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# Enhancing elementary students' computational thinking through problem-based learning in science education

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**Abstract:** The rapid advancement of digital technology has shifted educational priorities toward the development of higher-order thinking skills, including computational thinking. However, the integration of computational thinking into elementary science learning remains limited. This study aims to examine the effect of Problem-Based Learning (PBL) on students' computational thinking skills in science education. A quantitative approach with a quasi-experimental nonequivalent control group design was employed. The participants consisted of 40 fifth-grade students divided into an experimental group (n = 20) and a control group (n = 20), selected using a saturated sampling technique. The instrument was a descriptive test developed based on four computational thinking components: decomposition, pattern recognition, abstraction, and algorithms. Data were analyzed using normality and homogeneity tests followed by simple linear regression. The findings indicate that PBL has a statistically significant effect on students' computational thinking skills ($p < 0.05$), with a coefficient of determination ($R^2$) of 0.919. These results suggest that PBL is an effective instructional approach for fostering computational thinking skills in elementary science learning.
**Keywords:** PBL; computational thinking; science learning; elementary school.



## INTRODUCTION

The development of digital technology has shifted the orientation of education from mere content mastery to strengthening higher-order thinking skills. One competency that has received global attention is Computational Thinking (CT). Based on (Wing, 2006) defines computational thinking as the mental process of formulating problems and developing solutions systematically and logically so they can be executed effectively. These skills include decomposition, pattern recognition, abstraction, and algorithm development, all of which represent a systematic framework for problem-solving (Maharani et al., 2024; Misir & Emir, 2023; Paraskevopoulou-Kollia et al., 2025).

Computational thinking is considered a fundamental 21st-century competency, on par with reading, writing, and arithmetic (Shute et al., 2017; Wing, 2006). International institutions such as the OECD and UNESCO emphasize the importance of strengthening problem-solving and computational reasoning skills in response to global digital transformation. Even within the Program for International Student Assessment (PISA) assessment framework, reasoning and problem-solving skills are key indicators of student readiness to face 21st-century challenges. The 2022 PISA (OECD, 2023) results show that Indonesian students' scientific literacy achievement remains below the OECD average, indicating the need to strengthen analytical and systematic thinking skills from elementary school onward.

Computational thinking is not limited to the fields of informatics or programming. In educational contexts, several scholars conceptualize computational thinking not only as a technical skill but also as an approach for understanding and solving problems systematically (Farris & McLaughlin, 2024). Its four components, decomposition, pattern recognition, abstraction, and algorithms, are universal cognitive processes that can be applied across various disciplines, including science (Ogegbo & Ramnarain, 2022). In science learning, when students analyze natural phenomena, identify cause-and-effect relationships, filter important information, and construct coherent explanations, they are activating computational thinking processes (Afana et al., 2023; Bossér, 2024; Jupriyanto et al., 2025; Pearce et al., 2021). Thus, the integration of CT into science learning does not simply add new content (Aytekin & Topçu, 2026; Hsu et al., 2018; Poulakis et al., 2026; Zhao et al., 2026) but rather strengthens the cognitive dimensions inherent in science.

However, science learning practices in elementary schools are still dominated by conventional approaches focused on concept delivery and memorization (Dinh & Nakatsubo, 2025; Leftwich et al., 2026; Starke et al., 2021). Teacher-centered learning patterns limit students' opportunities to develop systematic and analytical thinking skills. Furthermore, most previous research examines CT integration in the context of science or technology-based learning (Maharani et al., 2024; Saputra et al., 2023), while empirical studies that explicitly map CT integration in elementary school science remain relatively limited.

One approach that has the potential to integrate computational thinking skills is Problem-Based Learning (PBL), as analyzed by (Cateté et al., 2018; Fakhriyah et al., 2019; Galamba & Matthews, 2021). PBL places authentic problems as the starting point of learning and encourages students to identify problems, conduct investigations, analyze information, and collaboratively construct and evaluate solutions (Misir & Emir, 2023). Conceptually, the stages of PBL align with the components of computational thinking: problem orientation facilitates decomposition, the inquiry process supports pattern recognition, information analysis encourages abstraction, and solution construction represents algorithmic thinking (Shute et al., 2017). Furthermore, reflection in PBL strengthens the metacognitive aspects essential to developing computational thinking.

Previous studies by Cateté et al. (2018); and Killen et al. (2023) discussed CT integration in middle-school science, but did not specifically examine PBL in elementary science classrooms. Although theoretically there is alignment between PBL syntax and CT components, empirical evidence that explicitly examines how PBL operationalizes computational thinking skills in elementary school science learning is still limited (Cateté et al., 2018; Misir & Emir, 2023). The novelty of this study lies in its empirical approach, which not only examines the impact of Problem-Based Learning (PBL) on students’ computational thinking skills but also explores how PBL's stages facilitate the application of computational thinking components in elementary science learning. Accordingly, this study aims to investigate the effect of implementing Problem-Based Learning on elementary school students’ computational thinking skills in science education.

## METHODS

This research employed a quantitative approach with a quasi-experimental non-equivalent control group design (Creswell, 2018). Two groups participated in the study, namely an experimental group exposed to Problem-Based Learning (PBL) and a control group receiving conventional instruction. Pre-tests and post-tests were administered to both groups to assess changes in students' computational thinking skills.

**Table 1.** Research Design

| Group | Sample (n) | Pre-test | Treatment | Post-test |
|---|---|---|---|---|
| Experimental Group | 20 | $O_1$ | Problem-Based Learning (PBL) integrated with computational thinking | $O_2$ |
| Control Group | 20 | $O_3$ | Conventional (lecture-based) learning | $O_4$ |

The participants of this study were fifth-grade students at an elementary school. A total of 40 students were involved, comprising 20 in the experimental group and 20 in the control group. The study used a saturated sampling technique, meaning all members of the population were included in the sample. The research was conducted at a public elementary school in Semarang, Indonesia, during the early phase of the second semester of the 2025/2026 academic year.

The instrument employed in this study was a descriptive test comprising 10 items, developed from four key components of computational thinking: decomposition, pattern recognition, abstraction, and algorithms. Each item was designed to assess students' ability to apply these components to solve contextual science problems systematically and logically.

The instrument underwent content validation through expert judgment involving two specialists in science education. Validity was determined by the alignment of each item with the specified indicators. Furthermore, a pilot test was conducted, and the instrument's reliability was analyzed using Cronbach's Alpha, yielding a coefficient of 0.82, indicating a high level of internal consistency.

Data were obtained through a pretest administered before the intervention and a posttest administered after the science learning activities on natural phenomena. Before hypothesis testing, the data were examined using prerequisite analyses, including the Shapiro–Wilk test for normality and Levene's test for homogeneity, to ensure that the assumptions for parametric analysis were satisfied. Once these assumptions were met, hypothesis testing was conducted using simple linear regression at the 0.05 significance level.

## RESULTS AND DISCUSSION

### Result

This section outlines the results of the data analysis examining the effect of implementing the Problem-Based Learning model on students' computational thinking skills in science learning. The analysis was carried out in several stages, including descriptive statistics to illustrate students' initial and final performance, prerequisite tests such as normality and homogeneity testing, and hypothesis testing using simple linear regression.

#### Descriptive Statistics of Computational Thinking Ability

Descriptive statistics were employed to describe students' computational thinking skills before and after the instructional treatment. The measurements were obtained through pretests and posttests administered to the experimental group, which received Problem-Based Learning (PBL), and the control group, which followed conventional instruction. The results of the descriptive statistical analysis are presented in Table 1.

**Table 2.** Descriptive Statistics of Students' Computational Thinking Ability

| Groups | N | Mean Pretest | Mean Posttest | Std. Deviasi Posttest |
|---|---|---|---|---|
| Experiment (PBL) | 20 | 60,42 | 65,63 | 14,78 |
| Control | 20 | 46,80 | 48,85 | 15,47 |

As shown in Table 1, the mean pretest score of students' computational thinking skills in the experimental group was 60.42, whereas the control group recorded a lower average of 46.80. Following the intervention, the experimental group's mean posttest score increased to 65.63, while the control group showed only a slight improvement to 48.85. The greater increase observed in the experimental group suggests that students exposed to the Problem-Based Learning (PBL) model demonstrated more substantial gains in computational thinking skills than those who received conventional instruction. These results indicate that PBL provides broader opportunities for students to develop analytical and systematic problem-solving abilities.

## Prerequisite Analysis Test Results

Before conducting hypothesis testing, the data were examined for normality and homogeneity to verify that they satisfied the assumptions required for parametric analysis. The results of these prerequisite tests are presented in Table 2.

**Table 3.** Prerequisite Analysis Test Results

| Statistical Analysis | Sig. Value | Decision |
|---|---|---|
| Normalitas (Experimen) | 0,784 | Normal |
| Normalitas (Control) | 0,384 | Normal |
| Homogenitas (Levene Test) | 0,779 | Homogeneous variance |

As shown in Table 2, the normality test results indicate significance values of 0.784 for the experimental group and 0.384 for the control group, both exceeding 0.05, indicating that the data are normally distributed. In addition, the homogeneity test yielded a p-value of 0.779 (> 0.05), indicating that the variances of the two groups are homogeneous. Since both the normality and homogeneity assumptions have been satisfied, the data are appropriate for further analysis using parametric statistical methods.

## Hypothesis Test Results

Hypothesis testing was carried out to examine the effect of implementing the Problem-Based Learning model on students' computational thinking skills in science learning. The analysis was performed using simple linear regression with a significance level of 0.05. The results of the regression analysis are presented in Tables 3, 4, and 5.

**Table 4.** Effect of Problem-Based Learning on Computational Thinking Skills

| Variable | B | Std. Error | Beta | t | Sig. | Interpretation |
|---|---|---|---|---|---|---|
| Constant | -14.423 | 5.520 | – | -2.613 | 0.018 | Constant value of the regression model |
| Problem-Based Learning (PBL) | 1.140 | 0.082 | 0.959 | 13.882 | 0.000 | PBL has a significant positive effect on computational thinking skills |

**Table 5.** Summary of Regression Model

| R | $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | Interpretation |
|---|---|---|---|---|
| 0.959 | 0.919 | 0.914 | 5.154 | The regression model shows a very strong relationship. PBL explains 91.9% of the variance in students' computational thinking skills. |

**Table 6.** Regression Model Feasibility Test

| Source of Variance | Sum of Squares | df | Mean Square | F | Sig. | Interpretation |
|---|---|---|---|---|---|---|
| Regression | 5119.028 | 1 | 5119.028 | 192.699 | 0.000 | The regression model is statistically significant and feasible to use |
| Residual | 451.604 | 17 | 26.565 | – | – | Residual variance not explained by the model. |

## Analysis of Computational Thinking Understanding

A more in-depth analysis was conducted on four indicators of computational thinking. The results are presented in Table 6.

**Table 7.** Analysis Of CT Understanding

| Indicators | Pretest (%) | Posttest (%) | Change |
|---|---|---|---|
| Decomposition | 68 | 65 | -3 |
| Pattern Recognition | 63 | 63 | 0 |
| Abstraction | 52 | 64 | +12 |
| Algorithm | 64 | 71 | +7 |

The abstraction indicator showed the highest increase at 12%. The algorithm indicator increased by 7%. The decomposition indicator decreased by 3%, while pattern recognition remained relatively stable.

## Discussion

The improvement in scores observed in the experimental group suggests that the Problem-Based Learning model positively affects the development of students' computational thinking skills in science learning. The greater increase compared to the control group indicates that the problem-based approach is more effective than conventional teacher-centered instruction.

Although the experimental group showed a higher initial average score than the control group, this difference does not reduce the validity of the findings, as the regression analysis revealed a strong effect of the treatment on score improvement. The high coefficient of determination ($R^2 = 0.919$) suggests that the effectiveness of Problem-Based Learning is not only statistically significant but also pedagogically meaningful. The structured phases of PBL serve as a cognitive framework that closely corresponds to the fundamental components of computational thinking. In the problem orientation stage, students engage in decomposition by breaking complex phenomena into simpler parts. During the investigation phase, students develop pattern recognition by identifying relationships among variables. The analysis stage supports abstraction by guiding students to focus on relevant information while disregarding less important details. Finally, the process of constructing solutions reflects algorithmic thinking, as students organize logical and systematic steps to address problems. This alignment indicates that PBL serves as an instructional framework that transforms computational thinking from a theoretical concept into a practical, measurable cognitive process in science learning.

The significant increase in the abstraction indicator indicates that students are increasingly able to filter important information from the phenomena being studied. The problem-orientation and group investigation stages encourage students to focus their attention on the main variables causing natural events (Lamanauskas, 2022; Lee et al., 2026; Sungur & Ozkan, 2026). Discussion and presentation activities strengthen the internalization of concepts, enabling students to identify relevant information and ignore distractors. These results align with the view that abstraction is the core of computational thinking.

The algorithm indicator also improved. The ability to sequence the processes of natural disasters sequentially demonstrates the development of systematic thinking. The PBL syntax, which requires students to formulate solutions before presenting them, trains them to develop structured solution steps (Darmawati et al., 2025). Reflection activities at the end of the lesson strengthened the ability to organize ideas in a logical format.

The decomposition indicator decreased by 3%. This indicates that some students still have difficulty breaking down complex problems into smaller parts. PBL presents challenges through relatively complex, authentic problems that require students to adapt and develop their initial analytical skills. This finding suggests the need to reinforce initial activities, such as practicing problem component identification, before conducting in-depth investigations (Angglena et al., 2026).

The relatively stable pattern recognition indicator indicates that students already possessed basic skills in recognizing cause-and-effect relationships before the treatment. PBL maintained these skills but did not significantly improve them. This situation may be influenced by the characteristics of the questions or the level of complexity of the material.

The regression results with a very high R value indicate a strong relationship between the treatment and learning outcomes. This finding reinforces the assumption that a student-centered learning structure contributes to the development of computational thinking. PBL provides a real-world problem context that encourages students to think analytically, work collaboratively, and reflect.

Conventional learning in the control class showed limited improvement. Lecture and question-and-answer methods tended to limit the exploration of ideas and did not provide ample space for students to develop solutions independently. This difference underscores the importance of learning strategies that activate higher-level cognitive processes.

The implications of this research indicate that the explicit integration of computational thinking indicators into PBL syntax effectively improves the quality of science learning (Christensen & Lombardi, 2024; Darling-Hammond et al., 2020; López et al., 2024). The greatest improvements in abstraction and algorithms indicate that problem-based learning has great potential for training systematic thinking and solution-building skills.

The contribution of this research lies in the empirical evidence that PBL not only improves cognitive learning outcomes but also measurably shapes computational thinking structures. The integration of scientific phenomena and computational thinking components provides a pedagogical approach aligned with the demands of 21st-century competencies.

The research findings support the development of science learning that emphasizes analysis, discussion, and reflection as an integral part of the learning process.

Sustainable implementation of PBL has the potential to strengthen the foundation of students' systematic thinking from elementary school onward.

The findings of this study demonstrate that implementing Problem-Based Learning (PBL) significantly impacts students' computational thinking skills in science learning. This is reflected in the higher average posttest scores achieved by the experimental group compared to the control group, as well as the regression analysis results, which indicate a significance value of 0.000 ($p < 0.05$). Furthermore, the coefficient of determination ($R^2 = 0.919$) indicates that PBL contributes substantially to improving students' computational thinking skills. This high $R^2$ value indicates that problem-centered learning activities effectively support the development of students' systematic and analytical cognitive processes.

From a theoretical perspective, the findings of this study are consistent with the principles of Problem-Based Learning, which positions problems as the starting point of the learning process. As noted by (Vogelzang et al., 2020) PBL is designed to foster analytical thinking and problem-solving skills through students' investigative activities. In this approach, students are not merely passive recipients of information; instead, they actively identify problems, collect relevant information, analyze data, and develop appropriate solutions. Such processes promote active and reflective thinking, ultimately supporting the development of higher-order cognitive skills.

The alignment between the stages of Problem-Based Learning and the core components of computational thinking can explain the improvement in students' computational thinking skills (Dong et al., 2025; Shute et al., 2017). Computational thinking, as introduced by Jeannette Wing, consists of four main elements: decomposition, pattern recognition, abstraction, and algorithmic thinking. Within the PBL framework, students are presented with problems that require systematic analysis. They deconstruct complex problems into smaller components, identify relationships among relevant information, eliminate irrelevant details, and develop structured procedures to arrive at solutions. This process directly supports the development of students' computational thinking skills.

Science learning characteristics that emphasize the scientific process also support the development of computational thinking skills (Misir & Emir, 2023). Science learning is not limited to the acquisition of concepts but also emphasizes the development of science process skills, such as observation, classification, data interpretation, and drawing logical conclusions. These activities require students to engage in systematic thinking when analyzing natural phenomena and constructing scientific explanations. Therefore, integrating science learning with a Problem-Based Learning (PBL) approach provides students with greater opportunities to develop analytical, logical, and structured thinking skills, which are fundamental components of computational thinking.

The findings of this study are consistent with previous research indicating that the implementation of Problem-Based Learning can enhance students' higher-order thinking skills, particularly in problem-solving and critical thinking (Firneno et al., 2023; Hashim & Alias, 2020; Winarto et al., 2025). Problem-Based Learning offers a more meaningful learning experience by actively engaging students in investigation and discussion to solve problems. Through this process, students not only gain a deeper understanding of concepts but also develop critical, analytical, and reflective thinking skills, which are key elements of computational thinking. The enhancement of computational thinking skills may also be supported by several components inherent in PBL, such as collaborative learning, authentic problem contexts, instructional scaffolding, and reflective activities (Purwati & Prasetyanti, 2019). Collaborative discussions allow students to share ideas and identify patterns, while authentic problems motivate them to apply abstraction and algorithmic thinking in real-world contexts (O'Toole et al., 2020; Sesigür & Edeer, 2020; Shute et al., 2017)

## CONCLUSION

The findings of this study indicate that implementing Problem-Based Learning (PBL) significantly influences students' computational thinking skills in science learning. This is reflected in the higher average scores achieved by the experimental group compared to the control group, as well as in the regression analysis results, which show a p-value of 0.000 ($p < 0.05$). Furthermore, the coefficient of determination ($R^2 = 0.919$) indicates that PBL contributes substantially to improving students' computational thinking skills.

Although this study shows that implementing Problem-Based Learning has a significant effect on students' computational thinking skills, several limitations should be acknowledged. The research involved a relatively small sample and was conducted in a single elementary school setting, which limits the generalizability of the findings. Therefore, further studies are needed in broader educational contexts.

This study demonstrates that implementing Problem-Based Learning in science education can effectively enhance elementary school students' computational thinking skills. A problem-centered learning approach provides students with opportunities to develop analytical reasoning and systematic problem-solving abilities. Therefore, integrating PBL into science instruction is a valuable pedagogical approach for supporting the development of 21st-century competencies, particularly computational thinking skills.

These findings suggest that Problem-Based Learning can be an effective approach for fostering students' systematic, analytical, and problem-solving skills in elementary science education. Based on these results, implementing PBL is recommended as a teaching strategy to enhance students' computational thinking skills. Teachers are encouraged to design learning activities centered on contextual problem-solving, enabling students to engage in analysis and solution development actively. Additionally, future research is recommended to involve larger samples and more diverse educational settings to obtain a more comprehensive understanding of how innovative instructional approaches support the development of computational thinking skills.

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