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PBL MODEL INTEGRATED STEM-EDP WITH DEEP LEARNING PRINCIPLES TO IMPROVE COMPUTATIONAL THINKING SKILLS

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Abstract :
This research evaluated whether a Problem-Based Learning (PBL) model combining STEM-EDP and Deep Learning principles could strengthen students' computational thinking in sound-wave instruction. A quasi-experimental pretest-posttest control group design was implemented at YP Unila High School, with class XI-6 assigned as the experimental class and XI-9 as the control class. Computational thinking was measured through essay questions. The experimental class achieved an average N-gain of 0.54, compared with 0.37 in the control class. The Independent Sample T-Test produced Sig. (2-tailed) < 0.05, while ANCOVA also yielded Sig. < 0.05 and a partial eta-squared value of 0.362, categorized as a large effect. These results show that integrating PBL, STEM-EDP, and Deep Learning principles effectively improved computational thinking. The contribution of the study lies in demonstrating how the three components can operate simultaneously in sound-wave learning: PBL establishes an authentic problem, STEM-EDP structures the engineering response, and Deep Learning principles maintain meaningful reflection. The design offers physics teachers and curriculum developers a reproducible option for strengthening computational thinking within Merdeka Belajar through engineering tasks connected to local contexts.

Keywords: Computational Thinking, STEM-EDP, PBL, Deep Learning

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INTRODUCTION

Preparing learners for the digital era requires education to cultivate competencies that enable them to respond to technological and informational change. Learning is expected to give students greater responsibility for developing their abilities, while teachers organize guidance, resources, and support so that classroom activities remain purposeful (Widodo & Wardani, 2020). Within this agenda, education commonly emphasizes communication, collaboration, critical thinking, and creativity, collectively referred to as the 4Cs (Lestari & Hindun, 2023).

The increasing influence of digitalization has broadened the 4C framework into 6C by adding computational thinking (CT) and compassion. The expanded framework seeks to combine systematic, technology-oriented reasoning with sensitivity and social responsibility, alongside the four competencies already emphasized in twenty-first-century education (Inganah et al., 2023).

Computational thinking is a central component of the 6C framework. Wing (2006) describes it through several related processes: abstraction selects information that is relevant to a problem, automation uses technology to improve the efficiency of a solution, decomposition separates a complex task into manageable components, and algorithmic thinking arranges logical steps for reaching an appropriate solution.

The growing use of digital technology makes these reasoning processes increasingly relevant to education. CT supports learners in responding to changing demands by encouraging problem solutions that are accurate, efficient, and innovative (Mardhiyah et al., 2021). Its relevance extends beyond computer science. CT can also support the study of natural science, including physics, because it helps learners organize concepts and examine physical problems in a structured way (Atmojo et al., 2024). Nevertheless, Indonesian students continue to record relatively weak outcomes in science, mathematics, and reading, as reflected in PISA 2022 results (OECD, 2022).

Yusmar and Fadilah (2023) associate the low PISA performance with students' limited capacity to work through scientific problems systematically. CT offers a possible response because its indicators guide learners to select essential information through abstraction, employ technology through automation, divide difficult problems through decomposition, and construct sequential solutions through algorithmic thinking. Strengthening these processes can make science problem solving more focused and efficient.

Sound waves provide a suitable setting for cultivating CT because students can relate the topic to phenomena encountered in daily life. These experiences can support observation, pattern recognition, analysis, and the simplification of relevant information (Negoro & Wiyanto, 2025). One instructional option for developing these abilities is Problem-Based Learning (PBL), which begins with an authentic problem and positions students as active problem solvers. During PBL, learners identify important information, divide complex issues into smaller tasks, and organize the steps needed to reach a solution (Asrianti & Rakhmawati, 2024).

Evidence from earlier studies indicates that PBL can strengthen students' thinking performance. Moreno-Palma et al. (2024) found that CT improves when PBL activities explicitly require learners to analyze and resolve problems, with gains reported in algorithmic thinking, critical thinking, and problem-solving measures. However, the effectiveness of PBL may be constrained when learners do not yet have sufficient support for organizing an open-ended problem.

Learner independence is one factor that affects how successfully students manage such tasks. Suherman et al. (2025) reported that learning autonomy contributes to self-confidence and academic achievement. Students with low self-directed learning may remain dependent on teacher assistance and encounter difficulty arranging a solution procedure. PBL therefore needs to be supported by an approach that gives greater structure to systematic reasoning. The integration of Science, Technology, Engineering, and Mathematics (STEM) with the Engineering Design Process (EDP) offers one relevant alternative.

PBL and STEM-EDP can be combined in physics instruction because they address complementary learning needs. PBL supplies the problem context, whereas EDP organizes the development of a response through design and prototype production (Abdurrahman et al., 2023). The sequence provided by STEM-EDP has also been associated with improvements in CT. Students are required to clarify a problem, separate it into simpler elements, and formulate a logical design. These activities exercise abstraction, decomposition, and algorithmic thinking while building habits of systematic problem solving (Rahman, 2022). Ma'ariif (2025) further argues that twenty-first-century instruction should incorporate Deep Learning. Rather than ending with the acquisition of information, this approach directs learners to interpret relationships among ideas and apply their knowledge to authentic situations.

Combining PBL, STEM-EDP, and Deep Learning principles is therefore expected to produce physics instruction that is contextual, learner-oriented, and meaningful. Analysis, exploration, design, and reflection are brought together so that CT can be developed through a coherent problem-solving experience. Although CT has been examined in physics and STEM education, previous work leaves several unresolved issues. Riwayani et al. (2025) confirmed the potential of physics instruction for CT development but observed that many studies relied on one instructional approach. Moreno-Palma et al. (2024) investigated PBL at the university level, whereas Ramli et al. (2024) used STEM-EDP to

develop critical thinking without making CT indicators the main outcome. Maulidia et al. (2025) and Ayida et al. (2025) likewise examined STEM-EDP or PBL separately. The present study brings PBL, STEM-EDP, and Deep Learning principles together in senior high school physics and assesses abstraction, decomposition, algorithmic thinking, and automation in sound-wave learning. It therefore investigates whether this integrated model can improve students' CT skills.

RESEARCH METHOD

Research Design

A quantitative quasi-experimental method was applied using a nonequivalent pretest-posttest control group design. Students in the experimental class learned through PBL integrated with STEM-EDP and Deep Learning principles. The control class received Direct Instruction combined with a scientific approach. Pretests and posttests were administered in both classes to examine changes in computational thinking (CT). The design followed Creswell and Creswell (2022) and is summarized in Table 1.

Table 1. Research design

Class Group	Pre-test	Treatment	Post-test
Experiment	O	X	O
Control	O	-	O

Notes:
O = Pre-test results
O = Post-test results
X = Behavior using the PBL learning model integrated with STEM-EDP and deep learning principles

Research Target/Subject

The research population comprised students at YP Unila High School. Class XI.6 served as the experimental group, and Class XI.9 served as the control group. These classes were selected purposively according to the study requirements. Because Physics was offered only in several grade XI classes, XI.6 and XI.9 were chosen from the classes that met the required subject and instructional criteria.

Research Procedure

The study was organized into preparation, implementation, and completion phases. During preparation, permission was obtained from YP Unila High School, physics teachers were interviewed to identify learning problems, the sample classes were selected, relevant literature was reviewed, and the teaching materials and research instruments were prepared.

During implementation, each group received the treatment assigned in the research design. The experimental class followed the integrated STEM-EDP PBL activities, whereas the control class learned through Direct Instruction with a scientific approach. The procedures for both classes are outlined in Table 2.

Table 2. Implementation phase in the experimental class and control class

Experimental Class	Control Class
a. Assessing students' initial CT skills by administering a pretest.	a. Assessing students' initial CT skills by administering a pretest.
b. Conducting learning activities using the STEM-EDP-integrated PBL model based on the principles of deep learning.	b. Implementing instruction using the Direct Instruction model with a scientific approach.
c. Administer a posttest to students to assess their CT skills.	c. Administer a posttest to students to assess their CT skills.

At the completion phase, pretest and posttest data were processed for both groups. N-gain values were calculated to describe the increase in CT skills, the statistical results were interpreted, conclusions were formulated, and the research report was prepared.

Instruments, and Data Collection Techniques

The study used learning materials and measurement instruments. The learning materials consisted of teaching modules and Student Worksheets (LKPD). Modules guided the sequence of instruction, while LKPD supported observation, experimentation, discussion, and interpretation of the topic. Computational thinking was measured before and after instruction through eight open-ended items covering decomposition, abstraction, algorithmic thinking, and automation.

Content validity was evaluated by two physics-education experts and one measurement expert. Their judgments produced an Average Validity Index (AVI) of 0.87, exceeding the valid-category criterion of 0.79. Empirical testing was then conducted with 30 students who were not members of the research sample. All eight items produced Pearson product-moment coefficients above the r-table value of 0.361 ($df = 28$, $\alpha = 0.05$). Cronbach's Alpha was 0.83, which is above 0.70 and indicates high reliability. On these grounds, the CT test was considered valid and reliable for da-ta collection.

Data Analysis Technique

Pretest and post-test scores from the experimental and control groups were processed with IBM SPSS Statistics version 27. N-gain was calculated first to describe the improvement in CT after instruction. The assumptions for inferential analysis were subsequently examined through the Shapiro-Wilk normality test, Levene's homogeneity test, a homogeneity-of-regression-slopes test, and a linearity test. An assumption was regarded as satisfied when $p > 0.05$.

After the prerequisite conditions had been met, paired-sample t-tests were used to compare pretest and post-test performance within each class, while an independent-sample t-test compared improvement between classes. The hypothesis rule specified rejection of H_0 and acceptance of H_1 when $p < 0.05$. ANCOVA was also applied to estimate the treatment effect after statistically controlling the pre-test as a covariate, thereby adjusting the post-test comparison for initial differences between groups (Field, 2013). The influence of the integrated PBL, STEM-EDP, and Deep Learning model on CT was then interpreted through effect-size criteria from Cohen et al. (2013), as shown in Table 3.

Table 3. Effect size interpretation

Interpretation	Partial eta-squared value
Large	$0{,}14 \leq \eta^2 p$
Medium	$0{,}06 \leq \eta^2 p < 0{,}14$
Small	$0{,}01 \leq \eta^2 p < 0{,}06$

Because the two groups did not begin with identical pretest scores, normalized gain (N-gain) was used to express improvement relative to each student's initial opportunity for gain. The resulting values were categorized according to Suyatna (2017).

Test criteria

a. If the significance value or probability value is <0.05 ($p < 0.05$), then H_0 is rejected.
b. If the significance value or probability value is > 0.05 ($p > 0.05$), then H_0 fails to be rejected.

RESULTS AND DISCUSSION

The analysis examined whether PBL integrated with STEM-EDP and Deep Learning principles improved computational thinking in sound-wave learning. The integrated model was implemented in the experimental group, whereas the control group received Direct Instruction through a scientific approach. Students' CT performance was measured with essay items representing the indicators proposed by Wing (2006).

Post-test performance was higher in the experimental class, with a mean of 77.33, than in the control class, whose mean was 47.89. This pattern corresponds with Maulidia et al. (2025), who also reported stronger CT performance in an experimental group. In the present study, students in the experimental class designed, tested, and evaluated a product, giving them repeated opportunities to exercise CT. Figure 1 presents the N-gain comparison after treatment.

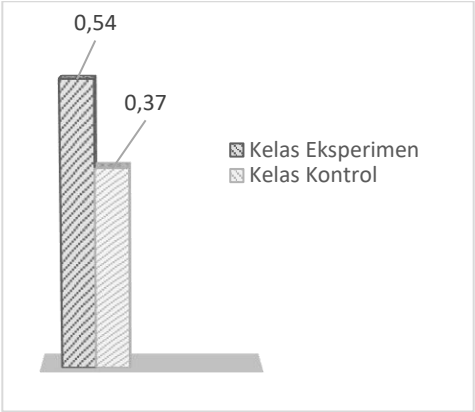

Figure 1. Graph of N-Gain

Figure 1 indicates an average N-gain of 0.54 for the experimental group and 0.37 for the control group; both values are classified as moderate. Although they fall in the same category, the gain obtained through integrated STEM-EDP PBL with Deep Learning principles was larger than that produced by Direct Instruction with a scientific approach. Riwayani et al. (2025) similarly reported that combining STEM learning with physics problem solving can support CT development.

The normality results produced significance values above 0.05 for every pretest and post-test dataset, so the score distributions were treated as normal. Levene's test yielded 0.513, also above 0.05, indicating equal variances between the groups. Tables 4 and 5 provide the complete normality and homogeneity statistics.

Table 4. Normality results

Test Type_Class	Kolmogorov-Smirnov			Category
	Statistic	df	Sig.	
Pre-test Control	.100	36	.200	Normal
Pos-test Control	.130	36	.132	Normal
Pre-test Experiment	.125	36	.166	Normal
Pos-test Experiment	.139	36	.078	Normal

Table 5. Homogenity results

	Lavene Statistics	df1	df2	Sig.
Based on Mean	.432	1	70	.513
Based on Median	.389	1	70	.535
Based on Median and with Adjusted df	.389	1	68.401	.535
Based on Trimmed Mean	.553	1	70	.460

Before ANCOVA was interpreted, the equality of regression slopes was examined to determine whether the association between pretest and posttest scores was comparable across groups. The relevant result appears in Table 6.

Table 6. Results homogeneity of regression test

Source of Variation	F	Sig.
Class*Pre-test	3.447	.068

Table 6 reports a significance value of 0.068, which is greater than 0.05. The interaction between class and pretest was therefore not significant, and the homogeneity-of-regression-slopes requirement was considered fulfilled. A linearity test was then conducted to assess whether pretest and posttest scores had a linear relationship; its results are displayed in Table 7.

Table 7. Linearity test results

	Mean Square	F	Sig.
(Combined)	173.968	1.379	.198
Linearity	1700.071	13.474	<.001
Deviation from Linearity	46.792	.371	.969

The linearity analysis reported a significance value of 0.542 (> 0.05). On this basis, the relationship between the pretest covariate and post-test outcome was interpreted as linear, satisfying the linearity assumption.

The independent-sample t-test generated Sig. (2-tailed) < 0.001, below the 0.05 decision threshold. H_0 was consequently rejected and H_1 accepted. Mean CT performance differed significantly between students taught with integrated PBL, STEM-EDP, and Deep Learning principles and those taught through Direct Instruction with a scientific approach. Table 8 contains the test statistics.

Table 8. Results of the independent sample T-test

	N	Mean	Std. Dev	Sig. (2-tailed)
Control Class	36	67.17	10.66	< 0,001
Experiment Class	36	77.33	10.332	< 0,001

For both groups, the paired-sample t-test returned a two-tailed significance value below 0.001. Because each value was lower than 0.05, H_0 was rejected and H_1 accepted. The pre-test post-test difference was therefore significant in the experimental as well as the control class. The detailed values are listed in Table 9.

Table 9. Results of paired sample T-test

	N	Mean	Std. Dev	Sig. (2-tailed)
Pre-test_Experiment	36	50.36	10.123	< 0,001
Post-test_ Experiment		77.33	10.332	
Pre-test_Control	36	47.89	9.146	< 0,001
Post-test_Control		67.17	10.123	

ANCOVA also produced Sig. < 0.001, leading to rejection of H_0 and acceptance of H_1. After initial ability was controlled, the PBL model integrated with STEM-EDP and Deep Learning principles still affected students' CT performance. The partial eta-squared value was 0.362, indicating the magnitude of the model's contribution. This result is consistent with Asrianti and Rakhmawati (2024), who linked PBL to improved systematic analysis and problem solving. Table 10 summarizes the ANCOVA output.

Table 10. ANCOVA test results

Source	Mean Square	Sig.	Partial Eta Squared
Correct Model	1154.837	<0,001	.362
Intercept	6348.290	<0,001	.509

The experimental-group improvement suggests that CT was supported by the way the instructional components were combined. PBL provided the problem framework (Arends, 2012), STEM connected scientific ideas with technology, engineering, and mathematics (Kelley & Knowles, 2016), EDP organized the design cycle (Long et al., 2020), and Deep Learning principles emphasized meaningful, mindful, and joyful engagement (Indonesian Ministry of Primary and Secondary Education, 2025).

Students did not work only with written problems; they used the Gamolan Pekhing as the focus of design and prototyping. The STEM-EDP sequence required them to recognize the problem, formulate a design, construct a prototype, test its performance, and judge the outcome. Ayida et al. (2025) similarly found that participation throughout STEM-EDP stages supports thinking and problem-solving development.

Problem orientation formed the first activity. A phenomenon involving sound frequency was presented, and students identified the issue to be investigated. Discussion, questioning, and the exchange of information were encouraged during this phase (Nasution et al., 2025). By linking the new situation with knowledge already held, students practiced decomposition and abstraction within a meaningful and reflective learning experience. This interpretation accords with Ausubel's (1978) view that new information becomes meaningful when it is connected to concepts in the learner's cognitive structure.

The second activity combined the science and technology elements of STEM with the research-and-imagine phase of EDP. Working collaboratively, students collected information, considered alternative solutions, and planned a Gamolan Pekhing prototype. Peer interaction enabled them to explain ideas, obtain assistance, and clarify concepts. This exploratory and collaborative process reflects Deep Learning principles and is compatible with Vygotsky's (2012) Zone of Proximal Development, in which learning is advanced through social interaction and appropriate support. It also reflects the finding of Putri et al. (2023) that STEM-based PBL can increase structured engagement with a problem.

The third activity covered all STEM domains and the plan-and-create stages of EDP. Students converted the information collected earlier into a prototype design, determined bamboo-slat dimensions, sequenced the construction steps, measured frequency, and examined the results. Arranging these procedures exercised algorithmic thinking. The authentic design task also supported reflective and learner-centered understanding, consistent with Abdurrahman et al. (2023), who connected STEM-EDP product design and testing with systematic thinking. Figure 2 documents the prototype-making activity.

Figure 2. Create a prototype

During the fourth activity, students developed and presented the project through the test-and-evaluate stage of EDP while applying science, technology, engineering, and mathematics. They presented their prototypes and measured frequency with the Phyphox application. Converting a design into a working product represents an important part of development (Febriansari et al., 2022). Students then examined the measurement results and applied the procedures they had learned, thereby exercising automation. Testing and evaluation also required active data interpretation and reflection, in keeping with Deep Learning principles.

The fifth activity focused on reviewing the solution and improving the prototype. Students considered the full STEM relationship, examined differences in measured frequency, identified their possible causes, and decided what changes were required. Relating the test evidence back to sound-wave concepts engaged abstraction and algorithmic thinking. The evaluation and revision process also supported deeper reflection on learning outcomes, consistent with Musfiroh et al. (2024), who associated reflective evaluation with analytical and problem-solving development.

Taken together, the learning activities show how contextual problem solving within integrated PBL, STEM-EDP, and Deep Learning principles can cultivate CT. The model linked conceptual understanding with the reasoning and problem-solving abilities expected in twenty-first-century learning (Ramli et al., 2024; Riwayani et al., 2025). Designing, constructing, testing, and revising the Gamolan Pekhing allowed students to apply sound-wave concepts to a recognizable real-world product. Meaningful, mindful, and joyful learning principles encouraged active involvement and helped learners relate new ideas to their previous experiences (Handayani, 2025). Related evidence also suggests that the combination of problem-based learning and CT activities can strengthen higher-order thinking, problem solving, and participation in learning (Chen et al., 2026).

The larger experimental effect can be understood from the distinct function of each component rather than simply from the number of approaches combined. PBL introduced an authentic problem, but an open-ended task can burden novice learners when procedural guidance is limited (Hmelo-Silver, 2004; Sweller, 1988). EDP reduced that difficulty by arranging the work into research and imagine, plan and create, test and evaluate, and improve. This sequence made decomposition and algorithmic thinking explicit as students moved from an initial problem toward a tested product. Deep Learning principles kept the activity conceptually focused by requiring students to connect each design decision and test result to sound-wave knowledge instead of treating prototyping as a separate technical exercise. The interaction of an authentic PBL context, procedural structure from STEM-EDP, and sustained conceptual reflection provides a plausible explanation for the large partial eta-squared value of 0.362. It also helps explain why gains were stronger for automation and algorithmic thinking, which rely directly on structured procedures, than for abstraction, which is more dependent on prior conceptual understanding.

Theoretical and Practical Implications

At the theoretical level, the results show that PBL, STEM-EDP, and Deep Learning principles can operate as one instructional framework for CT development in physics. The four indicators proposed by Wing (2006) were treated as assessable learning outcomes, while collaborative prototype construction illustrates how social support can scaffold higher-order reasoning in accordance with Vygotsky's (2012) perspective. The findings further indicate that meaningful, mindful, and joyful learning can be combined conceptually with inquiry-oriented and problem-based STEM instruction.

For classroom practice, the study provides a sequence that senior high school physics teachers can implement directly. Using the locally available Gamolan Pekhing as an engineering challenge demonstrates that CT can be embedded in culturally relevant project work. Schools and curriculum developers may adapt the same integrated structure to other physics topics while supporting competencies emphasized in the 2013 Curriculum and Merdeka Belajar framework.

Research Limitations and Future Directions

Several boundaries should be considered when interpreting the findings. The sample came from one school and included only two purposively selected classes, with 36 students in each group; consequently, the results cannot automatically be generalized to wider populations. The intervention was limited to sound waves, so its effect on other physics topics remains uncertain. Full random assignment was not possible under the quasi-experimental design, leaving a potential risk of selection bias. CT was measured only through written essay items, without observational or process-based triangulation. Further studies should involve larger samples from several schools, examine topics such as optics, thermodynamics, or modern physics, combine quantitative results with qualitative evidence of learning processes, and investigate whether the CT gains are retained over time.

CONCLUSION

The findings support the effectiveness of PBL integrated with STEM-EDP and Deep Learning principles for improving CT in sound-wave instruction. The experimental group obtained an average N-gain of 0.54, while the control group obtained 0.37; both were in the moderate category, but the experimental value was higher. The Independent Sample t-Test produced Sig. (2-tailed) = 0.000 < 0.05, demonstrating a significant difference between the integrated-model group and the group receiving Direct Instruction with a scientific approach. Within the experimental class, the Paired

Sample t-Test also yielded Sig. (2-tailed) < 0.001 < 0.05, indicating a significant pre-test post-test increase. ANCOVA confirmed the treatment effect with $p < 0.001$ after initial ability was controlled. The partial eta-squared value of 0.362 placed the magnitude of the effect in the large category. Thus, the integrated model was effective in strengthening students' CT skills on the topic of sound waves.

The results lead to several practical directions. Physics teachers may use the integrated model for sound waves and other contextual topics, particularly through engineering challenges based on local materials or cultural products. School leaders and curriculum planners can incorporate the sequence into instructional programs aimed at strengthening twenty-first-century competencies within Merdeka Belajar. Future investigations should test the model in optics, thermodynamics, electromagnetism, and other physics content; involve larger and more diverse samples; and examine whether improvements in CT and academic performance persist over longer periods.

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