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The Effect of PBL-STEM on Improving problem Problem-solving Ability and Self-efficacy of Vocational High School Students

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Abstract

Research needs to be conducted with the aim of significantly comparing the problem-solving skills and self-efficacy between students who follow learning with Problem Based Learning (PBL) enriched with Science, Technology, Engineering, Mathematics (STEM) and students who follow learning with a scientific lapproach to chemistry, focusing on substances and their changes. The research method is quasi-experimental quantitative research. Cluster random sampling techniques are used to determine the control group (classes applying a scientific approach) and the experimental group (classes applying the PBL-STEM model). The study uses 1 control class and 1 experimental class. Each class averages 36 students. The instruments consist of problem-solving questions and self-efficacy questionnaires validated for construct, content and empiric. Empirical validation of self-efficacy questionnaire, initial number of items = 48, Valid items = 35, Invalid items = 13. Cronbach's alpha reliability test using SPSS yielded a Cronbach's alpha coefficient of 0.779 > 0.6, indicating that the self-efficacy questionnaire is reliable. Empirical validation of problem-solving questions, initial number of items = 12, Valid items = 9, Invalid items = 3. The Cronbach's alpha coefficient is 0.644 > 0.6, indicating that the questions are reliable.The 9 prerequisite tests for MANOVA are met and followed by the MANOVA test. The research results indicate that the multivariate Hotelling's trace test with Sig 0.000 < 0.05 shows a significant difference in problem-solving skills and self-efficacy originating from different classes. The practical implication is that schools and teachers can consider adopting and integrating the PBL-STEM model into the curriculum, especially for science subjects like chemistry. Thus, teaching will not only focus on knowledge transfer but also on developing essential 21st-century skills.

Keywords: *PBL, Problem-solving skills, Self-efficacy, STEM*

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INTRODUCTION

Sustainable education, which is at the core of Sustainable Development Goal (SDG) 4, is extremely important because it serves as the foundation for progress across all sectors. Through inclusive and high-quality education, we can empower individuals with the skills, knowledge, and attitudes needed to address global challenges such as poverty, inequality, climate change, and conflict. Sustainable education does not only focus on basic literacy and numeracy but also promotes critical thinking, problem-solving abilities, and an awareness of the importance of living in harmony with the environment and society. Thus, education becomes a vital tool for creating a more just, prosperous, and sustainable society for current and future generations. In Indonesia, the state of education remains a major concern due to low-quality levels (Magfiroh & Nugraheni, 2024). SDG 4 plays a crucial role in improving sustainable education in Indonesia, with a focus on quality, inclusive, and equitable education (Milati & Nugraheni, 2024). Teachers need to implement good learning practices to support the SDGs, one of which is through good habits (Lestari et al., 2024).

The role of chemistry in Vocational High Schools (SMK) is fundamental and practical, especially in majors related to industry, agriculture, and health. Chemistry is not only taught as a theory but is also emphasized in its application to equip students with an understanding of materials, processes, and products. For example, in the Medical Laboratory

Technology major, students learn chemical analysis to identify biological samples. Meanwhile, in the Industrial Chemical Engineering major, they study how chemical processes transform raw materials into finished products such as plastics, detergents, or fertilizers, including quality control and work safety involving chemicals. Thus, chemistry lessons in SMK serve as a bridge connecting scientific theory with real-world practice, preparing students to become competent and ready-to-work professionals. It is important to have relevant chemistry content for the Laboratory Testing Analysis Competency in SMK to ensure a link and match with the working world (Pauline, Rosbiono & Anwar, 2020).

In Vocational High Schools (SMK), problems in chemistry learning often center on the gap between theory and practice, where the curriculum is sometimes too academic and not relevant enough to the needs of the industry. Many students find it difficult to understand abstract concepts like stoichiometry or thermodynamics because they do not see their direct application in the workplace. In addition, limited laboratory facilities in some schools hinder students from conducting crucial experiments to strengthen their understanding of concepts. This is compounded by the lack of teaching materials specifically designed for a vocational context, so teachers often have to adapt general materials that do not fully align with the required competency specifications, which ultimately can reduce students' motivation and interest in chemistry. SMK students in a study had difficulty solving problems at a rate of 19.3% (Karo, 2022). The literacy of SMK students is also still low (Ambarwati et al., 2024).

The low problem-solving ability of SMK students is often caused by a learning approach that focuses too much on memorizing theories and standard procedures, rather than on practical application in the real world. As a result, students struggle to connect the concepts they learn in class with the complex problems they might face at work. When confronted with an unusual situation, they tend to be confused and unable to think critically to find creative solutions. The lack of opportunities to engage in projects or case studies that demand analytical thinking and information synthesis also contributes to this weakness. This situation is worsened by limited infrastructure that does not support problem-based learning, so students are not accustomed to being trained to identify, analyze, and solve problems independently. A study with a sample of 36 students related to problem-solving abilities in chemistry learning provided information that 76% of students could not solve problems because they did not understand them (Rohayah, 2022). Students' problem-solving skills need to be improved so that in real life they are capable of solving the problems around them. Based on this, learning models that integrate problem-solving skills, such as Problem-Based Learning (PBL) or other similar approaches, are highly needed to prepare students to face various challenges in their daily lives. Various efforts have been made to improve scientific abilities, especially students' problem-solving abilities. A study with a sample of 11th-grade high school students using Manova analysis concluded that the implementation of a problem-based learning model was proven effective in enhancing the analytical thinking and scientific attitudes of high school students on the topic of reaction rates (Andriani & Supiah, 2021).

Low self-efficacy among SMK students is often caused by several interrelated factors. Many students feel less confident in mastering subjects, especially those considered difficult like chemistry or mathematics, because they feel unable to understand complex concepts. This is compounded by repeated failures in assignments or exams, which erodes their self-belief. In addition, a lack of adequate practical experience and limited facilities can also make students feel unprepared to meet the demands of the working world, leading to doubts about whether they have the necessary skills. An unsupportive learning environment or comparison with other students who are considered more successful can also reinforce feelings of helplessness, creating a negative cycle where low self-efficacy hinders their efforts to learn and grow. The confidence level of students is still low, as evidenced by the fact that many students still consider chemistry to be a difficult subject (Capanzana, 2020). Therefore, students' self-efficacy also needs to be improved so that they are confident in solving the problems they face. Another study mentioned that self-efficacy affects academic achievement by 7% (Pratiwi & Hayati, 2021). This means that self-efficacy also needs to be enhanced in learning. It is also important to note that self-efficacy is influenced by various factors, one of which is the sense of success in completing tasks (Fitriani & Rudin, 2020).

The application of Problem-Based Learning (PBL) is very important in SMK because this model bridges the gap between academic theory and the practical needs of the working world. PBL trains students to identify, analyze, and solve complex problems that are similar to real-life situations in the industry. By facing contextual challenges, students do not just memorize concepts but also develop important skills such as critical thinking, team collaboration, and the ability to adapt. This helps them build self-efficacy and the confidence that they are capable of applying their knowledge to overcome future challenges. Thus, PBL not only prepares students theoretically but also equips them with relevant competencies and a problem-solving mindset that is highly needed by the business and industrial world. The application of the scientific approach in Problem-Based Learning (PBL) on acid-base material according to the 2013 curriculum in Indonesia has proven effective in improving students' problem-solving abilities. Students who are routinely trained using appropriate problem-solving strategies will experience an improvement in their problem-solving skills (Jundu et al., 2018). PBL in SMK learning can improve students' critical thinking skills (Nafiah, 2014). The Problem Based Learning model can increase students' learning motivation (Rajma et al., 2022). Problem-based learning can improve chemistry learning outcomes on the concept of Mole for SMK students (Novita et al., 2023). SMK students understand the material learned faster if they discuss with their group (Khoerunnisa, 2021).

The Problem-Based Learning (PBL) model combined with STEM (Science, Technology, Engineering, Mathematics) is highly likely to help SMK students because this approach creates a strong synergy between contextual problem-solving and integrated disciplinary knowledge. PBL provides a framework where students are invited to face real-world challenges, while STEM equips them with essential tools and knowledge—ranging from scientific concepts, modern technology, engineering principles, to mathematical analysis—needed to formulate innovative solutions. Thus, students do not just learn theories in isolation, but use them in an integrated way to solve authentic problems. This not only enhances critical thinking and collaboration skills, but also provides practical application experience that is highly relevant to industry needs, significantly increasing their self-efficacy and readiness to enter the workforce. A study that applied STEM-based modules was able to improve general chemistry learning outcomes and students' motivation (Pane et al., 2022). A study involving 317 students in the control sample and 321 students in the experimental sample concluded that learning with a STEM approach can increase the complexity of students' cognitive structures (Baptista & Martins, 2023). The complexity of students' cognitive structures is necessary for them to be able to explain theories and provide ideas in problem-solving. A study conducted using quasi-experimental techniques concluded that modules integrated with STEM can improve learning outcomes and motivation (Pane et al., 2022). STEM can also enhance students' critical thinking skills (Davidi et al, 2021). Therefore, integrating the STEM approach into learning modules is a highly effective strategy to not only boost academic results and student motivation but also to strengthen essential critical thinking skills.

Research so far has used PBL and STEM separately to improve student learning outcomes and self-efficacy, but only with slight improvements. Therefore, the researchers hope that using PBL integrated with STEM can significantly enhance learning outcomes and self-efficacy. A study was conducted to investigate the potential of a combined PBL-STEM approach to produce more impactful and meaningful learning results. Subsequently, the researcher used a PBL (Problem-Based Learning) model that integrates STEM to improve students' problem-solving skills and self-efficacy. The stages of PBL consist of defining the problem, collecting data related to the problem, planning the solution, implementing the solution, reflection, and evaluation (Baden & Major, 2004). These stages can be applied in learning by integrating STEM analysis within them. PBL is used in this study because it incorporates various real-life problems faced by society, making it more contextual. STEM is used to train students to think structurally about science, technology, engineering, and mathematics. These two elements have the potential to improve students' problem-solving skills and self-efficacy. Furthermore, a PBL model that integrates STEM into learning will be able to enhance problem-solving skills and self-efficacy more effectively compared to classes guided by teachers using a scientific approach.

The novelty of the research combining Problem-Based Learning (PBL) and STEM lies in its synergistic and integrated approach. Traditionally, PBL and STEM are often used as separate learning methods, with results showing some improvement but not a significant one. This research innovates by combining both models to create a more holistic approach. PBL provides a contextual, real-world, problem-based framework, while STEM fills this framework with practical elements from science, technology, engineering, and mathematics. By integrating the two, this research tests the hypothesis that more significant outcomes—both in terms of improving learning outcomes and student self-efficacy—can be achieved because students not only solve problems but also do so in a structured and comprehensive manner, leveraging all the necessary elements for real-world solutions.

METHOD

This study used a quasi-experimental approach with a Posttest-Only Control-Group Design. This design is a type of quantitative research that assesses the effect of a treatment by comparing a post-treatment measurement between an experimental group and a control group. The design is specifically chosen to control for confounding variables that might arise from pre-testing. The experimental group received the PBL-STEM learning model, while the control group was taught using a scientific approach.

Table 1. Differences between the experimental and control group

Group	Treatment	Post-treatment Measurement
Experimental	PBL-STEM Model	Problem-Solving Test & Self-Efficacy Questionnaire
Control	Scientific Approach	Problem-Solving Test & Self-Efficacy Questionnaire

The study's population included all tenth-grade students at a vocational high school in Gunungkidul. A sample of 71 students was selected from this population and then assigned to either the experimental or control group through a process that ensured comparability between the groups. This approach was used to ensure the initial knowledge and abilities of the students in both groups were similar before the treatment began.

Data collection was performed using two main instruments: Problem-Solving Questions and a Self-Efficacy Questionnaire. The problem-solving questions were based on Polya's four indicators: understanding the problem, planning a solution, implementing the solution, and reviewing the answer. The self-efficacy questionnaire, with components of level, strength, and generality, was adapted from Bandura's work and Hairida's journal. Both instruments underwent validation to ensure their quality.

Table 2. Instrument grid

Instrument	Indicator	Reference
Problem-Solving Questions	1. Understanding the problem 2. Planning a solution 3. Implementing the solution 4. Reviewing the overall answer	Polya (1957)
Self-Efficacy Questionnaire	1. Level 2. Strength 3. Generality	Bandura (1997) & Hairida (2017)

The instruments were validated for both construct and content validity by university lecturers, yielding an average score of 3.5, which is categorized as "Good" and suitable for use with revisions. Empirical validation was conducted using SPSS Bivariate Correlation on a separate sample of 96 students.

The results of the instrument validation indicated that both the problem-solving questions and the self-efficacy questionnaire were reliable and valid for the study. For the self-efficacy questionnaire, out of 48 initial items, 35 were found to be valid, with a Cronbach's Alpha of 0.779, which is above the threshold of 0.6. This confirms the reliability of the instrument. Similarly, for the problem-solving questions, 9 out of 12 items were valid, with a Cronbach's Alpha of 0.644, also exceeding the 0.6 threshold, confirming its reliability.

The data analysis technique used was Multivariate Analysis of Variance (MANOVA), a statistical method for analyzing the effects of independent variables on multiple dependent variables simultaneously. Before the main MANOVA test, prerequisite tests were conducted. A key prerequisite test mentioned was the F-test for initial ability, which confirmed that the initial knowledge variances of the students in both the experimental and control groups were homogeneous (F-calculated, 1.356 < F-table, 1.83), meaning the groups were initially comparable. This step is crucial for a posttest-only design to ensure that any observed differences in the final results are due to the treatment, not pre-existing differences.

The final step in the data analysis involves using MANOVA to test the effectiveness of the PBL-STEM model. The test aims to determine whether there is a significant difference between the two groups (experimental and control) on the combined dependent variables of problem-solving skills and self-efficacy. This analysis directly addresses the study's main objective. Statistical Hypotheses:

H0: There is no significant difference in the combined mean scores of problem-solving skills and self-efficacy between the experimental group (PBL-STEM) and the control group (Scientific Approach).

H1: There is a significant difference in the combined mean scores of problem-solving skills and self-efficacy between the experimental group (PBL-STEM) and the control group (Scientific Approach).

RESULT AND DISCUSSION

The results of the learning evaluation using the PBL-STEM method (experimental class) compared to the learning outcomes with the scientific approach (control class) are as follows.

Table 3. Descriptive table

Group	n	Max Score	Min Score	SD
Control	30	23	17	2,436
Experiment	36	24	18	2,148

Based on the provided data, there's a comparison between two learning models: the Scientific model (control) and the PBL-STEM model (experiment). The Scientific model was applied to 30 subjects, yielding a maximum score (Max HB) of 23, a minimum score (Min HB) of 17, and a standard deviation (SD) of 2.436. In contrast, the PBL-STEM model, applied to 36 subjects, showed a maximum score of 24 and a minimum score of 18, with a slightly lower standard deviation of 2.148. This data implies that the PBL-STEM model resulted in a slightly higher range of scores and a slightly smaller data spread compared to the Scientific model.

The evaluation results for problem-solving using the PBL-STEM method (experimental class) compared to the problem-solving results using the Scientific approach (control class) are as follows.

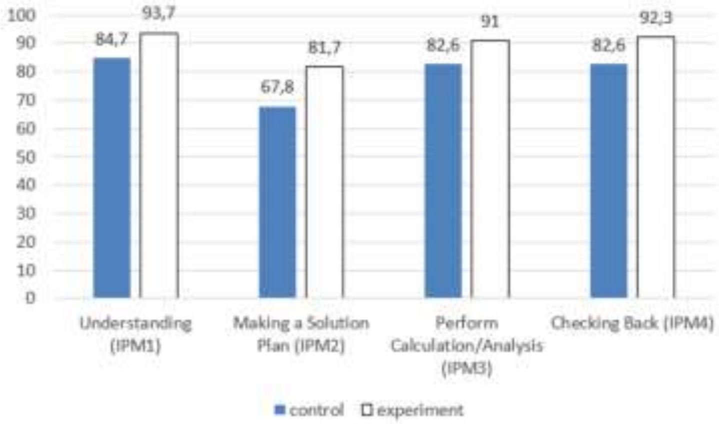

Figure 1. Results for the Experimental group compared to control group

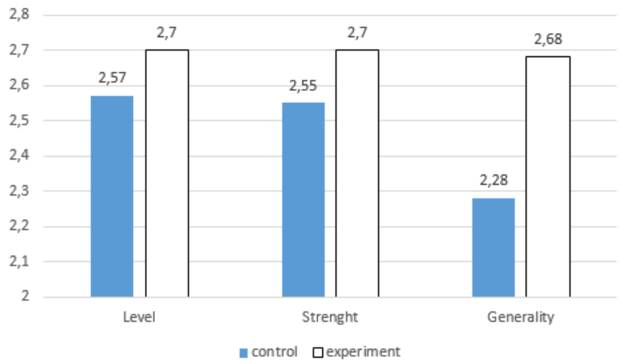

Figure 2. Comparison of the results between the control and experimental groups apects: level, strength, and generality

Based on the provided bar chart, there's a comparison of results between the control and experimental groups across four indicators. The experimental group consistently shows higher results than the control group for all indicators. Specifically, the experimental group has a significantly higher score on the "Making a Solution Plan (IPM2)" indicator (81.7) compared to the control group (67.8), which represents the largest difference among the four indicators. The smallest difference is seen in the "Checking Back (IPM4)" indicator, although the experimental group (92.3) still outperforms the control group (82.6). Overall, the graph indicates that the experimental treatment leads to a significant improvement in performance across every measured aspect.

Based on the bar chart presented, a comparison of the results between the control and experimental groups is visible across three aspects: Level, Strength, and Generality. In all aspects, the experimental group consistently showed higher results than the control group. Specifically, the experimental group achieved scores of 2.7 for both Level and Strength, and 2.68 for Generality. In contrast, the control group obtained scores of 2.57 for Level, 2.55 for Strength, and 2.28 for Generality. The most notable score difference occurred in the Generality aspect, where the experimental group significantly outperformed the control group, indicating that the experimental treatment had a greater positive impact on this specific aspect.

Before conducting the hypothesis test, researchers performed an F-test because this study compares only the post-test results, so it's essential to confirm that the initial conditions of the control and experimental classes are homogeneous or similar. The F-test data used the Regional Education Standardization Assessment (ASPD) scores, which were used for admission to the 10th grade. The F-test results show that F_calculated (1.356455895) is less than F_table (1.83), so H0 is accepted, meaning the variance of the initial scores of both classes is homogeneous or the variance of the two classes is the same. This confirms that the initial conditions of both classes were identical before the treatment was administered.

The assumption tests were conducted to ensure that the data to be entered into SPSS is theoretically and mathematically valid for statistical calculations. The assumptions for a one-way MANOVA test include the presence of several dependent variables that are all continuous. This study has two dependent variables: daily test results and self-efficacy scores, both of which are continuous variables with a range of 1-100 for daily test results and a modified 1-4 Likert scale for self-efficacy scores. There must be one independent variable that is categorical. The single independent variable in this study is the teaching method applied in the class, with category 1 for scientific learning and category 2 for PBL-STEM learning. The learning was categorized into the PBL-STEM model and the scientific-based learning model. In other words, there were two classes with different categories.

The independence of observations is ensured as the samples are objective; the sample used consisted of 15 classes that were randomized to obtain two classes using a cluster random sampling technique, with one class for scientific learning and one for PBL-STEM learning. The sample size was adequate. Each class consisted of more than 25 subjects. The control class with scientific learning had 35 students, while the experimental class with PBL-STEM learning had 36 students.

There were no univariate or multivariate outliers. Multivariate outliers were tested using

SPSS 20 and Excel. The SPSS 20 calculation results showed that the largest Mahalanobis distance was 9.77, which is far below the chi-square value of 13.81 calculated using Excel, so all 71 data points were free of multivariate outliers. Univariate outliers were tested using SPSS 20-boxplots (Islam, 2020), and the self-efficacy data was free of univariate outliers.

The data had a multivariate normal distribution. The researchers conducted a normality test using SPSS 20. In more detail, normality will be divided into two explanations: the normality of the scientific class and the normality of the PBL-STEM class. The normality test was conducted to ensure a linear relationship between each pair of dependent variables for each group of independent variables. This is because MANOVA requires a moderate relationship, neither too low nor too high.

The researchers performed a data homogeneity test using SPSS 20. The results of the homogeneity test are shown in the following table.

Table 4. Results of Homogeneity Test

Box's M	F	Df1	Df1	Sig.
7.805	2.513	3	6253462.272	0,057

The resulting Box's M value is 7.805 (p=0.057), so the covariance matrices between groups are assumed to be equal. Since the Sig value is above 0.001, homogeneity is met, meaning the data are homogeneous. Additionally, a test was performed to ensure there was no multicollinearity.

The linear regression analysis results showed an R-squared value of 0.645, which is less than 0.800. This indicates that the R-squared value is not very high, or is moderate, allowing for a MANOVA test to be conducted. The researchers performed hypothesis testing using SPSS 20 with the assistance of Excel 2013. The results of the test are presented in Table 10. We will focus on the Hotelling's Trace results because this study compares two different classes: the control class and the experimental class.

Table 5. *Hotelling's trace* multivariate test

Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Hotelling's Trace	174.070	5483.196b	2.000	63.000	.000	.994

Based on the Hotelling's Trace multivariate test (used for comparing two models), the Sig value is 0.000, which is less than the significance level of 0.05. This indicates a significant difference in problem-solving ability and self-efficacy between the two classes. The simultaneous contribution is 23.6%, which is considered a high effect size on Cohen's scale. This means the experimental class performed 23.6% better than the control class.

Table 6. Multivariate Test Result

Source	Dependent Variable	Type III Sum of Square	df	Mean Square	F	Sig	Partial Eta Square
Model	HBTotal	24.444	1	24.444	4.709	.034	.069
	EFtotal	830.063	1	830.063	16.641	.000	.206

The effect of the learning model on problem-solving ability has a significance value of 0.034 < 0.05, which means there is a difference in the problem-solving ability of students when taught using two different learning models. The effective contribution to problem-solving ability is 6.9% (a medium category on the Cohen's scale), meaning it is 6.9% better than the control class. The effect of the learning model on self-efficacy has a significance value of 0.000 < 0.05, which means there is a difference in students' self-efficacy when taught using two different learning models. The effective contribution to self-efficacy is 20.6% (a high category), meaning it is 20.6% better than the control class.

The problem-solving ability and self-efficacy of students in the PBL-STEM class were better than the control class that applied the scientific approach. This is because PBL classes can improve students' communication skills, namely asking questions, expressing opinions, communicating discussion results (Langitasari, 2021). Furthermore, STEM integration also challenges students to critically, creatively, and innovatively apply existing chemical knowledge, math skills, and technology to solve real problems. (Sumartati, 2020). The implementation of the PBL model on the topic has a positive impact on learning outcomes, including cognitive, affective, and psychomotor aspects. (Kartamiharja, Sopandi & Anggraeni, 2020).

The effect of learning model on problem solving ability is listed in Table 3, the significance value is 0.034 < 0.05, meaning that there is a difference in students' problem solving ability if taught using 2 different learning models. The effective contribution of problem solving ability is 6.9% (medium category on the cohen scale). PBL gives students the ability to solve contextual problems while STEM gives students the ability to analyze in detail in terms of science, technology, engineering, and mathematics. This is in line with the results of research which states that students must often be given more complex and contextual chemistry problem exercises to train problem solving skills in students (Rohayah, 2022). The same thing was also conveyed that the implementation of PBL and STEAM learning models can enhance cognitive learning outcomes in chemistry (Putri, et al., 2021)

The effect of learning models on self-efficacy has a significance value of 0.000 <0.05, meaning that there are differences in students' self-efficacy if taught using 2 different learning models. The effective contribution of self-efficacy is 20.6% (high category). PBL-STEM model learning provides challenges to student groups so that they will work together to overcome contextual problems given by the teacher. This is in line with the results of the study, a great effort and all their strength to complete the task or activity will increase student self-efficacy (Solikhin, 2020). The use of PBL with a STEM approach results in better understanding of chemistry concepts compared to learning with the PBL model alone (Prastika, Dasna & Santoso, 2022). PBL-STEM helps students understand a problem as a whole seen from various points of view so that student confidence increases. This is in accordance with the results of research which states that if students' understanding of a material is intact, it will increase students' self-efficacy (Tima, 2020). Learning with a STEM approach is able to enhance the complexity of students' cognitive structures (Baptista & Martins, 2023). STEM can improve general chemistry learning outcomes and student motivation (Pane, Manurung, Simangunsong, Mobo, Siahaan, Manurung, 2022).

The research findings are in line with the reference theory which states that PBL can enhance motivation, enjoyment, maturity, problem-solving skills, and understanding of cause and effect (Barrows & Tamblyn, 1980). The theoretical advantages of PBL are also outlined by Walsh (2007), which include fostering positive attitudes, nurturing creativity, enhancing deep understanding, and developing problem-solving skills and/or investigative skills that can be applied in various life domains.

CONCLUSION

This research provides the results of the PBL learning model that integrates STEM is able to improve students' problem solving skills and self-efficacy compared to learning with a scientific approach. This is because PBL that integrates STEM provides learning experiences for students to face contextual problems with detailed analysis in terms of science, technology, engineering, and mathematics. Group discussions that occur give students the ability to gather information, design solutions, and present so that their problem-solving skills increase along with their self-efficacy. Problem-based learning with STEM analysis is a student center approach so that students really learn in their groups. It is hoped that in the future this learning model can be applied in the classroom with contextual problems that vary according to the problems that arise in the students' environment where they live. Furthermore, the author suggests further research to develop PBL-STEM models with various modifications such as including the concept of green chemistry, the concept of socio scientific issues, or paying attention to students' digital abilities, artistic talents, and so on. The findings of this study have significant implications for Sustainable Development Goal (SDG) 4: Quality Education. By improving students' problem-solving skills and self-efficacy through the PBL-STEM model, this research directly contributes to several key targets of SDG 4. The model fosters critical thinking and problem-solving skills, which are essential for equipping students to address complex global challenges like climate change, poverty, and inequality. Furthermore, by improving self-efficacy, the model promotes a positive and resilient attitude toward learning, encouraging a mindset of lifelong learning. The emphasis on real-world, contextual problems ensures that the education provided is not just theoretical but also relevant and impactful, preparing students to be active, competent, and confident contributors to a more just and sustainable society.

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