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Implementation of Problem-Based Learning to Improve Students' Mathematics Learning Outcomes Class X Computer and Network Engineering Vocational School

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ABSTRACT

This study aims to enhance the mathematics learning outcomes of Class X students by implementing Problem-Based Learning (PBL) at SMK Negeri 1 Bengkalis. The research method employed is Classroom Action Research (PTK), involving Class X Computer and Network Engineering (TKJ) students as the research subjects. The study was conducted during the odd semester of the 2021/2022 academic year, from August 12, 2021, to November 30, 2021, and consisted of two cycles. Each cycle included stages of planning, implementation, observation, and reflection. The findings indicate that applying PBL significantly improved students' mathematics learning outcomes, with an increase of 62.86% in Cycle I and 97.43% in Cycle II. These results demonstrate that PBL is an effective teaching model for enhancing student engagement and conceptual understanding in mathematics. Therefore, PBL can be a valuable learning paradigm to help students at SMK Negeri 1 Bengkalis study mathematics more effectively and deeply.

INTRODUCTION

Education is one of the important factors in shaping the character and intelligence of the nation's next generation [1]. Moreover, the good quality of education depends on the effectiveness of the learning process implemented in schools. Innovative and effective learning methods are indispensable to ensure students achieve optimal learning outcomes. In this context, the role of education, particularly in mathematics, becomes crucial.

Especially in mathematics, optimal learning outcomes are key to building a strong foundation of knowledge for various disciplines. Learning outcomes can be interpreted as students' progress after participating in the learning process, which is measured through increased knowledge, skills, and attitudes. [2]. Various studies, including research at SMK Negeri 2 Yogyakarta, show the tendency of low mathematics learning outcomes among students [3]. These low learning outcomes contribute to students' lack of interest, ineffective teaching methods, and an unconducive learning atmosphere [4], [5].

Various factors have been identified as the cause of these low learning outcomes. From interviews with students in class X of SMK Negeri I Bengkalis, it was found that even though they had been learning in groups, the maths lesson was still perceived as difficult, making them less active participants when the teacher asked questions or gave assignments. The researcher's observations showed that only about 65% of students were engaged during the introduction to the lesson, with the rest still distracted, signaling the need for teachers to increase students' learning motivation and focus by linking the material with practical benefits and delivering clear learning objectives in accordance with Permendiknas No 41 of 2007.

Furthermore, although group learning has been implemented, there are still barriers to students' active participation during mathematics learning. This suggests the need for more effective learning methods to overcome this problem. To improve mathematics learning outcomes, the Problem-based Learning (PBL) approach was chosen for its ability to encourage active student engagement by solving real problems relevant to their daily lives and fields of study.

To overcome these problems, this research chose the Problem-Based Learning (PBL) approach. PBL is a learning model emphasizing problem-based learning that can increase students' engagement and understanding. PBL encourages students to work together in groups, develop critical thinking skills, and solve real problems relevant to their daily lives and the subject areas they are studying.

Given the importance of addressing this issue, Problem-Based Learning (PBL) was chosen as a solution as this approach emphasizes problem-based learning that can increase students' engagement and understanding more profoundly. Previous research shows that PBL is effective in improving student learning outcomes for Maths, as seen in a study in class VII.d [6], grade V of SD Negeri 28 Peusangan [7], and class VIII of SMP Merauke [8]. Therefore, this study aims to implement and evaluate the effect of PBL on improving the mathematics learning outcomes of Class X students at SMK Negeri 1 Bengkalis. Based on observation and current data, it was found that the learning outcomes of mathematics in Class X students of SMK Negeri 1 Bengkalis were still below the expected standard. This is characterised by low exam scores and lack of deep conceptual understanding in most students.

According to Grant and Tamin [9], PBL is a student-centered social constructivist theory-based learning model characterized by constructing various perspectives of knowledge with multiple representations of social activities and focuses on discovery and collaborative learning, scaffolding, training, and authentic assessment. In addition, according to Duch, PBL is a learning model that challenges students to "learn how to learn" by working in groups to find solutions to real-world problems. [10]. Then, according to John Dewey, the PBL learning model encourages teachers to encourage students to engage in problem-orientated projects or tasks and help them investigate these problems. [11]. Thus, PBL can be used as an effective learning model to increase student engagement, connect material with practical contexts, and motivate them to learn more meaningfully.

The selection of the title "Implementation of Problem-Based Learning to Improve Students' Mathematics Learning Outcomes Class X Computer and Network Engineering or TKJ SMK Negeri 1 Bengkalis" is based on the urgent need to improve the quality of mathematics learning at the school. Based on data obtained from observations and interviews, the mathematics learning outcomes of students in class X TKJ are still below the expected standard. The low exam scores and lack of conceptual understanding indicate the need for effective interventions to improve the learning process.

The novelty of this study lies in its specific focus on the application of PBL in the context of learning mathematics in the TKJ department at SMK Negeri 1 Bengkalis. Although many studies have been conducted on the effectiveness of PBL in various subjects and levels of education, research that specifically examines the impact of PBL on mathematics learning outcomes of vocational students with technical majors such as TKJ is still limited. This research is expected to make a new contribution to the educational literature by showing how PBL can be adapted and implemented effectively in specific learning environments.

The main objective of this study was to evaluate the effect of PBL learning model implementation on improving mathematics learning outcomes of students in class X TKJ at SMK Negeri 1 Bengkalis. Specifically, this study aims to (1) determine whether the application of PBL can improve learning outcomes of mathematics materials and (2) assess changes in students' attitudes towards mathematics lessons after applying PBL.

Thus, this study is expected to provide empirical evidence regarding the effectiveness of PBL in improving mathematics learning outcomes and practical recommendations for educators and educational institutions to adopt innovative learning methods that can improve the overall quality of education. Through systematic implementation and evaluation, the results of this study are expected to serve as a foundation for developing learning strategies that are more effective and relevant to the needs of students in this digital era.

METHODS

The type of research conducted was Classroom Action Research (PTK). In this study, researchers collaborated with mathematics teachers in identifying problems. The mathematics teacher implemented the action as an observer. There are four important steps in carrying out classroom action research, namely 1) planning, 2) implementation/action, 3) observation, and 4) reflection. [12].

The subjects of this study were students of class X TKJ, SMK Negeri 1 Bengkalis, and as many as 35 students, consisting of 23 male students and 12 female students with heterogeneous academic abilities. The data of this study are observation data and mathematics learning outcomes, while the research instruments used in the learning process are learning tools and data collection instruments. The learning tools used in this research are a syllabus, a Learning Implementation Plan (RPP), and a Learner Worksheet (LKPD). Data collection instruments in this study are data on the activities of students and teachers during the learning process. In addition to data on students' and teachers' activities, data on students' mathematics learning outcomes after participating in the learning process with the PBL model were also collected. This research consisted of 2 cycles, and its implementation refers to applying the problem-based learning (PBL) learning model.

The PBL model is a student-centered pedagogical approach where students learn about a subject through the experience of solving open-ended problems. The following is a complete description of how each stage in this PTK cycle was implemented using the PBL model.

The PTK process starts from the "Start" stage, where the researcher or educator identifies problems or areas that require improvement in the learning process. These problems can come from previous observations, student feedback, or performance evaluations. For example, the problem identified could be low student engagement in learning or students' lack of problem-solving skills. This problem identification becomes the basis for designing the next steps.

In the "Planning" stage, the researcher formulates the specific objectives for applying PBL. For example, goals could be to improve students' critical thinking skills and problem-solving abilities. The action plan includes developing problem scenarios relevant to the subject matter, strategies to encourage students' active participation, and evaluation tools to measure the success of PBL implementation. This planning also involves determining the necessary resources, such as teaching materials and learning media.

The "Cycle 1 Implementation" stage is where the action plan is implemented. At this stage, the problem scenario is introduced to the students, and they are invited to work in small groups to find a solution. The educator acts as a facilitator who helps students direct their thinking, provides trigger questions, and provides support when needed. This implementation aims to see how students apply their knowledge in a real context and interact in groups.

After implementing the first cycle, the "Cycle 1 Reflection" stage was conducted to evaluate the effectiveness of PBL implementation. This involved analyzing the data collected during the implementation, such as student work, observations of interactions within the group, and student feedback. The researcher assesses whether the learning objectives were achieved and identifies any obstacles. This reflection also helps understand how students can develop their critical thinking and problem-solving skills.

"Observations" are conducted to collect additional relevant data. These observations can be direct classroom observations, interviews with students, or analyses of student work. The data collected during observation provides greater insight into the classroom dynamics, student participation, and the effectiveness of the given problem scenario. This information is used to plan the next cycle.

The "Re-planning" stage was conducted based on the reflection and observation results. At this stage, the researcher makes adjustments or revisions to the action plan based on the findings from the first cycle. This re-planning may involve improving the problem scenario, adjusting facilitation strategies, or strengthening evaluation tools. The aim is to increase the effectiveness of PBL implementation in the second cycle.

The "Cycle 2 Implementation" stage begins with implementing the revised plan. In this cycle, the improved problem scenario is reintroduced to the students, who once again work in groups to find a solution. This implementation aims to test the changes and see if the adjustments yield better results. The educator continues as a facilitator, helping students develop their solutions.

After the implementation of the second cycle, the "Cycle 2 Reflection" stage was conducted to evaluate the results of the second implementation. The researcher analyzed the data obtained during the second cycle and compared it with the results from the first cycle. This reflection helps determine if the improvements made have had the expected positive impact or if there are still other aspects that need improvement. This assessment included an evaluation of student engagement, the quality of the solutions produced, and the development of critical thinking skills.

The "Second Observation" stage was conducted to collect updated data after implementing the second cycle. The data collected during this observation provides a more comprehensive picture of the progress and areas that still require attention. It also helps in assessing the sustainability and consistency of the implemented changes.

Finally, the PTK process reaches the "Done" stage, which signifies that the research has achieved its objectives. At this stage, the final results of the research process are evaluated as a whole to ensure that all the objectives have been set. This final evaluation allows the researcher or educator to summarise the results of the actions taken and provide recommendations for future learning practices. These final results can also disseminate the best practices discovered during the research to other educators.

By following these steps, the classroom action research method using the PBL learning model can effectively increase students' engagement and develop their problem-solving skills. The iterative cycles of planning, implementation, observation, and reflection ensure that the learning process is continuously improved based on the feedback and data collected.

The subjects of this study were 35 students from class X TKJ at SMK Negeri 1 Bengkalis, consisting of 23 male students and 12 female students with heterogeneous academic abilities.

Participants were selected based on purposive sampling, considering their involvement in the specific class targeted for the intervention.

Data were collected through classroom observations, interviews, and written tests. The primary instruments included observation sheets, a Learning Implementation Plan (RPP), a Learner Worksheet (LKPD), interviews, and written tests. Observation sheets are used to record the activities of both teachers and students during the learning process. These sheets helped assess the implementation of the PBL model and identify areas for improvement. The validity of the observation sheets was tested through expert judgment, while reliability was ensured through inter-rater reliability tests. A Learning Implementation Plan (RPP) guides the learning process and ensures that the PBL steps are followed consistently. The RPP was validated through expert review to ensure alignment with curriculum standards. Learner Worksheet (LKPD) facilitates student activities and ensures active participation in the learning process. The validity of the LKPD was assessed by aligning the content with learning objectives and receiving feedback from experienced educators. Reliability was tested through pilot implementation and subsequent revisions. Interviews were conducted with students to gather qualitative data on their perceptions and experiences regarding the PBL approach. The interview questions were validated through expert review and pilot testing to ensure they accurately captured the intended information. Written tests are administered at the end of each cycle to evaluate students' learning outcomes and mastery of the mathematics material. The validity of the test items was established through content validation with subject matter experts, and reliability was determined using Cronbach's alpha coefficient.

The data collected were analyzed using both qualitative and quantitative methods. Data from observations, interviews, and LKPD were analyzed using descriptive narrative techniques to provide a detailed account of the learning process and identify student engagement and participation patterns. Data from written tests were analyzed using descriptive statistical methods to measure the improvement in students' learning outcomes. The scores were compared against the Minimum Competency Criteria (KKM) set by the school, with students scoring$\geq$65 considered to have met the KKM. The improvement in learning outcomes was tracked across three key stages: 1) Baseline Scores: Initial scores obtained before the implementation of PBL; 2) Cycle I Scores: Scores obtained after the first cycle of PBL implementation; 3) Cycle II Scores: Scores obtained after the second cycle of PBL implementation.

RESULTS AND DISCUSSION

The data on the results of class action research were obtained from class research conducted on students of class X - TKJ SMK Negeri I Bengkalis odd semester of the 2021/2022 academic year, with the implementation of this research starting from August 12, 2021, to November 30, 2021. The action taken is implemented using the problem-based learning model. The action taken consisted of two cycles.

The implementation stage is divided into 4 meetings. The first meeting discusses determining the mathematical model of a two-variable linear program based on RPP-1 using LKPD-1 for observation, and teacher activity observation sheets and student activity observation sheets are used. At the second meeting, the material discussed was a linear program for the settlement set area. At this meeting, the researcher was guided by the lesson plan and LKPD, and the researcher prepared observation sheets for teacher and student activities. At this third meeting, the material discussed was a two-variable linear program about the optimum value of the objective function (maximum value).

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At this meeting, researchers were guided by lesson plans and LKPD, and they prepared observation sheets for teacher and learner activities. The steps used in the learning process with the Problem Based Learning model were carried out in the first to third meetings. Some students are already willing to complete tasks from LKPD and discuss them so that there is interaction between students. The results of group discussions are presented to the front of the class so that students can provide solutions to the problems given. Furthermore, at the fourth meeting, the teacher carried out a daily test assessment by providing a learning outcome test on the material of the system of linear equations of two variables. The test was carried out for 80 minutes and consisted of 3 questions according to the indicators set by the teacher.

Data analysis on teacher and learner activities was obtained through observations during the learning process. The suitability between planning and implementation of actions was assessed through observation sheets in cycle 1 and cycle 2. The action is appropriate if the Problem-Based Learning learning model is well implemented. The results of this analysis can be found in more detail in Table 1, which records the activities of teachers and learners and conformity with planning in each learning session. The data collected on the observation sheet will be processed as a reflection for improvement in the next cycle.

Table 1. Multiple Student Observation Data for PBL Learning Activities - Cycle 1

No.	Student Code	Initial Score	Cycle I	Teacher Activity	Learner Activity	Conformity with Planning	Description
1	AA	62	75	Explains basic mathematical concepts clearly	Actively participate in group discussions	As per	
2	AR	71	68	Provide real case examples in the material	Make a mind map as a result of group discussion	Not quite right	Need more encouragement for participation
3	DF	80	82	Facilitate group discussions well	Present problem solutions in a structured manner	As per	
4	DM	67	78	Using multimedia to support learning	Contribute to group presentations	As per	
5	PR	58	70	Providing extra challenges for high-achieving students	Discuss problems with a group of friends	As per	
6	TTL	80	85	Provide guidance when students are having difficulty	Take group work seriously	As per	

From Table 1, it can be observed that most students improved their scores after Cycle I. For instance, student AA's score increased from 62 to 75, which indicates a significant enhancement in understanding basic mathematical concepts through active participation in group discussions. However, student AR's score decreased from 71 to 68, suggesting additional encouragement and engagement strategies were needed. These findings indicate that while PBL generally positively impacts student performance, some students might require more tailored support to benefit from this learning model fully.

Data analysis techniques on students' mathematics learning outcomes are carried out by looking at the acquisition of individual student learning outcomes, namely by descriptive statistical analysis. Descriptive statistics organize and analyze numerical data to provide an orderly description and analyze data on the achievement of individual student learning outcomes. Data on students' mathematics learning outcomes are analyzed based on the accomplishment of KKM in class / carried out by comparing the value of learning outcomes with KKM set by the school. In this study, students are said to have achieved KKM if the acquisition of learning outcomes ≥ 65.

The improvement in learning outcomes can be seen from the development of basic scores, Daily Test I and Daily Test II. The daily test I and II scores were analyzed for each indicator to determine the achievement of the predetermined KKM and then compared to the base score. The base score value is obtained from students' learning outcomes before the action is given.

The success of the action can be determined by comparing the baseline scores with the scores of students after the action. Action is said to be successful if the number of students who reach the KKM from the basic score to the daily test remains or increases. Conversely, if the number of learners who achieve the KKM from the basic score to the test is increasing, it is said that the action has not been successful.

The data from the baseline score, daily assessment I, is quantitative. The quantitative data is processed and presented with the frequency distribution table shown in Table 2. In the presentation, the KKM value is made into one of the lower limits of the class. This aims to increase the number of learners who score above the KKM.

Table 2. Frequency Distribution of Test Scores

Value	Frequency	
	Initial Score	**Cycle I**
55-64	20	3
65-74	11	10
75-84	4	15
85-94	0	7
Total	**35**	**35**

The KKM at SMK Negeri 1 Bengkalis is 65. It can be seen that the value of 65 is in the 2nd class. In the initial score, the number of participants who achieved scores below the KKM was 20 students, and the lowest score was 55. For those who reached the KKM score, there were 11 students and 4 students above the KKM score. Then, after cycle I was carried out, it was seen that the results in cycle I had improved; namely, 3 learners scored below the KKM, and the lowest score was 58. To see the data in the form of an increase in the number of students in each class of data, Table 3 presents the data in percentage form.

Table 3. Score Frequency Distribution Table (In Percent)

Value	Frequency	
	Initial Score	**Cycle I**
55-64	57,14%	8,57%
65-74	31,42%	28,57%
75-84	11,42%	42,86%
85-94	0	20%
Total	**35**	**35**

Based on the analysis of daily test data of students in class X SMK Negeri 1 Bengkalis, student learning outcomes after applying the problem-based learning model were better than before the action was taken. The increase in the number of students who reached the KKM can be seen in Table 3. The table shows that the percentage of students below the KKM in the initial score was 57 14%, and in cycle I, those below the KKM were only 8%. At the same time, the value above the KKM has increased quite a bit, namely 62.86%. From Table 3, it can be seen that the scores of students increased from the basic score to the daily assessment. The increase in daily assessment scores is because, in

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problem-based learning, students with groups can actively find their knowledge and solve problems from the material studied. By discovering for themselves, learning becomes meaningful. The knowledge gained lasts a long time, and students are accustomed to having a problem-solving logic of thinking, which empowers students and increases their self-confidence. This indicates that PBL effectively improves student engagement and comprehension, leading to better performance in mathematics.

Based on the analysis of students' answers on the results of the assessment of Daily Test I, the mistakes made by students, in general, include students who are less precise in writing problem-solving plans, which result in students making mistakes in solving problems, students lack understanding of concepts, students are less careful in answering questions so that they make calculation operation errors, and also found students who do not carry out all steps in problem-solving. Learning should be done by increasing practice problems through problem-solving in the learning process. In cycle II, Table 4 records teachers' and learners' activities and conformity with planning in each learning session and compares it with cycle I.

Table 4. Multiple Student Observation Data for Problem-Based Learning (PBL) Learning Activities Cycle 2

Student Code	Initial Score (Cycle 1)	Cycle I	Initial Score (Cycle 2)	Cycle II	Teacher Activity	Learner Activity	Conformity with Planning	Description
AA	62	75	65	65	Explains basic mathematical concepts clearly	Actively participate in group discussions	Appropriate	
AR	71	68	72	72	Provide real case examples in the material	Make a mind map as a result of group discussion	Appropriate	
DF	80	82	85	85	Facilitate group discussions well	Present problem solutions in a structured manner	Appropriate	
DM	67	78	72	72	Using multimedia to support learning	Contribute to group presentations	Appropriate	
PR	58	70	65	65	Providing extra challenges for high-achieving students	Discuss problems with a group of friends	Not quite right	Need more encouragement for participation
TTL	80	85	80	85	Provide guidance when students are having difficulty	Take group work seriously	Appropriate	

Data on student learning outcomes can be seen in Table 5 as follows.

Table 5. Student Learning Outcome Data

Value	Frequency	
	Initial Score	Cycle II
55-64	45, 20%	2,57%
65-74	21,42%	28,57%
75-84	23,42%	48,86%
85-94	9,96%	20%
Total	**35**	**35**

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Based on Table 5 above, there was an increase in student learning outcomes, with the percentage of students who reached the KKM 97.43%. Table 5 shows that the percentage of students below the KKM in the initial score is 45.20%, and there is an increase in cycle II, which is below the KKM by only 2 57%.

These results are important because they demonstrate the potential of PBL to address common challenges in mathematics education, such as low student engagement and poor problem-solving skills. The findings align with previous studies that have shown the effectiveness of PBL in enhancing students' learning outcomes [6], [7], [8]. By providing a more interactive and student-centered learning environment, PBL helps students better understand and apply mathematical concepts essential for their overall academic success.

Furthermore, the qualitative data from observations and interviews supported the quantitative findings, showing that students were more engaged and motivated during PBL activities. The interaction among students during group discussions and problem-solving tasks facilitated a deeper understanding and retention of the material. This is consistent with the social constructivist theory underlying PBL, which emphasizes learning as a collaborative and interactive process [9], [10], [11].

Overall, the implementation of PBL in this study significantly improved students' mathematics learning outcomes and provided valuable insights into effective teaching practices for vocational education settings. Future research should continue to explore the long-term impact of PBL and investigate ways to optimize its implementation further to support diverse learners.

Based on the data and analysis that has been done, it can be concluded that the application of the Problem-Based Learning (PBL) learning model has succeeded in improving the mathematics learning outcomes of students in class X TKJ at SMK Negeri 1 Bengkalis. The main factors contributing to this improvement include more interactive learning methods, increased student participation, and a more relevant and contextual approach.

Firstly, the PBL learning model encourages students to participate actively in the learning process. With PBL, students are faced with real problems that require collaborative solutions. This differs from traditional teaching methods that tend to be one-way and lack direct student involvement. PBL allows students to discuss, share ideas, and work together in groups, significantly increasing their class participation. Data from Table 1 and Table 4 show that student activity increased during the first and second cycles, with many students actively participating in group discussions and presentations.

Second, PBL helps students develop critical thinking and problem-solving skills. In PBL, students memorize mathematical concepts and learn how to apply those concepts to solve complex problems relevant to their lives. This process strengthens their understanding of the material and helps them develop analytical skills. Analysis of the daily test results showed that students' conceptual understanding improved, as seen from the increase in scores from the initial to the second cycle.

Third, the implementation of PBL makes learning more meaningful and contextualized. By linking the subject matter with real-world problems, students can see the direct relevance of their learning to their daily lives. This increases students' interest and motivation to learn and helps them apply the knowledge gained in a practical context. Table 3 shows the percentage of students who achieved scores above the KKM after the first cycle, which increased in the second cycle. This indicates that students not only learn better but are also able to apply their knowledge effectively.

In addition, improved learning outcomes can also be attributed to improved quality of interaction between teachers and students. The teacher acts as a facilitator who guides students through the learning process by providing constructive feedback and necessary support. Observations of teacher activities during PBL learning show that teachers provide more real case examples, facilitate discussions, and use multimedia to support learning. This makes learning more interesting and helps students understand the material better.

Another contributing factor is learner worksheets (LKPD), designed to encourage students to complete tasks independently and collaboratively. LKPDs provide a clear structure for students to follow the steps of problem-solving, which helps them stay focused and organized during the learning process. The use of LKPDs in PBL has proven effective in assisting students to master the material and improve their performance in daily assessments.

Overall, the successful implementation of PBL in improving mathematics learning outcomes in class X TKJ SMK Negeri 1 Bengkalis shows that this method can be an effective alternative to conventional learning. By encouraging active participation, developing critical thinking skills, and making learning more contextualized, PBL can help students achieve better learning outcomes and prepare them to face challenges in the real world. The results of this study also provide recommendations for educators to adopt the PBL method in their curriculum to improve the quality of learning and student learning outcomes.

CONCLUSIONS AND SUGGESTIONS

Implementing the Problem-Based Learning (PBL) model in Class X TKJ at SMK Negeri 1 Bengkalis has significantly improved students' mathematics learning outcomes. The research findings indicate a substantial increase in students achieving the Minimum Competency Criteria (KKM), with notable improvements from the baseline scores to Cycle I and further enhancements in Cycle II. This study contributes to the field of education by demonstrating the effectiveness of PBL in vocational education settings, particularly in enhancing student engagement, critical thinking, and problem-solving skills in mathematics. The positive outcomes observed in this research underscore the potential of PBL to address common challenges in mathematics education, such as low student participation and conceptual understanding.

The findings from this study have important implications for teaching practices in vocational high schools (SMK) and other secondary education settings. The successful implementation of PBL highlights the need for innovative and student-centered pedagogical approaches to improve learning outcomes. Educators are encouraged to adopt PBL and similar interactive methods to create a more engaging and effective learning environment that fosters a more profound understanding and retention of mathematical concepts.

Based on the findings of this study, several recommendations can be made to enhance the implementation of Problem-Based Learning (PBL) and improve mathematics learning outcomes in vocational high schools and other secondary education settings. These recommendations provide practical guidance for educators, administrators, and policymakers to effectively integrate PBL into the curriculum and support its successful execution.

First, effective implementation of PBL. Providing teachers with comprehensive training on the PBL model is essential to ensure its effective implementation. This training should cover the theoretical foundations of PBL, practical strategies for facilitating group discussions, and techniques for guiding students through problem-solving processes. Besides that, develop and distribute high-quality teaching materials, such as problem scenarios and learner worksheets (LKPD), specifically designed for PBL. These resources should align with the curriculum and learning objectives to maximize effectiveness.

Second, ongoing professional development. Organize regular workshops and seminars to share best practices and successful case studies of PBL implementation. These sessions can provide teachers valuable insights and practical tips for enhancing their teaching methods. Collaborative Learning Communities: Establish collaborative learning communities where teachers can exchange ideas, discuss challenges, and support each other in implementing PBL. This can foster a culture of continuous improvement and innovation in teaching practices.

Third, tailored support for diverse learners. Recognize students' varying ability levels and provide differentiated instruction to meet their needs. This may include additional support for students who struggle with PBL and enrichment activities for high-achieving students. Besides that, implement a system for providing regular and constructive feedback to students on their performance in PBL activities. This feedback should help students understand their strengths and areas for improvement, motivating them to engage in the learning process actively.

Fourth, monitoring and evaluation. Data from observations, assessments, and student feedback will be used continuously to evaluate the effectiveness of PBL implementation. This information can inform necessary adjustments and refinements to the teaching approach. Besides that, longitudinal studies should be conducted to assess the long-term impact of PBL on students' academic performance and skills development. This can provide deeper insights into the sustainability and scalability of PBL as a teaching model.

By implementing these recommendations, educators and educational institutions can enhance the effectiveness of PBL and other innovative teaching methods, ultimately improving the overall quality of education in vocational high schools and beyond. The insights gained from this study can serve as a foundation for developing more effective and relevant learning strategies that cater to the diverse needs of students in the digital era.

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