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Implementation of STEM based PBL with design thinking strategies to improve students creative problem solving capability on renewable energy topics

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Abstract

This research aims to describe the effectiveness of STEM-based PBL with design thinking strategies in improving students' creative problem-solving abilities on renewable energy. This research was conducted at SMAN 1 Sungkai Jaya using a non-equivalent control group design research design. The research instrument used was a description test sheet. Learning by applying the STEM-based PBL model with design thinking strategies can improve creative problem-solving abilities; this can be seen from the average N-gain for the experimental class of 0.49 in the medium category. This is also supported by the data obtained from the Independent Sample t-test, which obtained a Sig value. (2-tailed) is 0.000, and the effect size value is 0.862 in the large category, which can be concluded that the implementation of STEM-based PBL with design thinking strategies can improve students' creative problem-solving abilities on renewable energy topics.

Keywords: PBL, STEM, design thinking, creative problem solving

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I. Introduction

Education in the 21st century expects students to master a variety of skills, with the aim that education can prepare students to become successful individuals in life. These skills are anticipated to help students develop four crucial aspects in life: mastery of knowledge, practical skills, formation of self-identity, and the ability to interact with other people [1]. In this case, physics subjects at school play a significant role in providing students with skills that align with current and future demands.

Renewable energy physics is especially pertinent due to its impact on climate change mitigation and environmental sustainability. It offers a clean alternative to fossil fuels, contributing to air pollution. Reducing reliance on fossil fuels and minimizing greenhouse gas emissions underscore the importance of renewable energy, necessitating robust comprehension of related concepts [2].

However, renewable energy development faces challenges, including evolving technology, limited infrastructure, and public understanding. Education plays a vital role in addressing these challenges. In Indonesia, the current learning approach is passive and needs more ability to foster creative problem-solving skills, which results in low scientific literacy [3]. Given the high reliance of modern society on technology, skills like Creative Problem Solving (CPS) are essential to tackle renewable energy challenges.

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STEM-based PBL with a Design Thinking Strategy offers a solution by engaging students in real-world projects where they apply STEM knowledge to solve tangible problems. Design thinking, in particular, provides a collaborative and innovative framework that encourages critical thinking and creativity, which is essential in developing sustainable solutions to technical, economic, and environmental issues in renewable energy [4].

Creative problem-solving focuses on a learning approach that encourages students to formulate problems, produce innovative alternative solutions, and choose the most effective solutions [5]. STEM-based PBL with design thinking strategies on renewable energy, it is hoped that students can be involved in challenging projects where they apply STEM knowledge and skills to solve real problems. The design thinking strategy involves a creative and collaborative thinking process in designing innovative solutions to a problem. In this context, students need to be trained to think critically, combine STEM knowledge, and develop creativity in designing sustainable and efficient solutions to technical, economic, social, and environmental challenges related to renewable energy [6].

Interviews with Physics teachers at SMA Negeri 1 Sungkai Jaya revealed that the current learning approach relies on the direct instruction method combined with a scientific approach. However, this method has proven less effective, as students need more initiative and low engagement during classroom discussions, particularly in asking and answering questions. The direct instruction method, with its focus on teacher-centered delivery, is increasingly seen as incompatible with the demands of 21st-century education, which emphasizes fostering creativity and problem-solving skills. To address this gap, there is a pressing need to shift toward interactive learning methods that can nurture students' creativity and adaptability in solving complex problems. Integrating STEM-based Problem-Based Learning (PBL) with design thinking strategies, particularly on renewable energy topics, presents a promising alternative. This approach encourages students to engage in hands-on, challenging projects, address real-world issues related to renewable energy, and enhance their Creative Problem Solving (CPS) abilities. By tackling practical problems, students are expected to develop critical thinking skills, creativity, and innovative solutions aligned with future needs.

Based on the description above, this study focuses on implementing STEM-based PBL and design thinking strategies to enhance students' CPS skills in renewable energy topics. The findings aim to contribute valuable insights into innovative and sustainable teaching practices, particularly in addressing real-world challenges in renewable energy education.

II. Methods

This study utilized a quasi-experimental method with a non-equivalent control group design. One experimental group received specific treatment in this design, while a control group did not. The experimental group underwent pretests and posttests before and after instruction using the STEM-based Problem-Based Learning (PBL) model to assess the improvement in their creative problem-solving abilities. The study population comprised 169 tenth-grade students at SMAN 1 Sungkai Jaya during the 2023/2024 academic year. The sample included class X2 as the experimental group (32 students) and class X3 as the control group (32 students), selected using a purposive sampling technique to compare average learning outcomes across the population.

The research instrument was a test sheet to evaluate students' creative problem-solving skills during the pretest and posttest phases. The test consisted of descriptive questions to assess four key indicators of creative problem-solving: clarifying, ideating, developing, and implementing.

Data collection focused on students' learning outcomes, obtained through tests administered to the experimental and control groups. The pretest was conducted before the instructional sessions to establish a baseline, and the posttest was administered after the learning sessions to measure the effects of the intervention. The descriptive questions in the test provided insights into students' progress in creative problem-solving across the specified indicators.

Data Analysis

1. N-Gain Test

The N-Gain test was conducted to determine the increase in student learning outcomes after being treated. This increase is based on students' pretest and posttest scores in the experimental and control classes. N-Gain can be calculated using the following equation (1).

$$N-\text{Gain}=\frac{\text{Posttest value}-\text{Pretest value}}{\text{Ideal minimum skor}-\text{Pretest value}}\times 100\% \quad (1)$$

The criteria for interpreting the N-Gain value [7] are in Table 1.

Table 1. N-Gain Interpretation Criteria

N-Gain	Criteria
0.7 ≤ 1.0	High
0.3 ≤ 0.7	Medium
N-Gain < 0.3	Low

2. Normality Test

The data normality test in this research was analyzed using the Kolmogorov-Smirnov Test on SPSS software. The basis for decision-making is if the Asymp. Sig. or significant > 0.05 means the data is normally distributed if the Asymp. Sig. or significant < 0.05 means the data is not normally distributed.

3. Homogeneity Test

A homogeneity test is conducted to determine whether the research sample is homogeneous. Homogeneous data is continued with parametric statistical hypothesis testing and inhomogeneous data is continued with non-parametric hypothesis testing. The basis for decision-making in this test is if the Sig. or significant value > 0.05 means that the data has a homogeneous variant, but if the Sig. or significant value < 0.05, it means that the data has an inhomogeneous variant.

4. Independent Sample T-Test

The Independent Sample T-test test was conducted to determine whether there was a difference in students' Creative Problem Solving (CPS) ability before and after learning in each control class and experimental class.

5. Effect Size Test

Effect size determines the effect of using a STEM-based PBL model with design thinking strategies to improve students' creative problem-solving abilities. Effect size can be calculated using the equation (2) according to [8].

$$d = \frac{\bar{x}_1 - \bar{x}_2}{S_{\text{pooled}}} \tag{2}$$

The results of the calculation can be interpreted in Table 2.

Table 2. Interpretation of Cohen's Value

Effect Size Value	Category
0.00 – 0.199	Very low
0.20 – 0.399	Low
0.40 – 0.599	Medium
0.60 – 0.799	High
0.80 – 1.000	Very high

III. Results and discussion

Results

1. N-Gain Test

The results of the N-Gain test for each class are presented in Table 3.

Table 3. Average N-Gain Data Test Results

Class	Score Acquisition			
	Highest N-gain	Lowest N-gain	Average N-gain	Category
Experiment	0.71	0.31	0.49	Medium
Control	0.41	0.10	0.27	Low

2. Normality Test Result

The results of the normality test in the control and experimental classes are presented in Table 4.

Table 4. Normality Test Results

Class	Komogorov Smirnov			Category
	Statistic	df	Sig.	
Pretest Experiment	0.136	32	0.139	Normal
Posttest Experiment	0.086	32	0.200	Normal
Pretest Control	0.136	32	0.142	Normal
Posttest Control	0.093	32	0.200	Normal

Table 4 shows that the experimental and control classes have a significance value greater than 0.05. Based on the test hypothesis, if Sig. > 0.05, the data is normally distributed.

3. Homogeneity Test Results

The results of the homogeneity test carried out to determine the homogeneity of the given sample can be seen in Table 5.

Table 5. Homogeneity Test Results

Levene Statictic	df1	df2	Sig.	Category
1.941	1	62	0.169	Homogen

Based on the Levene Statistic test results in Table 5, the Sig value is known. 0.169 > 0.05 so that the data on the results of experimental and control classes have the same variant or homogeneous.

4. Independent Sample T-Test Results

Independent Sample T-Test Results can be seen in Table 6.

Table 6. Independent Sample T-Test Results

Class	N	*Mean*	S.D	T	Sig. (2-tailed)	Interpretation
Experiment	32	67.51	1.90903	10.116	0,000	Significant
Control	32	48.20	1.90903	10.116	0,000	Difference

The Independent Sample T-Test test results in Table 6 show the sig value. (2 -tailed) 0.000 < 0.05 means a significant difference in the average creative problem solving after treatment using a STEM based PBL model with design thinking strategies.

5. Effect Size Test

The results of the Effect Size test are presented in Table 7.

Table 7. Effect Size Test Results

Effect Size Value	Interpretation
0.862	Very High

Based on Table 7, it can be seen that the partial eta squared size is 0.862 in the large category. This means that STEM based PBL with the design thinking strategy has a big influence on increasing students creative problem solving abilities.

Discussion

This research was conducted to determine the effectiveness of the problem-based learning (PBL) model with a design thinking-based STEM approach in improving students' Creative problem-solving abilities on renewable energy. In the experimental class, the researchers used PBL model learning steps with a STEM approach, while in the control class, the researchers used a direct instruction learning model. Learning in the experimental class and control class has been carried out directly by researchers to determine the increase in students' creative problem-solving abilities as measured through pretest and posttest with the average N-gain, which can be seen in Figure 1.

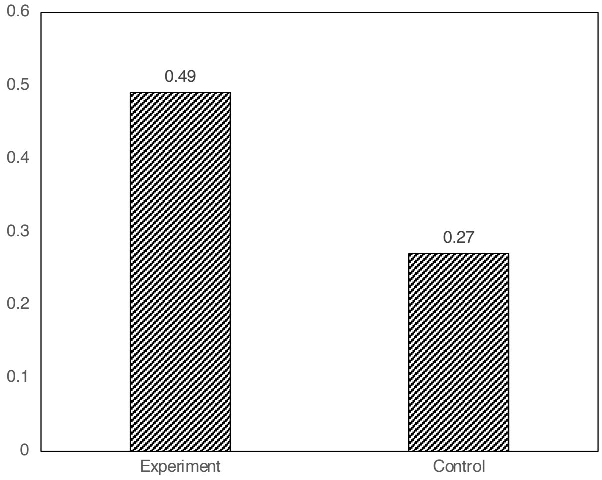

Figure 1. N-Gain Average Value Graph

The average creative problem-solving ability in the experimental class before learning was 31.25, and after implementing the PBL learning model with a STEM approach to learning was 66.54. In the control class, the average creative problem-solving ability before learning was 29.41, and after learning with the direct instruction model was 48.20. The average difference in learning outcomes in the experimental class experienced a more significant increase, namely 35.29. Based on this, learning using the PBL model with a STEM approach in the experimental class can improve creative problem-solving abilities with an average N-Gain in the experimental class of 0.49 in the medium category. STEM-integrated PBL model can influence learning outcomes and improve students' creative problem-solving (CPS) abilities [9].

Based on the results of hypothesis testing using the independent sample T-test, a sig.2 value of $0.000 < 0.05$ was obtained, meaning there is a difference in students' creative problem-solving abilities between the experimental and control classes. The difference in creative problem-solving abilities in the experimental class is more significant than in the control class; this is because, in the experimental class, learning applies the PBL model where students search for and find solutions to a given problem so that aspects of students' creative problem-solving increase. These results are based on the opinion of [10], who states that PBL is a learning model where students are actively involved and free to think creatively and develop their reasoning to solve real problems for students in everyday life.

Students' creative problem-solving abilities before learning and after learning have increased in each indicator of creative problem-solving abilities, which can be seen in Figure 2.

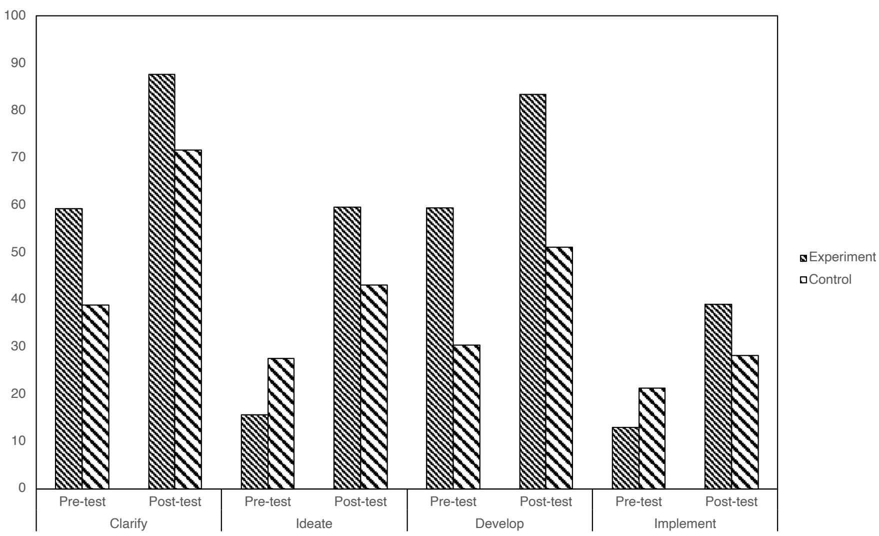

Figure 2. Percentage Graph of Creative Problem Solving Ability Indicator

Based on the percentage graph of creative problem-solving ability indicators, the experimental class that used the PBL learning model with a STEM approach experienced a higher increase in creative problem-solving ability than the control class. The average percentage increase in the creative problem-solving ability indicator for experimental class students was 30.86% of all indicators, where the clarify indicator was the indicator with the highest percentage in both the experimental class and the control class, where in this indicator, students were able to understand and formulate problems. Applying STEM in the learning process can develop students' knowledge and cognitive skills by providing ideas related to the problems [11].

The second indicator, ideate, increases fairly significantly before and after learning; in this case, students can solve problems and produce creative and innovative alternative solutions. In STEM activities, students are encouraged to represent their understanding of basic concepts that focus on problem-solving and creating innovative and creative thinking to solve real problems [12]. In the development indicator, students can develop ideas for finding alternative solutions to existing problems. Applying the PBL STEM model in the learning process can explore creative thinking skills, and students can develop ideas related to solutions to existing problems [13].

In the last indicator, the implementation indicator is the smallest percentage of each indicator in both the experimental and control classes. Many students need help to plan ideas or solutions that will be implemented correctly and need more details regarding students' answers. In learning using the PBL model, students are less able to apply ideas and connect concepts with ideas, so the implementation indicators do not experience a significant increase [14].

The first stage of the PBL learning process with a STEM approach is orientation. At this stage, students' creative problem-solving abilities are trained on the creativity indicator by STEM activities related to science and technology and by the design thinking strategy at the empathize and define stage. Namely, students can determine problems and express ideas in solving problems based on the information in the images presented in their way. Students look for solutions to problems by discussing them in their respective groups. By conducting group discussions, students must be more active in expressing their opinions and interacting with each other in groups to ensure the discussion runs well and find the right solution. This is related to the constructivist theory that learning must construct students to interact actively with each individual and the surrounding environment [15].

The second stage is organizing students to learn. Researchers divide students into several groups to discuss problem-solving, where students develop ideas as alternative solutions to a problem. At this stage, students train their creative problem-solving skills on ideation indicators, which can be seen in STEM activities in the science aspect, which implements the design thinking strategy at the ideate stage, where students can develop their ideas regarding processing organic waste into biogas as a substitute for fuel in solving problems. In the technological aspect, students use the internet to look for examples of biogas designs to be made.

The third stage is to guide individual and group investigations. Before making a product, students create a design for the biogas product that will be made first. Making this biogas product is one of the STEM aspects, namely engineering and applying design thinking strategies at the prototype stage, where students make biogas products to solve problems in the school environment and preserve the surrounding environment. This is related to constructivist learning theory, which states that students build their knowledge based on interactions with the environment around them [16].

The next stage is developing and presenting the results, where students are asked to present the results of problem-solving. At this stage, students practice creative problem-solving skills on the ideate indicator, where STEM activities are in the science aspect. Namely, students can express ideas for problem-solving to their friends in front of the class by compiling a report on the problem-solving results into a worksheet. In STEM learning, students are required to solve problems in the real world, and students are actively involved in ill-defined tasks to achieve well-defined outcomes in groups [17]. Then, in the final stage, researchers evaluate the results of each group. The things that must be evaluated are the suitability of the literacy results obtained with the correct concept of renewable energy.

The creative problem-solving abilities of experimental class students after implementing STEM-based PBL learning with design thinking strategies experienced a higher increase compared to learning in the control class, which used a direct instruction model on renewable energy material. This is because the PBL model requires students to be able to solve problems not only with concepts but also with the solution to solving the problem [18]. Based on student activities during the learning process using the PBL model with a STEM approach, it was found that students paid more attention during the problem-solving process. Also, student enthusiasm during learning and product creation was higher than students who used the direct instruction model. This is because the PBL model with a STEM approach motivates students to participate actively in the learning process and problem-solving [19].

Apart from the findings described above, there are limitations to this research, namely that it needs better adaptation between students and the environment so that there is a lack of extensive learning experience for students. However, despite these limitations, the results show that the implementation of STEM-based PBL on the topic of renewable energy causes students creative problem-solving abilities to increase because students can solve problems by combining the four disciplines in the learning process so that students become more active, easier to understand and understand the physics material. The PBL model can make students more active by freely expressing their opinions and exploring information, and solving problems from various sources in the environment around students [20].

IV. Conclusions

Based on the results and discussion, the STEM-based PBL model with design thinking strategies effectively improves students' creative problem-solving abilities. This can be seen from the test results; the average difference in the posttest is more significant than the pretest, and the N-Gain is categorized as medium, which shows an increase in students' creative problem-solving abilities. The STEM-based PBL model with design thinking strategies significantly increases students' creative problem-solving abilities compared to learning using the direct instruction model on renewable energy. This is shown by the response to the activities of students who use the PBL model with a STEM approach, paying more attention to the problem-solving process. Also, students' enthusiasm level during the learning process and when making products is higher than that of students who use the direct instruction model.

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