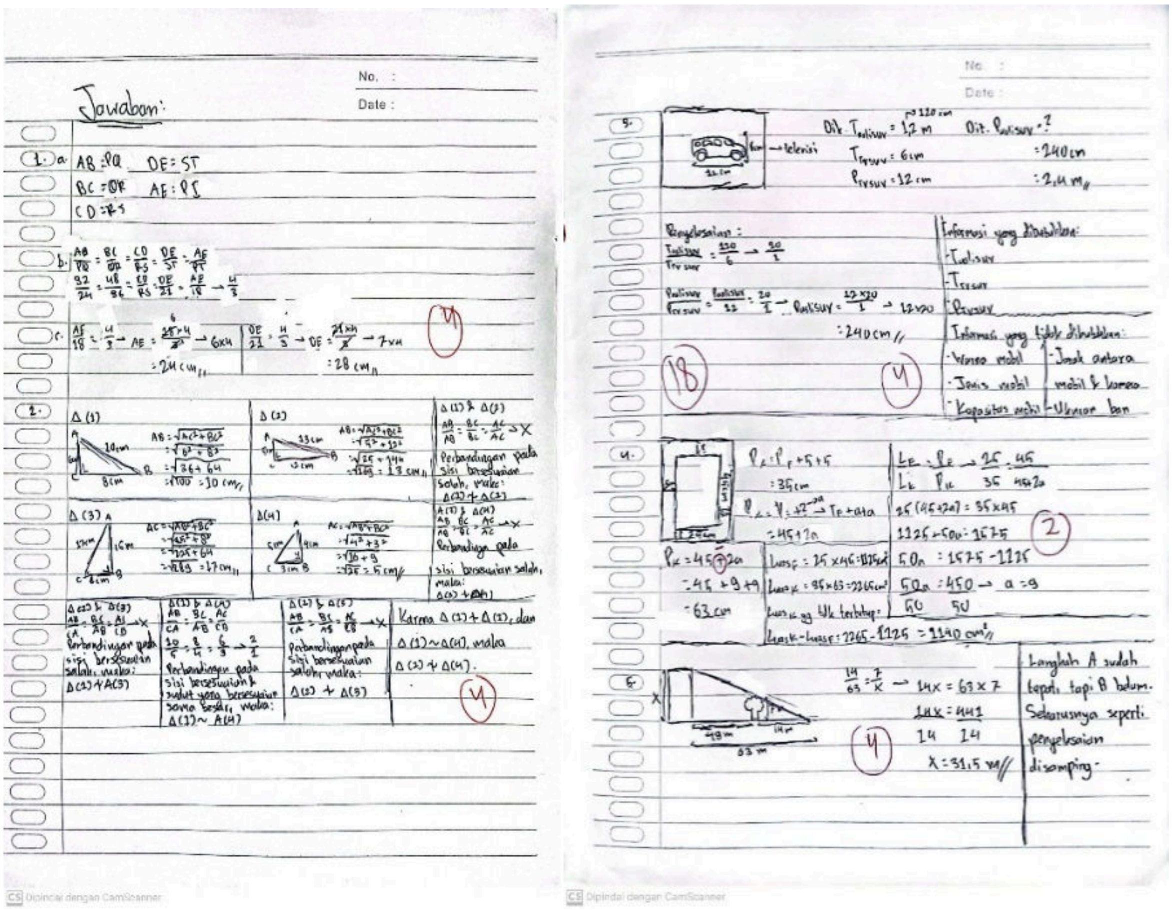

Figure 3. Experimental class post-test answer

4. CONCLUSION

This research was conducted on ninth-grade students with similar academic characteristics from a junior high school in Serang City using a quasi-experimental design involving two classes, an experimental class and a control class. The research samples were taken randomly and given different treatments. The results of research and data analysis on the effect of PBL-STEAM on students' critical thinking skills are as follows.

1. The increase in students' critical thinking skills in the experimental class using the PBL-STEAM model was better than the control class that applied the collaborative learning model, namely 83% in the experimental class versus 78% in the control class.
2. Students' responses to the PBL-STEAM model showed positive results, with an average of 80.32% and included in the good category.

The better improvement in students' critical thinking skills and students' positive response to the PBL-STEAM model in the experimental class clearly show that PBL-STEAM has a significant impact on optimizing the development of students' critical thinking skills. Thus, it can be concluded that there is a positive influence of the PBL-STEAM model on students' critical thinking skills.

6. RECOMENDATION

Researchers who wish to explore the PBL-STEAM model further can examine the effectiveness of this model in different contexts with more diverse groups of students, as this study was limited by critical thinking skills and inadequate facilities for implementation.

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