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IMPLEMENTATION OF PBL MODEL INTEGRATED STEM-EDP WITH DEEP LEARNING PRINCIPLES TO IMPROVE CREATIVE PROBLEM SOLVING

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Abstract :
One of the important competency that students need to have in the 21st century is creative problem solving ability. Preliminary study results indicate that students creative problem solving ability have not been optimally trained in the learning process. This study aims to determine the effectiveness of the PBL model integrated STEM-EDP with deep learning principles in improving students' creative problem-solving abilities on the topic of alternative energy. The research sample was taken using a purposive sampling technique, consisting of class X-E1 with 35 students and class X-E2 with 36 students at SMAN 5 Bandar Lampung. The method used was quasi-experimental with a non equivalent control group design. The data collection technique used was a test technique in the form of pretest and posttest question sheet consisting of the three essay questions. The results showed an improvement in creative problem solving ability, with an average N-gain of the experimental class of 0,61 (moderate category), higher than the control class which was 0,40 (moderate category). The results of the independent sample t-test and ANCOVA showed a Sig. (2-tailed) value of 0,000 < 0,05, and an effect size value of 0,406 (large category), which means that the PBL model integrated STEM-EDP with deep learning principles is effective in improving the creative problem solving ability of high school students, particularly on the topic of alternative energy.

Keywords: Creative Problem Solving Ability, PBL, STEM-EDP.

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INTRODUCTION

The development of technology and information requires the education sector to adapt curricula, strategies, and learning models that are relevant to the demands of the times. Students need to be equipped not only with theoretical knowledge but also with the ability to face complex and dynamic global challenges. Learning should be developed through innovations that not only focus on mastery of subject matter but also provide deep, contextual, and enjoyable learning experiences. Learning should encourage students' active engagement, foster awareness of their learning processes, and help them connect knowledge with everyday life. The implementation of such learning can serve as a means of continuously strengthening students' 21st-century competencies.

One of the important competencies that students need to possess in the 21st century is creative problem-solving ability (Ayida et al., 2025). Creative problem-solving ability plays an important role in helping students understand and solve problems from various perspectives when facing challenging situations. It can also train students to think creatively when dealing with various problems (Rabbani et al., 2023). Creative problem-solving ability is closely related to creative thinking because both emphasize the process of deeply understanding a problem and finding innovative solutions (Rulyansah et al., 2022). Creative problem-solving ability serves as an important foundation in physics learning because it helps students apply physics concepts to solve various real-world problems encountered in everyday life.

Physics learning trains students to identify problems through the collection of relevant facts. This process is closely related to students' ability to find and identify relevant information concerning the problems they encounter (Treffinger & Isaksen, 2005). However, the findings of Indriani et al., (2024) indicate that the implementation of creative problem-solving ability in science learning, particularly physics, is still not optimal. Students tend to focus on memorization, have limited involvement in exploratory activities, and are not accustomed to thinking creatively when dealing with real-world problems.

One learning model that has the potential to develop this ability is the Problem-Based Learning (PBL) model. The PBL model emphasizes real-world problem solving as the core of the learning process, enabling students to construct their own knowledge, develop learning independence, and build self-confidence (Arends, 2012a). This is supported by Arifin, (2020) who stated that PBL connects learning with real-life problems to help students explore and develop their thinking abilities. The implementation of PBL can be integrated with the STEM approach, as STEM-based learning can help students develop their ability to solve problems encountered in real-life contexts.

The STEM approach involves students in design activities that reflect their thinking processes within the STEM context. According to Ulum et al., (2021) one of the main characteristics of the STEM approach is the implementation of the Engineering Design Process (EDP). EDP involves an iterative decision-making process by applying concepts from science, mathematics, and basic engineering to find optimal solutions for achieving predetermined goals. EDP is also used as a strategy within the STEM approach to guide students in designing and developing prototypes as solutions to the problems they encounter (Abdurrahman et al., 2023). The STEM-EDP approach is suitable for integration with the PBL model in physics learning (Nasution et al., 2025). The integration of PBL with STEM-EDP can improve students' creative problem-solving ability more effectively and contextually. PBL trains students to solve real-world problems, while STEM-EDP helps students apply concepts of science, technology, engineering, and mathematics throughout the learning process.

However, the integration of these approaches still requires further development to support not only problem-solving activities but also deeper and more meaningful learning processes. To ensure that the learning process does not only focus on outcomes but also develops deep and sustainable understanding, the principles of deep learning need to be applied (Fatmawaty, 2024). Deep Learning as a learning principle encourages students to understand the material, apply it in various situations, and reflect on what they have learned as part of a complete and meaningful learning process (Fatihah & Wiji, 2025). Deep Learning does not merely focus on memorization but encourages students to understand the meaning behind each concept, establish connections between ideas, and apply knowledge in various relevant real-world situations (Mailani et al., 2025).

Although previous studies have demonstrated the potential of PBL, STEM-EDP, and Deep Learning to support students' learning and problem-solving processes, several limitations remain. Previous research has generally examined these approaches individually or in partial combinations, while the simultaneous integration of PBL, STEM-EDP, and Deep Learning principles in physics learning remains limited. In addition, previous studies have commonly focused on general problem-solving ability, conceptual understanding, or other learning outcomes, rather than specifically examining Creative Problem Solving (CPS) through a comprehensive set of indicators. In the context of physics learning, there is therefore still a need to investigate how PBL, STEM-EDP, and Deep Learning principles can be systematically integrated to facilitate students in identifying problems, interpreting information, generating and developing ideas, producing solutions, and evaluating those solutions.

This gap is particularly relevant in learning about alternative energy, which requires students not only to understand physical concepts but also to apply them to real-world problems. Learning activities that connect alternative energy concepts with authentic environmental problems can provide students with opportunities to apply scientific knowledge, engage in engineering design, and develop creative solutions. Therefore, integrating PBL with STEM-EDP and Deep Learning principles may provide a more comprehensive learning experience by combining problem orientation, interdisciplinary application, iterative design, meaningful understanding, and reflection within one learning process.

Based on interviews with physics teachers at SMAN 5 Bandar Lampung, it was found that PowerPoint presentations (PPT) have been used in the learning process, but their use remains limited. Classroom learning is still teacher-centered and mainly focuses on explaining concepts from textbooks, while direct practical activities have not been implemented. Students have not been widely involved in prototype development activities or in applying physics concepts to real-world situations. Consequently, design activities and the application of technology and engineering have not been optimally implemented in the classroom.

Nevertheless, teachers have implemented Deep Learning principles in the learning process as an effort to improve students' understanding. However, learning activities that provide opportunities for students to experiment, test ideas, or solve problems individually or collaboratively are still limited. As a result, students' understanding has not developed optimally, particularly in the topic of alternative energy, which requires the direct application of concepts. Teachers also reported that learning on alternative energy has not been implemented optimally due to time constraints and limited learning activities that allow students to directly apply the concepts.

In addition, the school's location near a major roadway creates another problem, namely high levels of dust and air pollution around the school environment. This condition indicates that students are exposed to real-world problems that require creative and sustainable solutions. Rather than presenting alternative energy only as an abstract concept, this local environmental condition provides an opportunity for students to apply their knowledge to develop a practical solution. Therefore, it is important to seek solutions that not only help reduce the impact of dust and air pollution in the surrounding environment but also provide educational value for students. Based on this problem, students can apply their skills through a project to develop a simple *solar-powered vacuum cleaner*.

To address the identified research gap and the contextual learning needs at the school, the present study integrates the PBL model with STEM-EDP and Deep Learning principles in physics learning on alternative energy. The novelty of this study lies in the simultaneous implementation of these three components within an authentic project-based learning context and its specific focus on students' Creative Problem Solving ability. The learning is designed around the development of a simple solar-powered vacuum cleaner as a solution to the dust problem surrounding the school. Through this project, students are involved in identifying and interpreting the problem, generating and developing ideas, designing and testing a prototype, evaluating the proposed solution, and reflecting on the learning process. Thus, the integration provides a learning experience that connects physics concepts, engineering design, technology, and real-world environmental problems while emphasizing meaningful, conscious, and reflective learning.

Therefore, this study aims to investigate the effectiveness of the PBL model integrated STEM-EDP with Deep Learning principles in improving students' Creative Problem Solving ability on the topic of alternative energy.

RESEARCH METHOD

Research Design

The design of this study is quantitative experimental research approach using a quasi-experimental method with a nonequivalent pretest-posttest control group design. This design involved two classes: an experimental class that received the treatment and a control class that received conventional instruction. Both groups were administered a pretest before the treatment and a posttest after the treatment to measure changes in students' creative problem solving ability. This design was selected because the study aimed to examine the effectiveness of the PBL model integrated with STEM-

EDP with Deep Learning principles in improving students creative problem solving ability (Creswell & Creswell, 2018).

Research Target/Subject

The population of this study consisted of all tenth-grade students at SMA Negeri 5 Bandar Lampung in the second semester of the 2025/2026 academic year. The sample was selected using purposive sampling based on the similarity of students' initial abilities, as indicated by their previous learning outcomes. Two classes were selected as the research samples. Class X-E1, consisting of 35 students, was assigned as the experimental class, while Class X-E2, consisting of 36 students, was assigned as the control class. The experimental class received instruction using the PBL model integrated with STEM-EDP and Deep Learning principles, while the control class received instruction using the direct instruction model with a scientific approach. The study focused on the topic of alternative energy.

Research Procedure

The research was conducted in three stages: preparation, implementation, and final stages. The intervention was conducted over four learning sessions, with each session lasting 35 minutes. The research procedure is described as follows.

1. Preparation Stage
   The activities carried out during the preparation stage were as follows:
   a. Obtaining permission from the school to conduct the research at SMA Negeri 5 Bandar Lampung,
   b. Conducting interviews with the physics teacher at SMA Negeri 5 Bandar Lampung,
   c. Determining the classes to be used as the research samples and scheduling the research implementation, and
   d. Preparing the learning materials and research instruments used during the study.

2. Implementation Stage
   The activities carried out during the implementation stage can be seen in Table 1.

Table 1. Implementation Stage

Experimental Class	Control Class
Administering a pretest to measure students' initial creative problem solving ability.	Administering a pretest to measure students' initial creative problem solving ability.
Providing treatment using the PBL model integrated STEM-EDP with deep learning principles.	Providing treatment using the direct instruction model with a scientific approach.
Administering a posttest to determine students' final creative problem solving ability.	Administering a posttest to determine students' final creative problem solving ability.

Experimental Class Treatment

In the experimental class, the PBL model was integrated with STEM-EDP and Deep Learning principles throughout the learning process. The learning began with the presentation of an authentic problem related to alternative energy and environmental conditions surrounding the school. Students were then guided to identify and analyze the problem, collect relevant information, generate and develop possible ideas, and design a solution using the Engineering Design Process.

Students subsequently developed and tested a simple solar-powered vacuum cleaner prototype as a solution to the environmental problem of dust around the school. During this process, students applied concepts from science, technology, engineering, and mathematics. The Deep Learning principles were implemented through activities embedded in the PBL and STEM-EDP learning process. The mindful principle was implemented by encouraging students to focus on the authentic problem, and consciously participate in identifying and analyzing the problem. The meaningful principle was implemented by connecting students' prior knowledge of physics with the

real-life problem of dust and air pollution and applying physics concepts to the development of a solar-powered vacuum cleaner. The joyful principle was implemented through collaborative discussions, idea generation, prototype design, construction, testing, and communication of solutions. At the end of the learning process, students were guided to reflect on their learning experiences, the difficulties they encountered, and the improvements needed for their solutions.

Control Class Treatment

In the control class, learning was conducted using a direct instruction model with a scientific approach. The teacher explained the concepts related to alternative energy, followed by question-and-answer activities, discussions, and exercises. Students were guided to observe, ask questions, collect information, associate concepts, and communicate their learning outcomes. The control class did not receive the integrated PBL, STEM-EDP, and Deep Learning treatment.

3. Final Stage
   The final stage consisted of collecting and analyzing the pretest and posttest data. The results were analyzed to determine the improvement in students creative problem solving ability in both groups. Conclusions were then drawn based on the results of the data analysis.

Instruments, and Data Collection Techniques

Data on students' creative problem solving ability were collected using an essay test. The instrument consisted of three essay questions developed based on the six creative problem solving indicators proposed by Treffinger and Isaksen (2005), namely fact finding, fact interpreting, idea finding, idea developing, solution generating, and solution evaluating.

The same test instrument was administered as the pretest and posttest. The test was designed to measure students' ability to identify relevant information, interpret facts, generate and develop ideas, formulate possible solutions, and evaluate solutions to problems related to physics and alternative energy.

Instrument Blueprint

Table 2. Blueprint of the Creative Problem Solving Instrument

No	Creative Problem Solving Indicators	question indicators	Scor
1	Fact Finding	When presented with images depicting dusty environmental conditions, students are able to accurately identify the environmental problems that arise.	4
	Fact Interpreting	When presented with images of a dusty environment, students are able to analyze the causes and effects of this problem on the community.	4
2	Idea Finding	When presented with problems related to the use of alternative energy in schools, students are able to come up with creative ideas for using alternative energy to address dust in the classroom.	4
	Idea Developing	When presented with issues related to alternative energy, students are able to select one idea and explain its rationale and function logically and in detail.	4
3	Solution Generating	When presented with the problem of energy-inefficient dust cleaners, students are able to design solutions that allow the devices to continue functioning without wasting electricity.	4
	Solution Evaluating	When presented with a proposed solution, students are able to logically evaluate its strengths and weaknesses.	4

Assessment Rubric

Each essay item was assessed using a scoring rubric based on the level of achievement of the corresponding creative problem solving indicator. The scoring scale ranged from 1 to 4, with higher scores indicating a higher level of achievement.

Tabel 3. Test Instrument Scoring Rubric

No	Creative Problem Solving Indicators	Assessment Indicators	Description	Scor
1.	Fact Finding	Identify air pollution issues related to the given phenomenon.	Explain environmental issues clearly and in a way that is relevant to the given image.	4
			Explain environmental issues relevant to the image, but not very accurately.	3
			Merely list environmental issues.	2
			Unable to explain environmental issues	1
	Fact Interpreting	Analyzes the causes and effects of the problem depicted in the image.	Analyzes the causes and environmental effects clearly and in a manner relevant to the given image.	4
			Analyzes the causes and environmental effects relevant to the image, but not entirely accurately.	3
			Analyzes only the causes or effects.	2
			Unable to analyze the causes and effects.	1
2.	Idea Finding	Generating creative ideas that utilize environmentally friendly alternative energy sources.	rovides highly relevant creative ideas	4
			Provides relevant and fairly accurate creative ideas	3
			Provides relevant but less accurate creative ideas	2
			Does not provide relevant ideas	1
	Idea Developing	Provides reasons for selecting an idea based on its strengths and weaknesses, along with its function	Able to select one idea and provide accurate reasons for the selection and its function	4
			Able to select one idea and provide reasonably accurate reasons for the selection and its function	3
			Able to select one idea but provides less-than-accurate reasons for the selection and its function	2
			Unable to select one idea and provide reasons for the selection and its function	1
3.	Solution Generating	Provides alternative energy solutions to solve problems.	Provides highly relevant solutions	4

No	Creative Problem Solving Indicators	Assessment Indicators	Description	Scor
			Provides relevant and reasonably accurate solutions	3
			Provides relevant but less accurate solutions	2
			Does not provide relevant solutions	1
	Solution Evaluating	Identifies the strengths and weaknesses of the proposed solution	Identifies the strengths and weaknesses very accurately	4
			Identifies the strengths and weaknesses fairly accurately	3
			Identifies the strengths and weaknesses but not very accurately	2
			Does not accurately identify the strengths and weaknesses	1

Instrument Validity and Reliability

Before being administered to the research participants, the creative problem solving instrument was tested for validity and reliability using IBM SPSS Statistics 25.0. Item validity was assessed using the Pearson Product-Moment correlation by comparing the obtained correlation coefficient with the critical value of 0.3494. The results showed that all three essay items met the validity criteria and were therefore declared valid (Fraenkel et al., 2023). Instrument reliability was assessed using Cronbach's Alpha. The analysis yielded a Cronbach's Alpha coefficient of 0.726 for the three items (Field, 2009). Therefore, the instrument was considered sufficiently valid and reliable for measuring students' creative problem-solving ability.

Data analysis technique

The data analysis technique used in this study is inferential quantitative analysis. The collected data was analyzed using IBM SPSS Statistics 25.0 software. The tests conducted included the N-gain test, normality test, and homogeneity test. Furthermore, hypothesis testing was performed using the independent sample t-test, paired sample t-test, and effect size analysis in ANCOVA .

RESULTS AND DISCUSSION

This study aimed to determine the effectiveness of the Problem Based Learning (PBL) model integrated STEM-EDP with deep learning principles in improving students' creative problem solving ability on the topic of alternative energy. The results showed that the implementation of the STEM-EDP integrated PBL model with deep learning principles had a significant effect on improving students' creative problem solving ability in the experimental class. In other words, the implementation of the PBL model integrated STEM-EDP with deep learning principles was effective in improving creative problem solving ability. The improvement in creative problem solving ability was evident from the comparison of the pretest and posttest scores administered before and after the learning process. The results of the N-Gain test in both classes after the treatment can be seen in Table 4.

Table 4. N-Gain Mean Test Results

	Score Achievement			
Class	Highest N-gain	Lowest N-gain	Average N-gain	Interpretation
Experimental	0,81	0,25	0,61	Moderate
Control	0,64	0,07	0,40	Moderate

Based on the average N-Gain data in Table 1, the experimental class obtained an average N-Gain score of 0.61, categorized as moderate, whereas the control class achieved an average N-Gain of 0.40, which is also included in the moderate category (Meltzer, 2002). The higher average N-Gain in the experimental class indicates the implementation of the PBL model integrated with STEM-EDP and Deep Learning Principles was more effective compared to the Direct Instruction model combined with a Scientific Approach used in the control class.

This study used prerequisite analyses consisting of normality and homogeneity tests. The results showed that the data from both the experimental and control classes were normally distributed and homogeneous, as evidenced by the significance value being greater than 0,05 ($\alpha > 0,05$).

Table 5. Independent Sample T-Test Results

	N	Mean	Std. Dev	Sig. (2-tailed)
Experimental Class	35	0,61	0,130	0,000
Control Class	36	0,40	0,144	

The Independent Sample T-Test results presented in Table 5 indicate that the Sig. (2-tailed) value is 0,000 < 0,05. This indicates a significant difference in the improvement of students' creative problem solving ability between the class that applied the PBL model integrated with STEM-EDP and deep learning principles and the class that used the Direct Instruction model with a Scientific Approach.

Table 6. Paired Sampe T-Test Results

	N	Mean	Std. Dev	Sig. (2-tailed)
Pretest_ Experimental	35	42,77	6.306	0,000
Posttest_ Experimental	35	78,11	6.672	
Pretest_Control	36	43,33	6.261	0,000
Posttest_Control	36	66,19	6.672	

The results of the Paired Sample T-Test presented in Table 6 show that the Sig. (2-tailed) value is 0.000 < 0.05; therefore, the H_0 hypothesis is rejected and H_1 is accepted. This indicates that there is a significant difference in the improvement of students' creative problem solving ability when using the PBL model integrated STEM-EDP with deep learning principles, as seen from the learning outcomes before and after the treatment was administered.

Table 7. ANCOVA Test Results

Souce	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1	2521.466	47.237	0,000	0,406
Intercept	1	369570.593	6923.463	0,000	0,990

The results of the ANCOVA test presented in Table 7 show that the Sig. value for the Source Corrected Model is 0,000 < 0,05; therefore, the H_0 hypothesis is rejected and H_1 is accepted. This indicates that the PBL model integrated with STEM-EDP and deep learning principles is effective in improving senior high school students' creative problem solving abilities, with an effect size of 0,406 (large category) (Cohen et al., 2007).

Creative problem solving ability was measured through pretest and posttest scores, which were then analyzed using the average N-gain as presented in Table 4. The average N-gain results indicate that the improvement in students' abilities in the experimental class taught using the PBL model integrated STEM-EDP with deep learning principles was higher than that of the control class taught using the Direct Instruction model with a Scientific Approach. The improvement in students' abilities can be seen in the average N-gain outcome scores for each creative problem solving indicator after the treatment was administered, as shown in Figure 1.

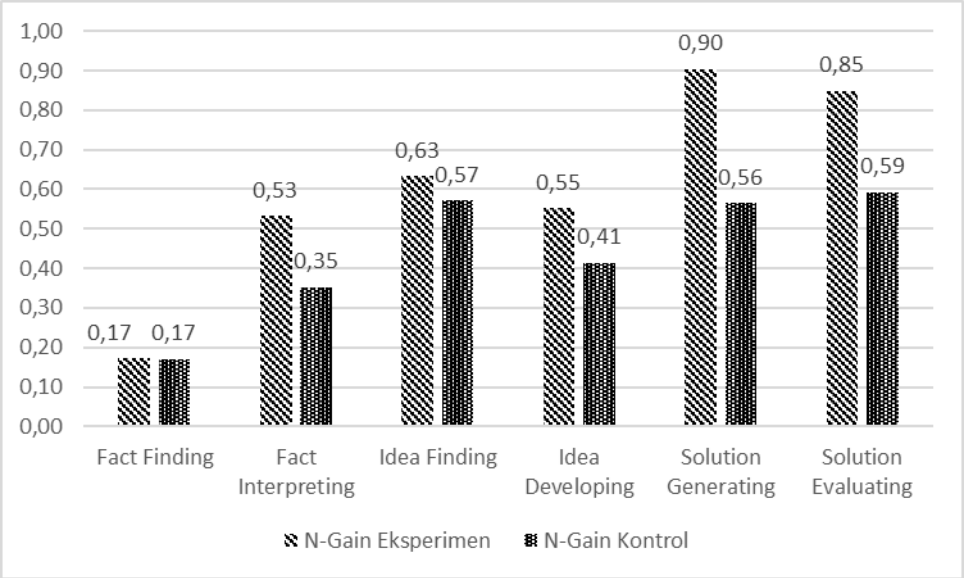

Figure 1. Graph of the Average N-Gain Analysis of Creative Problem Solving Indicators.

The graph illustrating the scores for each indicator shows that, before the treatment, both the experimental and control classes had relatively similar initial ability levels. However, after the treatment, the experimental class demonstrated a greater improvement compared to the control class. These results indicate the implementation of the PBL model integrated STEM-EDP with deep learning principles was more effective in improving students' creative problem solving ability than the control class.

The fact finding indicator in the experimental class obtained an average N-gain of 0.17 in the low category, similar to the control class. However, improvement in the experimental class was observed during the orient students to problem phase in the PBL model integrated with STEM-EDP and deep learning principles. In this phase, students observed dust phenomena in their surroundings, identified sources of problems, and compared dust-cleaning tools to identify facts related to their advantages and disadvantages, thereby training fact finding ability through direct fact exploration. These activities reflected the application of science and technology aspects in STEM, as well as the identify problem and constraints stage in the engineering design process (EDP). In addition, deep learning principles were demonstrated through students' active involvement in understanding problems contextually, connecting information with real-life situations, and analyzing the causes of problems more deeply (Ausubel, 1968). These findings are consistent with Widiastuti & Budiyanto, (2022) and Lamalani et al., (2025) who stated that STEM-EDP-based learning with contextual problems can improve students' ability to collect and analyze information in a more meaningful way.

In the fact interpreting indicator, students' improvement was observed during the organize students for study phase, where students identified problems, gathered information from various sources, analyzed alternative solutions, and determined the most effective solution. These activities trained students to interpret information more deeply. This finding is in line with Hidayati et al., (2024), who stated that activities involving information analysis and solution selection can improve students' interpretation ability. In addition, activities in this phase reflected the application of science and technology aspects as well as the research stage in the engineering design process (EDP). Students' active involvement in connecting various information with problem contexts also demonstrated the implementation of deep learning principles, consistent with Mariskhantari et al., (2022), who stated that activities involving the integration of various information in problem solving can improve the ability to understand relationships between concepts.

Improvement in the idea finding and idea developing indicators was observed during the assist independent and group investigation phase. In this phase, students conducted individual investigations and group discussions to generate and develop solution ideas in the form of prototype designs. These activities trained students to analyze various alternative solutions and develop ideas into more directed designs. This finding is consistent with Rahmawati et al., (2024), who found that students' involvement

in evaluating and developing solution ideas can strengthen problem-solving skills. The implementation of STEM was reflected through the science, technology, and engineering aspects, while the EDP stages were shown in the ideate and analyze idea activities. This phase also demonstrated the application of deep learning principles, where students were actively involved in the learning process, connected prior knowledge with new information in designing solutions, and showed enthusiasm and engagement during discussions and design activities, making learning more meaningful and in-depth (Michael & Langworthy, 2014).

The solution generating indicator showed the highest improvement compared to the other indicators. This improvement was observed during the develop and exhibits phase when students transformed their designs into a simple solar-powered vacuum cleaner prototype. At this stage, students not only generated ideas but also developed, tested, and refined solutions in the form of real products (Morgan et al., 2013). This finding is consistent with Ayida et al., (2025) who reported that STEM-EDP-based learning can improve students' ability to generate and develop creative solutions through the processes of designing, creating, and testing products. These activities also involved the application of science, technology, engineering, and mathematics aspects, making learning more contextual and meaningful.

Figure 2. Prototype Testing.

In the solution evaluating indicator, students' improvement was observed during the analyze and evaluate the problem solving process phase. Students discussed the experimental results, presented their products, evaluated the strengths and weaknesses of the prototypes, and provided suggestions for improving the solutions that had been developed. These activities trained students' ability to assess the effectiveness of solutions and reflect on the learning process. This finding is consistent with Octafianellis et al., (2021), who stated that STEM-integrated problem-based learning can improve students' ability to evaluate and refine solutions. The communicate and reflect stages in the engineering design process (EDP) also supported students in connecting the test results with alternative energy concepts more deeply. In this phase, the application of deep learning principles was evident as students evaluated the results, connected testing outcomes with previously learned concepts, discussed the weaknesses of the solutions, and considered possible improvements, making learning more meaningful.

Overall, the implementation of the PBL model integrated with STEM-EDP and deep learning principles provided an active, meaningful, and contextual learning experience. These findings are supported by Nasution et al., (2025), who reported that PBL integrated with STEM-EDP can improve students' learning outcomes, and Kua et al., (2026), who found that Deep Learning principles can promote active and student-centered learning. The implementation of the integrated model is also consistent with constructivist theory Piaget & Inhelder, (1969) and the PBL theory of Arends, (2012), which emphasize that students construct knowledge through active involvement in problem-solving processes.

The improvement in students' Creative Problem-Solving ability can be understood through the complementary contributions of PBL, STEM-EDP, and Deep Learning principles. PBL primarily provided the authentic problem context and problem-solving structure, encouraging students to identify problems, investigate relevant information, and engage in collaborative problem solving. STEM-EDP provided a systematic process for developing and refining solutions, guiding students through idea generation, analysis, research, prototype development, testing, communication, and reflection. Meanwhile, Deep Learning principles strengthened the depth and quality of students' engagement and

understanding by encouraging them to connect physics concepts with real-life situations, participate consciously in the learning process, collaborate with others, and reflect on their learning experiences (Kemendikdasmen, 2025). The interaction of these three components created a continuous learning process in which students were not only required to generate solutions but also to justify their ideas, apply relevant concepts, test their prototypes, evaluate the results, and refine their solutions based on evidence. Thus, the three components served different but interconnected functions rather than operating independently. The higher improvement observed in the experimental class can therefore be understood as the result of this integrated learning process rather than the contribution of any single component or merely students' involvement in project activities.

These findings address the research gap identified in previous studies, particularly the limited integration of PBL, STEM-EDP, and Deep Learning principles within a single physics learning process to specifically develop students' Creative Problem-Solving ability. While previous studies have demonstrated the benefits of PBL, STEM-EDP, and Deep Learning individually or in partial combinations, the present study provides empirical evidence of their simultaneous implementation in an authentic physics learning context. The novelty of this study lies not only in combining the three components but also in applying them to an authentic environmental problem through the development of a simple solar-powered vacuum cleaner. This context enabled students to connect alternative energy concepts with a problem encountered in their school environment while engaging in the processes of problem identification, idea generation and development, prototype design and testing, solution evaluation, and reflection. Thus, the findings extend previous research by demonstrating how the complementary functions of PBL, STEM-EDP, and Deep Learning can be integrated to support Creative Problem-Solving ability through a contextual and meaningful physics learning experience.

The findings have several implications for physics education. For teachers, the integrated PBL-STEM-EDP with Deep Learning approach can provide an alternative strategy for designing learning activities that connect physics concepts with authentic problems and involve students in designing, testing, evaluating, and improving solutions. The use of environmental problems surrounding students can also make physics learning more relevant and meaningful, while the Deep Learning principles can encourage students to engage consciously, connect new knowledge with prior experiences, and reflect on their learning. In addition, this approach may be particularly relevant for schools with limited opportunities for conventional laboratory activities because authentic environmental problems can be used as learning contexts for simple engineering projects.

Nevertheless, this study has several limitations. First, the study involved only two classes from one senior high school, with a relatively limited sample size, which may restrict the generalizability of the findings to other educational contexts. Second, the intervention was conducted over a limited number of learning sessions, so the long-term effects of the integrated approach on students' Creative Problem-Solving ability could not be determined. Third, the study focused specifically on alternative energy and used a solar-powered vacuum cleaner as the main project; therefore, the findings may not fully represent the effectiveness of the approach when applied to other physics topics or different types of engineering projects. Future research could involve larger and more diverse samples, longer intervention periods, and various physics topics and authentic problem contexts to examine the consistency and long-term effectiveness of the integrated approach.

CONCLUSION

Based on the results and discussion, it can be concluded that the implementation of the PBL model integrated with STEM-EDP and Deep Learning principles was more effective in improving students' creative problem-solving ability than the direct instruction model with a scientific approach on the topic of alternative energy. This finding is indicated by the higher average N-Gain score obtained by the experimental class (0.61) compared with the control class (0.40). Furthermore, the effect size of 0.406 indicates a large effect of the intervention on students' creative problem-solving ability. The integration of PBL, STEM-EDP, and Deep Learning principles provided students with opportunities to engage in authentic problem solving, apply physics concepts through prototype design and testing, generate and evaluate solutions, and reflect on their learning experiences. Therefore, this integrated learning approach can be considered an alternative strategy for developing students' creative problem-

solving ability in physics learning, particularly on alternative energy topics. Future research is recommended to implement the approach in different physics topics, learning environments, and student populations to further examine its effectiveness.

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