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ENHANCING CRITICAL THINKING AND MATHEMATICAL ACHIEVEMENT THROUGH PROBLEM-BASED-LEARNING: A CLASSROOM ACTION RESEARCH AT SMKN 6 SURABAYA

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ABSTRACT

This study aimed to enhance students' critical thinking skills and mathematics learning outcomes on the topic of relations and functions through the implementation of the Problem-Based Learning (PBL) model. Conducted as a Classroom Action Research (CAR) at SMKN 6 Surabaya, the study involved 40 students of class X ULP 2 and was carried out over three months in two cycles. Data were collected using tests, observations, and questionnaires. The results showed a significant improvement in cognitive learning outcomes. The average score in the basic cognitive domain (C1–C3) increased from 73.71 in the first cycle to 75.9 in the second cycle. The lowest score rose from 37.5 to 54.2, and the number of students who achieved completion increased from 22 to 34. In the complex cognitive domain (C4–C6) that showed critical thinking skills, the average increased from 40.09 to 61.4. The highest score rose from 70.83 to 91.7, and there were no more students in the low-scoring category. These findings suggest that the PBL approach, when supported by structured assignments and exercises, can effectively foster critical thinking and improve mathematics achievement in vocational high school setting.

Keywords: critical thinking, learning outcomes, Problem-Based Learning, relations and functions

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INTRODUCTION

Mathematics learning plays a crucial role in developing students' logical and analytical thinking abilities (Ningrum et al., 2023; Sari & Juandi, 2023). The connection between mathematics and critical thinking is well established, as students are required to analyze problems, identify patterns, and use logical reasoning—key aspects of critical thinking (Solikhah et al., 2024; Sosa-Gutierrez et al., 2024). However, achieving optimal learning outcomes depends not only on clear material delivery but also on maximizing student engagement (Titin et al., 2023; Wulandari & Maulidin, 2024). A variety of appropriate strategies, media, and presentation methods are essential to create a dynamic and engaging learning atmosphere, which in turn can encourage students to think more actively and participate (Sahabudin et al., 2024; Subekti & Pitriyana, 2024). Students' active involvement will positively impact mastering the material and developing their wider potential, so that students are better prepared to face social challenges in society (Aji et al., 2024; Musyarrofah, 2025).

Despite various efforts, many students, especially in vocational settings, struggle to learn mathematical concepts such as relations and functions. At SMKN 6 Surabaya, particularly in class X ULP 2, students' mathematics achievement is still relatively low. This underachievement is often linked to passive learning environments, lack of motivation, and insufficient use of interactive methods (Pradnyana & Amanda, 2023).

Although Problem-Based Learning (PBL) has been widely applied in general education settings, its impact on students' critical thinking in vocational high schools, particularly on the topic of relations and functions, remains underexplored. This presents an important gap that this study seeks to address. PBL is a student-cantered model known to improve analytical skills through real-life problems and group collaboration (Aflah & Rahmani, 2022; Kurniasih et al., 2024).

Additionally, the importance of integrating active learning approaches such as Problem-Based Learning (PBL) is increasingly emphasized due to the rising demand for critical thinking skills in the workplace, particularly among graduates of vocational high schools (SMK). In the context of vocational education, mathematics serves not merely as a tool for solving academic problems but also as a foundational element for developing analytical skills applicable within specific professional fields (Sari & Juandi, 2023; Subekti & Pitriyana, 2024). Therefore, the application of instructional models that foster students' critical and analytical thinking, such as PBL, is not only relevant to enhancing academic achievement but also crucial in preparing students to tackle the real-world complexities they will encounter in the workplace.

Moreover, several studies have confirmed that students' critical thinking skills develop optimally when they are directly confronted with authentic situations that require collaborative real-world problem-solving (Sahabudin et al., 2024; Solikhah et al., 2024). Within the PBL model, students actively engage with real-life problems relevant to their field of study, thereby encouraging active participation in group discussions, solution formulation, and the systematic development of problem-solving strategies. Through this approach, students not only learn theoretical concepts conceptually but also become capable of applying them across various life contexts. Ultimately, this enables them to evolve into more independent, reflective, and adaptive learners capable of addressing future challenges.

To address this gap, this study aims to enhance students' critical thinking skills and mathematics learning outcomes on the topic of relations and functions through the implementation of the Problem-Based Learning model in a vocational school context. The following questions guide the research:

1. How does the PBL model affect students' critical thinking skills in mathematics?
2. How does PBL improve student achievement in learning relations and functions?

METHOD

Research Setting

This study uses a collaborative Classroom Action Research (CAR) approach between researchers and peer teachers in the Mathematical learning process. CAR is a reflective study conducted by teachers to improve the learning process and deepen understanding of the actions taken (Rain, 2022). This research activity is directed to improve the quality of the Teaching and Learning Process (PBM) and student learning outcomes through the application of more effective learning methods. The CAR model used refers to the Kemmis and McTaggart models (in Arikunto et al., 2006) which consists of four stages: (1) planning, (2) implementation, (3) observing, and (4) reflecting. Each cycle consists of these four stages, and can be continued to the next cycle if the expected changes have not been achieved.

To ensure the accuracy and consistency of the research instruments, all items in the test, questionnaire, and observation sheets were reviewed by two subject-matter experts in mathematics education. The test items were validated for content relevance and alignment with cognitive domains (C1–C6), especially those reflecting critical thinking components. A pilot test was conducted on a similar group of students to test internal consistency, and necessary revisions were made based on feedback and item analysis. The instruments were then finalized for use in the actual data collection process.

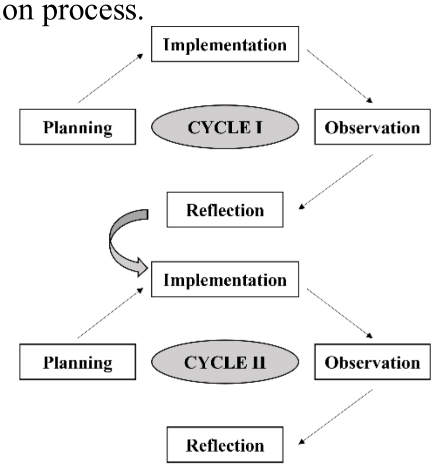

Figure 1. CAR Flow

Place and Time of Research

The research was carried out at SMKN 6 Surabaya on 40 students in class X of ULP 2. The research lasted for three months and was carried out according to the mathematics learning schedule in the class.

Research Procedure

The research was carried out through two cycles, each consisting of two meetings. Each cycle includes the following stages:

1. Planning
   Planning involves the development of instructional materials aligned with Competency Standards (SK) and Basic Competencies (KD), namely: Finding the concept of composition functions and the operational properties of composition functions. The researcher also prepares research instruments and problem-based learning measures.
2. Implementation
   Implementation was carried out according to plan, by applying the PBL model that encourages students to be actively involved, think critically, and solve problems based on daily experiences.
3. Observation and Evaluation
   Observations are carried out by peer teachers using observation sheets to record student activities during the learning process. Evaluation is carried out through a formative test at the closing stage of the cycle to determine the achievement of learning objectives.
4. Reflection
   Reflection is carried out with fellow teachers by analysing the results of observation and evaluation. Reflection is used to identify learning deficiencies in the previous cycle and design improvements in the next cycle.

Data Collection Techniques

The data obtained in this study includes quantitative data in the form of cognitive learning outcome scores and qualitative data through questionnaires and observation sheets. Before learning actions are carried out, researchers first provide a pretest to determine the initial ability of students. After the action process is carried out through the application of the Problem-Based

Learning (PBL) method, re-measurements are carried out at the end of each cycle to find out any changes, both in learning outcomes and students' attitudes towards learning.

Several instruments were used to support the data collection process, namely learning outcome tests, questionnaires, and observation sheets. The learning outcome test consisted of six essay questions designed according to Bloom's taxonomy cognitive domains, ranging from lower-order thinking skills (C1–C3) to higher-order thinking skills (C4–C6). This structure was deliberately chosen to align with the characteristics of Problem-Based Learning (PBL), which requires students to recall, apply, analyse, and evaluate mathematical concepts in solving contextual problems. The higher-level items (C4–C6) were particularly targeted to assess students' critical thinking abilities, such as reasoning, logical argumentation, and problem-solving, all of which are essential in evaluating the impact of PBL. The questionnaire was used to gather students' attitudes and responses toward the PBL approach, while observation sheets were used to assess active participation and collaborative behaviours during group work. The learning outcome test grid is shown in Table 1.

Table 1. Learning Outcome Test Grid

Material	Indicator	Medium Realm/ Grain		Critical Thinking Domain/Item	
1. Understand the notation, domain, range, and graph of a function 2. Algebraic function operations	1. Describe the meaning of notation, domain, range, and graph of a function. 2. Describe the composition functions of algebraic operations of addition, subtraction, multiplication, and division.	C1, C2, C3	1, 2, 3, 4, 5, 6.	C4, C5, C6	7, 8, 9, 10, 11,12.
3. Discovering the Composition Function and the Operation Properties of the Composition Function. 4. Inverse function and find the formula of inverse function.	3. Describe the compositional functions of the two and three functions. 4. Explain the inverse function, the inverse function composition of the two and three functions	C1, C2, C3	1, 2, 3, 4, 5, 6	C4, C5, C6	7, 8, 9, 10, 11,12.

Data Analysis Techniques

The data on learning outcomes and critical thinking skills obtained were analysed using descriptive statistical techniques. Descriptive statistics are used to describe data characteristics through cantering measures such as mean, median, and mode, as well as presenting data in the form of percentages. This analysis aims to provide an overview of the level of achievement of learning outcomes and students' critical thinking abilities following the use of the Problem-Based Learning (PBL) approach.

Qualitative data, such as observation results and questionnaires, are converted quantitatively through a codification process, namely by converting the results of observations and student responses into numbers. The numbers are then processed and represented in the form of tables, charts, or graphs (e.g. histograms), to make them easier to analyse and understand.

To analyze effective learning outcomes, data processing based on logic formulas is used in a spreadsheet application with the following conditions: =IF(H63>=5,"Sangat Baik",IF(H63>=4,"Baik",IF(H63>=3,"Cukup","Kurang"))). Meanwhile, the learning outcomes of the psychomotor domain were analysed with the formula: =IF(M140>=70,"Kritis","Tidak Kritis"). Through this analysis, student learning outcomes can be classified into certain categories that describe the success rate of each domain, both affective, psychomotor, and cognitive.

Success Indicators

Goal indicators make it easier for researchers to see the achievement of the goals of each cycle in supporting the achievement of the final goal, namely, increasing results, activities, and PBM. Because CAR is integrated research in daily learning activities, the duration of the action is adjusted to the time allocation that has been planned in the activity schedule at SMKN 6 Surabaya. Each of these meetings, according to the schedule, is allocated a time of 2 x 45 minutes. The following are the success indicators used in CAR. Indicators of success are shown in Table 2.

Table 2. Success Indicators

Purpose	Success Indicators	Volume
Applying PBL learning	Procedures are implemented correctly Find other components to optimize PBL	75% steps There are the right components
Simple cognitive learning outcomes	Students get a score of 75	75% of students
Affective learning outcomes	Students show the predicate of Good and Excellent	75% of students

If the student has reached the above indicators, the cycle is stopped. If students have changed their critical thinking skills from bad to good as many as 75% of the total number of students, the cycle is stopped.

RESULTS

1. Cycle I

a. Planning

In Cycle I, only two meetings were planned. In Cycle I, the PBL method prioritizes a discussion component that is integrated with the training method. The material is a material assignment during the pre-cycle about the meaning of relations and functions. The steps are: 1) Forming a group of 4 students; 2) The teacher presents the lesson and then the students work in their groups; 3) Provide opportunities for students to repeat what has been done; 4) Ensure that all group members have mastered the material on the meaning of relations and functions; 5) Giving tests to students. Students are given tests where at the time of this test they cannot help each other. The points of each member of this team are then added up to get a group score.

b. Implementation

In Cycle I, the PBL method emphasizes the questioning component which is integrated with the training method. The steps are: 1) Forming a group of 4 students; 2) The teacher presents the lesson and then the students work in their groups; 3) Provide opportunities for students to repeat what has been done; 4) Ensure that all group members have mastered the subject matter of how to describe the meaning of relations and functions; 5) Giving test games to students. Students are given tests where at the time of this test they cannot help each other. The points of each member of this team are then added up to get a group score.

Through the guidance of the teacher, each group representative reflected on the material that had been demonstrated by each group. Hold a post-test. Assign tasks about relations and functions for the next cycle.

c. Observation and Assessment

Outcome tests and measurement of cognitive learning outcomes were given after treatment in Cycle I at the third meeting. The measurement of critical thinking skills was carried out by analysing test results in the cognitive domains of strata C4, C5, and C6. Observation of the learning process was carried out by peers using only special notes. The learning outcome test is given in the last 30 minutes of learning. Based on these observations and assessments, the data can be displayed as follows.

1) Learning Outcomes C1, C2, C3, C4, C5, C6

The questions given include the realms of C1, C2, C3, and C4, C5, C6. Each level consists of 2 questions. The learning outcomes of the Pre-Cycle and Cycle I cognitive domains, shown consisting of 9 points of descriptive statistics, are shown in Table 3.

Table 3. Description of Precycle and Cycle I Cognitive Learning Outcomes Data

Yes	Type of Description	Precycle		Cycle I		Increased	
		C1-3	C4-6	C1-3	C4-6	C1-3	C4-6
1.	Average	48.0	19.97	73.71	40.09	25.7	20.11
2.	Middle Value	41.7	20.83	75.00	37.5	33.3	16.67
3.	Mode	41.7	20.83	75.00	54.17	33.3	33.33
4.	Baku Junction	20.5	9.34	10.63	15.41	-9.8	6.06
5.	Variansi	418.7	87.28	112.98	237.4	-305.7	150.09
6.	Range	70.8	37.50	45.83	54.17	-25.0	16.67
7.	Lowest Score	12.5	4.17	37.50	16.67	25.0	12.50
8.	Highest Score	83.3	41.67	83.33	70.833	0.0	29.17
9.	Sum	1391.7	579.17	2137.50	1162.5	745.8	583.33
10.	A Lot of Data	40	40	40	40		

The table above shows the change in the average, standard deviation, range, lowest value, highest score and amount from Precycle to Cycle I. There is an increase in cognitive learning outcomes C1, C2, C3, and C4, C5, C6, from Precycle to Cycle I. Strata C1, C2, C3, are simple cognitive domains. The average increase in C1, C2, C3, occurred by 25.7 from 48.0 in the pre-cycle to 73.71 in Cycle I. The lowest value increased by 25.0 from 12.5 in the Precycle to 37.5 in Cycle I. The highest value remained 83.3 in the Precycle to 6 in Cycle I. The mode shifted from 41.7 to 75.

Strata C4, C5, C6, are complex cognitive domains that show critical thinking skills. The average increase occurred by 20.11 from 19.97 in the pre-cycle to 40.09 in Cycle I. The lowest value increased to 12.50 from 4.17 in the Pre-cycle to 16.67 in the first cycle. The highest value remained 41.67 in the Pre-cycle to 70.83 in the first cycle. The number of data analyzed was 40 in both the pre-cycle and the first cycle.

2) Critical Thinking Skills

The learning outcomes of the cognitive domain of strata C4, C5, C6 as indicators of critical thinking skills are categorized into 4 categories, namely lacking, sufficient, good and very good. The category of less in the pre-cycle is still as many as 27 students then drops to 4 in cycle I. The category is only 13 students in the pre-cycle to 22 in cycle I. The good category is not in the pre-cycle to 13 students in cycle I.

The completeness of the domains C1, C2, C3 shows that in the pre-cycle there are still unanswered items, or a score of 0 as many as 48 times then drops to 7 in cycle I. Students who complete only 8 in the precycle then become 30 people in cycle I.

2. Cycle II

a. Planning

Actions in Cycle II, based on the results of reflection from Cycle I, are planned to hold two meetings. The method used in Cycle II is the PBL method, with a focus on the questioning component, which is based on the problem of the previous task. 1) Form a group of 4 students with relation and function materials; 2) The teacher presents the lesson and then the students work in their groups; 3) Provide opportunities for students to repeat what has been done; 4) Ensure that all group members have mastered the subject matter; 5) Giving tests to students. Students are given tests where at the time of this test they cannot help each other. The points of each member of this team are then added up to get a group score.

b. Implementation

Learning activities are carried out as follows: Perception. Classroom readiness in learning. Motivate. Exploring students' learning readiness by giving oral questions; Competency information to be achieved.

Learning is carried out as follows: 1) Students are divided into groups of four; 2) After the teacher delivers the lesson, students collaborate within their groups; 3) Provide opportunities for students to repeat what has been done; 4) Ensure that every group member has a solid understanding of the concepts of relations and functions, as well as the properties of composition function operations; 5) Giving tests to students. Students are given tests where at the time of this test they cannot help each other. The points of each member of this team are then added up to get a group score.

At the end with the guidance of the teacher, each group representative reflects on the material that has been discussed by each group; 2) Setting up post-test; 3) Give homework in the form of studying material that will be studied in the following week.

c. Observation and Assessment

1) Learning Outcomes C1, C2, C3, C4, C5, C6

The data of the Cycle II learning outcome test is shown in the Table 4. There was a change in the magnitude of the mean size, standard deviation, variance, range, lowest value, highest value and amount from Cycle I to Cycle II. There was an increase in cognitive learning outcomes from Cycle I to Cycle II.

Table 4. Description of Cognitive Learning Outcomes Cycle II

No	Type of Description	Cycle I		Cycle II		Increased	
		C1-3	C4-6	C1-3	C4-6	C1-3	C4-6
1.	Mean	73.71	40.09	75.9	61.4	2.16	21.26
2.	Median	75.00	37.50	79.2	62.5	4.17	25.00

3.	Mode	75.00	54.17	83.3	58.3	8.33	4.17
4.	Standard Deviation	10.63	15.41	9.2	15.5	-1.42	0.10
5.	Variance	112.98	237.37	84.8	240.4	-28.18	3.08
6.	Range	45.83	54.17	29.2	58.3	-16.67	4.17
7.	Minimum	37.50	16.67	54.2	33.3	16.67	16.67
8.	Maximum	83.33	70.83	83.3	91.7	0.00	20.83
9.	Sum	2137.50	1162.50	2200.0	1779.2	62.50	616.67
10.	Sample Size	40.00	40.00	40.0	40.0	0.00	0.00

There was a steady improvement in students' cognitive learning outcomes from Cycle I to Cycle II across both basic (C1–C3) and complex (C4–C6) domains. For the basic cognitive domain (C1–C3), the average score increased slightly by 2.16 points, from 73.71 in Cycle I to 75.9 in Cycle II, indicating that students consistently improved their factual and conceptual understanding through repeated exposure and structured assignments.

More significantly, the complex cognitive domain (C4–C6), which reflects students' critical thinking abilities, showed a substantial improvement. The average score in this domain rose by 21.26 points, from 40.09 in Cycle I to 61.4 in Cycle II. This dramatic increase suggests that students became more capable of engaging in analytical reasoning, evaluation, and problem-solving—skills that align closely with the objectives of the PBL model. The rise in minimum and maximum scores also reflects a more evenly distributed improvement across all students.

These results confirm that the PBL approach not only supported mastery of basic mathematical concepts but also successfully cultivated higher-order thinking, fulfilling the core aim of the study to improve students' critical thinking and achievement in mathematics.

2) Critical Thinking Skills

The learning outcomes in the higher-order cognitive domain (C4, C5, C6), used as indicators of students' critical thinking skills, showed remarkable progress across the research cycles. Initially, 28 students were categorized as "lacking" in the pre-cycle, but this number dramatically dropped to 4 in Cycle I and completely disappeared in Cycle II. Conversely, the number of students categorized as "good" and "very good" increased substantially, with 25 and 9 students reaching those levels respectively in Cycle II.

This shift indicates a transformation in students' ability to analyse, evaluate, and synthesize mathematical concepts. The increase of 21.26 points in the average score of the C4–C6 domain—from 40.09 in Cycle I to 61.4 in Cycle II—reflects substantial development in students' analytical reasoning and problem-solving capabilities. These results strongly suggest that the PBL approach effectively nurtures critical thinking by engaging students in structured problem-solving activities that mirror real-world challenges.

DISCUSSION

1. Learning Outcomes C1, C2, C3, C4, C5, C6

This study aimed to examine the impact of the Problem-Based Learning (PBL) model on students' critical thinking and mathematics achievement in the topic of relations and functions. The findings demonstrate that PBL can significantly improve both basic understanding (C1–C3) and higher-order thinking skills (C4–C6), with the most notable gain observed in students' ability to reason analytically and solve complex problems. The increase in students categorized as "good" and "very good" in critical thinking skills further supports the model's effectiveness in vocational school settings. This approach allows them to identify issues in applying concepts or theories as they occur during the learning process.

These findings are consistent with (Kurniasih et al., 2024), who found that PBL significantly improved problem-solving and student engagement in mathematics classrooms. Similarly, Solikhah et al. (Solikhah et al., 2024) emphasized that PBL fosters students’ ability to evaluate arguments and justify reasoning, which aligns with the observed improvement in C4–C6 cognitive domains in this study. Sosa-Gutierrez et al. (Sosa-Gutierrez et al., 2024) also argued that critical thinking in mathematics is best developed when students are exposed to real-life contextual problems—a core principle of the PBL approach.

Furthermore, Subekti and Pitriyana (Subekti & Pitriyana, 2024) noted that students’ critical thinking ability increases when collaborative tasks are embedded in mathematical problem-solving. This supports the group-based design used in this study. Heard et al. (2020) introduced a skill development framework highlighting the importance of systematic questioning and reflection in enhancing critical thinking, both of which were structured into the PBL stages implemented in this research.

Thus, the current study not only confirms existing findings on the benefits of PBL but also extends their relevance to vocational high school contexts, where similar research remains limited.

Problem-solving in PBL should follow the steps of the scientific method. Thus, students develop the ability to solve problems systematically and planned. Thus, implementing PBL can offer students a valuable learning experience in conducting scientific work. Students learn to identify problems, collect data, analyse data, plan the implementation of problem-solving, and test against established plans.

The process of identifying problems is a crucial step in PBL. Choosing the right problem to provide a learning experience that reflects scientific work is often a challenge for both lecturers and students. This means that selecting a problem that is too broad, irrelevant to the learning material, or too advanced for the students' level of thinking can prevent the achievement of learning objectives.

Assistance by teachers at the identification stage greatly determines the next learning activity. Although the teacher does not intervene in the problem, he can focus the problem through questions so that students reflect more deeply on the chosen problem. In this case, teachers must play the role of facilitators so that learning remains within the planned frame.

2. Critical Thinking Skills

The PBL learning model can enhance critical thinking skills, encourage student initiative, boost internal motivation to learn, and improve interpersonal relationships in group work. A common issue among students today is their tendency to be "reluctant to think"; they often respond to questions by quoting from books or other sources without offering their own opinion or analysis. If this situation persists, students will struggle to apply the knowledge they acquire in class to real-life situations. In other words, classroom lessons will become focused solely on achieving test scores, which may not accurately reflect their true level of understanding. Therefore, the PBL model could serve as a solution to motivate students to think critically and actively engage in work, rather than just memorizing information and reciting it.

Problem-solving in PBL should adhere to the steps of the scientific method, enabling students to approach problems in a systematic and structured way. Consequently, the PBL model provides an excellent opportunity for students to gain valuable experience in conducting scientific work. There are various ways to implement PBL in learning. Typically, the process begins with a problem that students must address, which can either be introduced by the teacher or generated by the students themselves. The students will focus their learning around this problem, using theories and scientific methods to find solutions, making the problem the central point of their learning.

At each stage of problem-solving, students' skills should not be limited to "How" skills, but should also include the ability to explain the problems and understand how and why they arise. Ultimately, the goal of the learning process is to enable students to comprehend the problems, the underlying reasons for their occurrence, and the role these problems play within a larger, broader system.

This study is limited to a single class in one vocational school and was conducted over a relatively short period of three months. As a result, the generalizability of the findings may be restricted. Additionally, the absence of a control group makes it difficult to isolate the effect of the PBL model from other contextual factors that may have influenced the outcomes.

Future research could explore the long-term impact of PBL on critical thinking and mathematics achievement by conducting studies over extended periods or academic semesters. Comparative studies using control and experimental groups are also recommended to provide more robust evidence of causality. Moreover, further research could investigate how PBL can be adapted and scaled across different subjects, school levels, and student populations in vocational education contexts.

CONCLUSION AND SUGGESTIONS

The application of the Problem-Based Learning (PBL) method, accompanied by assignments and exercises, has proven to be effective in improving the learning outcomes and critical thinking skills of students in class X ULP 2 SMKN 6 Surabaya in relation and function of materials. This improvement was observed in both lower-order cognitive domains (C1–C3) and higher-order domains (C4–C6), indicating a comprehensive impact on students' understanding and analytical reasoning.

To maximize the effectiveness of learning, it is recommended that PBL be implemented gradually and accompanied by practice-based methods, especially in the initial phase. This helps students feel more comfortable and engaged with the learning process. Assignments and exercises following group work should be provided consistently to reinforce conceptual understanding and critical thinking skills.

Mathematics teachers are encouraged to embed real-world scenarios in group tasks to stimulate student inquiry, reasoning, and collaboration. This aligns with the strengths of the PBL approach in fostering deeper analytical thinking. Additionally, school administrators should provide training and mentoring on effective PBL facilitation to ensure its consistent and scalable implementation across vocational school contexts. Finally, teachers should ensure that PBL implementation includes ongoing assessment and timely feedback addressing the cognitive, affective, and psychomotor domains, enhancing students' holistic development in mathematical learning.

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