The Impact of PjBL-STEM Integrated EDP Strategy with Deep Learning to Improve Creative Problem-Solving Skills

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***Abstract** – Students' Creative Problem-Solving (CPS) skills in physics require further development to prepare them for the challenges of the twenty-first century. This study aimed to examine the effectiveness of an integrated Project-Based Learning (PjBL)-STEM model incorporating Engineering Design Process (EDP) strategies and Deep Learning principles in improving senior high school students' CPS skills on the topic of Bernoulli's Principle. A quasi-experimental method with a non-equivalent control group design was employed at SMAN 1 Kalirejo. The sample consisted of two Grade 11 classes, with Class XI.F6 serving as the experimental group and Class XI.F5 as the control group. Data were collected using a two-item essay test, each comprising six sub-questions representing the six CPS indicators. The results demonstrated that the integrated PjBL-STEM model effectively enhanced students' CPS skills. The experimental group achieved an N-gain score of 0.67, substantially higher than the control group's score of 0.28. These findings were supported by the independent-samples t-test and paired-samples t-test, both of which indicated statistically significant differences ($p < 0.001$). The ANCOVA results further confirmed the effectiveness of the intervention ($p < 0.001$). Moreover, the effect size analysis yielded a partial eta squared (η^2) value of 0.697, indicating a large effect of the instructional model on students' CPS skills. The improvement in CPS skills can be explained through the constructivist perspectives of Piaget and Vygotsky, which emphasize knowledge construction through experience, social interaction, and reflection. These findings are further supported by Ausubel's meaningful learning theory, as students connected the concept of Bernoulli's Principle with real-world experiences through the development of a simple insecticide project.*

***Keywords**: PjBL-STEM; Creative Problem-Solving; Deep Learning; Engineering Design Process.*

INTRODUCTION

21st-century education requires students to be able to address increasingly complex global challenges and environmental changes. The learning process no longer focuses solely on mastering subject matter but also on developing competencies relevant to the workplace and everyday life (Zubaidah, 2018). These competencies are known as 21st-century skills, which include Critical Thinking, Creativity, Collaboration, and Communication, commonly referred to as the 4Cs framework (Miller et al., 2023). These skills provide an essential foundation for students to cope with the challenges and dynamics of modern society. Therefore, 21st-century learning should be designed to equip students with critical, creative, and adaptive thinking skills to address global challenges and rapid technological advancements (Mahanal, 2017; Syahputra, 2024).

Physics instruction in secondary schools still faces various challenges in supporting the development of 21st-century skills. Learning activities remain predominantly teacher-centered and focus mainly on solving routine problems, limiting students' opportunities to explore ideas, conduct experiments, and construct conceptual understanding independently (Irwan & Kamarudin, 2021). Consequently, the development of students' creative thinking skills has not yet been optimal (Rahono, 2014).

Creative thinking is one of the essential 21st-century skills that students need to develop (Hidayatullah et al., 2021; Iskandar et al., 2020). In science education, particularly physics, one skill closely related to creative thinking and still challenging to develop is Creative Problem-Solving (CPS) (Rokhmat et al., 2022). CPS emphasizes a creative and reflective problem-solving process (Azmi & Khaira, 2023; Meidina et al., 2024). This process encourages students to generate multiple alternative solutions creatively while reflecting on their thinking processes and decision-making (Sari et al., 2020). In the context of physics learning, CPS enables students to develop conceptual understanding as well as higher-order thinking skills during problem-solving activities (Maheva et al., 2023).

The development of CPS skills can be facilitated through the implementation of the Project-Based Learning (PjBL) model, which engages students in meaningful projects and promotes creativity and reflective thinking (Zubainur et al., 2017). The PjBL model aligns well with the STEM (Science, Technology, Engineering, and Mathematics) approach, which integrates these four disciplines within the context of real-world problem solving (Tseng et al., 2013; Maryanti, 2021; Suwardi, 2021). STEM encourages students to explore, experiment, and evaluate various alternative solutions to contextual problems. Laboy-Rush (2010) developed the PjBL-STEM model, which consists of the stages of Reflection, Research, Discovery, Application, and Communication. The implementation of this model can be further optimized through the integration of the Engineering Design Process (EDP), which guides students in identifying problems, designing solutions, developing products, and evaluating outcomes (Guzey et al., 2016; Abdurrahman et al., 2023). In addition, the application of Deep Learning principles that emphasize conscious, meaningful, and enjoyable learning experiences can help students develop a deeper and more contextual understanding of concepts.

Bernoulli’s Principle is often considered one of the most challenging topics in physics learning. Students frequently experience difficulties in connecting Bernoulli’s equation with real-life phenomena (Schafle & Kautz, 2021). As a result, they often make errors when applying the concept and solving problems related to Bernoulli’s Principle. Previous studies have shown that many students struggle with this topic because they focus on the mathematical equation without fully understanding the underlying concepts (Jumilah et al., 2022). Furthermore, teacher-centered learning practices limit students’ active involvement in constructing conceptual understanding. Therefore, innovative learning approaches are needed to help students understand Bernoulli’s Principle in a more concrete, engaging, and meaningful manner.

Several previous studies have demonstrated that both PjBL and PjBL-STEM are effective in improving students’ Creative Problem-Solving (CPS) skills. Chen and Chan (2021) reported that the implementation of PjBL significantly improved students’ abilities to identify problems, generate solutions, and evaluate outcomes. Similarly, Rabbani (2023) found that PjBL-STEM enhanced CPS skills through contextual projects integrating science, technology, engineering, and mathematics. However, studies investigating the integration of the Engineering Design Process (EDP) and Deep Learning principles within the PjBL-STEM model to improve CPS skills in learning Bernoulli’s Principle remain limited. Therefore, this study aims to examine the impact of PjBL-STEM integrated with the Engineering Design Process (EDP) and Deep Learning principles on Creative Problem-Solving (CPS) skills in learning Bernoulli's Principle.

RESEARCH METHODS

This study employed a quasi-experimental method using a Non-Equivalent Control Group Design with pretest and posttest assessments administered to both groups. The research was conducted at SMAN 1 Kalirejo during the 2025/2026 academic year. The population consisted of eleventh-grade students at SMAN 1 Kalirejo. The sample was selected using purposive sampling based on the similarity of students' academic abilities and recommendations from the physics teacher. The study involved 60 eleventh-grade students, comprising 30 students from class XI.F6 as the experimental group and 30 students from class XI.F5 as the control group. The experimental group received learning through the PjBL-STEM model integrated with the Engineering Design Process (EDP) strategy and Deep Learning principles, whereas the control group was taught using direct instruction based on the scientific approach.

The instrument used in this study was an essay test administered as both the pretest and posttest to measure students' Creative Problem-Solving (CPS) skills. The instrument consisted of two essay questions, each containing six sub-questions (a–f). Each sub-question represented one CPS indicator proposed by Treffinger and Isaksen (2005), namely Fact Finding, Fact Interpreting, Idea Finding, Idea Developing, Solution Generating, and Solution Evaluating. Thus, both essay questions assessed all six CPS indicators through different Bernoulli's Principle problem contexts. The correspondence between the essay questions, CPS indicators, and task specifications is presented in Table 1. Students' responses were scored using an analytic rubric adapted from Treffinger and Isaksen (2005). The analytic rubric consisted of four performance levels (1–4) for each CPS indicator, assessing the completeness, relevance, and scientific accuracy of students' responses.

Table 1. Mapping of Essay Questions to CPS Indicators

CPS Indicator	Question	Description
Fact Finding	1a & 2a	Identify the issues related to the phenomenon of insect sprayers that produce different spray patterns and explain the factors influencing these differences based on Bernoulli's principle
Fact Interpreting	1b & 2b	Analyze and interpret the relationship between the causes of variations in spray patterns and the concepts and equations of Bernoulli's principle to explain the observed phenomena
Idea Finding	1c & 2c	Propose three creative ideas for designing or modifying an insect sprayer to produce a finer mist based on Bernoulli's principle
Idea Developing	1d & 2d	Develop the selected idea into a more detailed design for a modified insect sprayer by presenting the design, component specifications, tools and materials, and the function of each part based on Bernoulli's principle
Solution Generating	1e & 2e	Develop a procedure for using and testing a modified insect sprayer to demonstrate that the design can improve spray quality based on Bernoulli's principle

CPS Indicator	Question	Description
Solution Evaluating	1f & 2f	Evaluate the results of the modified insect sprayer design by explaining the strengths and weaknesses of the design based on the device's performance effectiveness and the quality of the spray produced.

Prior to implementation, the instrument was tested on 30 students outside the research sample to examine its validity and reliability. The validity analysis showed that the two essay items obtained Pearson correlation coefficients of 0.918 and 0.946, respectively, which exceeded the critical value ($r > 0.361$), indicating very high validity. The reliability analysis yielded a Cronbach's Alpha coefficient of 0.889, indicating that the instrument was highly reliable.

Data were collected through pretest and posttest activities. The improvement of students' CPS skills was analyzed using the N-Gain test. Prior to hypothesis testing, normality and homogeneity tests were conducted as prerequisite analyses. The effectiveness of the learning model was examined using the Independent Sample T-Test, Paired Sample T-Test, and Analysis of Covariance (ANCOVA). Furthermore, effect size analysis using Partial Eta Squared (η^2) was performed to determine the magnitude of the treatment effect on students' Creative Problem-Solving skills.

RESULTS AND DISCUSSION

Result

Prior to data analysis, the instrument met the required validity and reliability criteria and was therefore considered suitable for measuring students' Creative Problem-Solving (CPS) skills.

Table 2. Descriptive Statistics of Pretest and Posttest CPS Scores

Class	N	Pretest Mean	Posttest Mean
Experimental	30	39.03	80.00
Control	30	39.24	56.60

Table 2 presents the descriptive statistics of students' pretest and posttest Creative Problem-Solving (CPS) scores in both groups. The experimental and control groups had comparable mean pretest scores (39.03 and 39.24, respectively), indicating relatively similar initial CPS abilities before the intervention. Following the learning process, the experimental group achieved a substantially higher mean posttest score (80.00) than the control group (56.60), suggesting that the implementation of the PjBL-STEM model integrated with the Engineering Design Process (EDP) strategy and Deep Learning principles resulted in greater improvement in students' Creative Problem-Solving skills.

Table 3. N-Gain Test Result

Class	Score Achievement	
	Average N-Gain	Category
Experimental	0.67	Medium
Control	0.28	Low

Table 3 indicates that the average N-Gain score obtained by the control class was 0.28, placing it in the low category, while the experimental class recorded an average score of 0.67, corresponding to the moderate category. The learning process in the experimental class, which applied the PjBL-STEM model integrated with EDP and Deep Learning principles, yielded a higher average compared to the control class, which used the Direct Instruction model with a Scientific approach.

This research employed the following prerequisite tests: the normality test, the homogeneity test, the regression homogeneity test, and the linearity test. Based on these tests, the research data from the experimental and control classes were found to be normally distributed and homogeneous with a Sig. value > 0.05. In addition, the regression slope was found to be homogeneous with a Sig. value of 0.350, and the data relationship was found to be linear with a Sig. value of 0.175.

Table 4. Independent Sample T-Test Results

Variable	t	df	Sig. (2-tailed)	Mean Difference
Posttest CPS	10.105	58	0.00	23.405

The Independent Sample T-Test results revealed a significant difference in posttest Creative Problem-Solving (CPS) scores between the experimental and control groups ($t = 10.105$, $df = 58$, Sig. (2-tailed) = $0.00 < 0.05$). The mean difference between the two groups was 23.405, indicating that students in the experimental group achieved significantly higher posttest CPS scores than those in the control group. These findings indicate that the implementation of the PjBL-STEM model integrated with the Engineering Design Process (EDP) strategy and Deep Learning principles was more effective in improving students' Creative Problem-Solving skills than direct instruction based on the scientific approach.

Table 5. Paired Sample T-Test

	Sig. (2-tailed)
Pretest Eksperimen Posttest Eksperimen	0.00
Pretest Kontrol Posttest Kontrol	0.00

The results of the Paired Sample T-Test presented in Table 5 show that the Sig. (2-tailed) value is $0.00 < 0.05$. These results indicate that there is a significant difference in the improvement of CPS skills before and after instruction using the PjBL-STEM model integrated with EDP and Deep Learning principles in the experimental class. A significant difference in the improvement of CPS skills was also found in the control class before and after instruction using the Direct Instruction model with a Scientific approach.

Table 6. ANCOVA Test Results

Source	*df*	*Mean Square*	F	*Sig.*	*Partial Eta Squared*
Correct Model	2	4488.339	65.501	0.00	0.697
Intercept	1	4466.178	65.177	0.00	0.533

The ANCOVA results presented in Table 6 revealed a significant effect of the PjBL-STEM model integrated with the Engineering Design Process (EDP) strategy and Deep Learning principles on students' Creative Problem-Solving (CPS) skills ($F = 65.501$, $Sig. < 0.05$). The Partial Eta Squared value of 0.697 indicates a large effect size, demonstrating that the implementation of the learning model had a substantial impact on improving students' CPS skills.

Discussion

Students' Creative Problem-Solving skills were assessed using a test consisting of two items, administered before and after the learning process. The improvement in CPS skills for each indicator, based on pretest and posttest scores, is shown in Figure 1.

Based on Figure 1, there is a clear difference between the pretest and posttest scores on all Creative Problem-Solving indicators, in both the experimental and control classes. Visually, the graph shows that the posttest scores on each indicator are higher than the pretest scores, which indicates an improvement in the students'

Creative Problem-Solving skills. The increase in performance was evident across each of the six indicators, including Fact Finding, Fact Interpreting, Idea Finding, Idea Developing, Solution Generating, and Solution Evaluating (Treffinger & Isaksen, 2005).

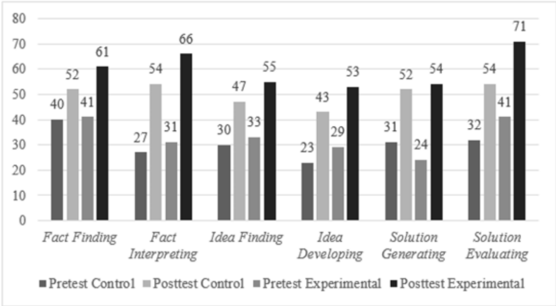

Figure 1. Pretest and Posttest Scores of CPS Indicators.

The experimental class, which was treated with the implementation of an integrated PjBL-STEM model incorporating EDP strategies and the principles of Deep Learning, showed a greater improvement compared to the control class, which was treated with the implementation of a Direct Instruction learning model using a scientific approach.

In the experimental class, the indicator showing the greatest improvement was Fact Interpreting. This indicates that students were able to interpret facts, analyze information, and connect the concept of Bernoulli's Principle with the phenomena observed during the learning process. The improvement in this indicator is believed to be influenced by the students' high level of motivation and active engagement throughout the project-based learning process. Students were seen to be active in discussions, expressing opinions, and exchanging ideas and information with their group members, thereby fostering the emergence of various ideas to solve the given problems. The results are in line with Wahyuni's (2023) findings, which indicate that project-based learning contributes to the development of students' critical thinking, creativity, and problem-solving abilities by engaging them actively in experimental, discussion-based, and experiential learning processes.

These findings indicate that students' Creative Problem-Solving skills develop through the interactions and discussions that occur during instruction. This aligns with Vygotsky's social constructivism theory, which emphasizes the importance of social interaction and scaffolding in the learning process (Vygotsky, 1968). In the learning process, the worksheets serve as hard scaffolding that provides step-by-step guidance, making it easier for students to develop ideas, engage in discussions, and find solutions to the problems presented.

The use of worksheets as hard scaffolding reflects the application of the Zone of Proximal Development (ZPD) concept in Vygotsky's constructivist theory because students receive learning support to reach higher levels of cognitive development (Suryadi et al., 2022). This support enables students to develop their ideas from simple to more complex and detailed ones. During learning, students actively identify the facts they discover, compare their observations with the theories they have studied, and discuss the causes of a phenomenon. Thus, student engagement in each stage of learning not only enhances conceptual understanding but also strengthens their fact-interpreting skills in analyzing and explaining facts based on relevant physics concepts.

Ausubel's learning theory is closely related to the learning process being carried out because it emphasizes that learning will be more meaningful if new information is linked to the knowledge that students already possess (Huda and Djono, 2025). In this study, the worksheets helped students connect their prior knowledge with the concept of Bernoulli's Principle through activities such as observing the phenomenon of an insect sprayer, searching for information, designing a project, and conducting experiments. The questions in the worksheets serve as advance organizers that help students build an understanding of the concepts being studied. Thus, students do not merely memorize concepts but connect them to real-world experiences, making learning more meaningful in accordance with Ausubel's theory (Ausubel, 1968; Istiarini et al., 2023).

This approach is reinforced through the implementation of PjBL-STEM learning, which integrates STEM elements into the learning process. Through activities such as identifying problems, gathering information, designing solutions, and testing design outcomes on projects related to real-world issues, students are actively engaged in developing Creative Problem-Solving skills. This finding aligns with the research by Nuzula and Jatmiko (2023), which states that STEM-based learning effectively enhances students' critical thinking and problem-solving skills.

The development of Creative Problem-Solving skills is also supported by the implementation of the Engineering Design Process (EDP) and the principles of Deep Learning. Through the stages of the EDP, students are trained to understand problems, design and test solutions, and make improvements based on evaluation results. Additionally, the application of mindful, meaningful, and joyful learning encourages students to more actively explore ideas and reflect on the solutions they generate. These findings align with the research by Vania Sapphira and Sari (2024) as well as Syafi'i and Darnaningsih (2025), which demonstrates that EDP strategies and Deep Learning principles can enhance students' problem-solving skills and active engagement.

During the reflection stage, students observe the phenomenon of insect sprayers and identify problems related to Bernoulli's Principle. This activity helps students discover initial information relevant to the problem. The EDP strategy applied is identify problem and constraints, where students identify the problem, objectives, and project constraints based on the insect sprayer phenomenon. This activity is supported by the principles of Deep Learning through conscious, meaningful, and enjoyable learning, thereby helping to improve fact-finding skills.

During the research phase, students search for, collect, and interpret information regarding the concept of Bernoulli's Principle through various learning resources and group discussions. These activities help students understand the relationships between concepts and analyze the causes of a phenomenon. In this stage, students collect and analyze information related to Bernoulli's Principle in accordance with the EDP research stages. This process is supported by the principle of Deep Learning, which encourages students to actively seek information and connect it to real-world phenomena, thereby enhancing their fact-interpreting skills.

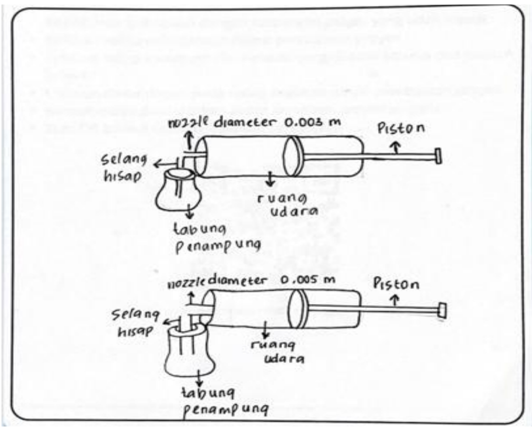

Figure 2. Student Design Schematic of the Insect Sprayer

Figure 2 illustrates the design schematic of an insect sprayer project generated by students during the discovery phase. During this phase, students discussed the best alternative solutions and developed a design based on Bernoulli's principle, specifically exploring the modification of nozzle diameters to manipulate fluid velocity and pressure. This activity trains students to creatively identify and develop ideas. The EDP strategies applied at this stage include ideate and analyze ideas, where students generate, analyze, and select the best alternative solutions for the project. Through conscious, meaningful, and enjoyable learning, students are freer to explore ideas, thereby enhancing their idea-finding and idea-developing skills.

Figure 3. Student Produced Insect Sprayer Prototype.

Figure 3 displays the actual insect sprayer prototype constructed by students during the implementation phase, corresponding to the design variations planned in the earlier phase. During this phase, students turn their paper designs into functional products, conduct tests, and refine their devices based on the experimental results. In this phase, students apply the EDP phases of build, test, and refine by creating, testing, and improving their insect sprayers. This activity is grounded in the principles of Deep Learning, which provides hands-on learning experiences that enhance students' solution-generating skills.

During the communication phase, students present their project outcomes, receive feedback, and reflect on the process they have undergone. This activity helps students assess the strengths and weaknesses of the solutions they have developed and plan for improvements. At this stage, students apply the EDP communicate and reflect phase through presentations, reflection, and evaluation of project outcomes. Supported by the principles of Deep Learning, this activity helps students understand the strengths and weaknesses of the solutions they have developed, thereby enhancing their solution-evaluation skills.

This instrument has been modified to align with the implementation of an integrated PjBL-STEM model that incorporates EDP strategies and Deep Learning principles. These modifications were made to ensure that the instrument can facilitate students' active engagement at every stage of the learning process, from identifying problems and designing solutions to systematically evaluating results. As such, this instrument is expected to support the development of students' Creative Problem-Solving (CPS) skills.

CONCLUSION

The results of the study suggest that applying the PjBL-STEM model integrated with the Engineering Design Process strategy and Deep Learning principles, is effective in improving the Creative Problem-Solving skills of high school students regarding Bernoulli's Principle. This is evident from the average N-Gain scores: 0.67 for the experimental class taught using the PjBL-STEM model integrated with the EDP strategy and Deep Learning principles, and 0.28 for the control class taught using the conventional learning model.

Based on the Independent Samples T-Test analysis, the hypothesis test produced a Sig. (2-tailed) value of < 0.05, indicating that there is a significant difference in the improvement of CPS skills between students taught using the PjBL-STEM model integrated with EDP strategies and Deep Learning principles and those taught using the conventional learning model. Additionally, the results of the Paired Sample T-Test for the experimental class yielded a Sig. value (2-tailed) < 0.05, which indicates that there is a difference in the improvement of students' CPS skills before and after being taught using the PjBL-STEM model integrated with EDP strategies and Deep Learning principles.

This finding is supported by an ANCOVA test showing a significance level (Sig.) of < 0.05, which indicates that the implementation of the PjBL-STEM model integrated with EDP strategies and Deep Learning principles is effective in improving high school students' CPS skills regarding the concept of Bernoulli's principle, as evidenced through an effect size test with a Partial Eta Squared (η^2) value of 0.697.

The improvement in students' CPS skills is supported by the implementation of project-based learning integrated with STEM, EDP strategies, and Deep Learning principles, which actively engage students in identifying problems, designing solutions, creating prototypes, testing results, and evaluating and reflecting on the learning process in a creative and meaningful manner. These findings suggest that integrating PjBL-STEM with the Engineering Design Process (EDP) and Deep Learning principles provides an effective instructional alternative for improving high school students' Creative Problem-Solving skills in physics learning.

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