JPF | Volume 12 | Number 3 | 2024 | 185 - 195
p - ISSN: 2302-8939
e - ISSN: 2527-4015

Jurnal Pendidikan Fisika
https://journal.unismuh.ac.id/index.php/jpf
DOI: 10.26618/jpf.v12i3.10946

Improving Students' Computational Skills through the Implementation of Problem-Solving Laboratory Learning Models

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Received: May 05, 2023; Accepted: July 20, 2024; Published: August 30, 2024

Abstract – *In the digital era, computational thinking skills are essential for students to succeed in science education, including physics. However, traditional teaching methods often fail to cultivate these skills effectively. This study aimed to evaluate the effectiveness of the problem-solving laboratory learning model in enhancing students' computational thinking skills, specifically in alternating current electricity topics. The research employed a pre-experimental design with a one-group pre-test and post-test approach, involving 35 twelfth-grade students from a public high school in Banjar City, West Java, Indonesia. Data were collected using observation sheets to assess problem-solving laboratory implementation and computational thinking skill tests. The problem-solving laboratory model was implemented effectively, achieving an average implementation success rate of 78.4%. The analysis revealed a significant improvement in students' computational thinking skills, with an average N-gain score of 0.73, categorized as high. Among the computational thinking indicators, abstraction showed the highest improvement, followed by decomposition, data analysis, pattern recognition, and algorithmic thinking. These results suggest that the problem-solving laboratory model provides an effective framework for fostering computational thinking skills through hands-on problem-solving activities and structured learning processes. The study recommends integrating the problem-solving laboratory model into other physics topics and broader educational contexts to enhance students' 21st-century competencies. Future research should consider incorporating control groups and extending the scope to explore long-term impacts across diverse learning environments.*

Keywords: *alternating current; computational thinking; learning model; problem-solving laboratory*

I. INTRODUCTION

The 21st century has been defined by rapid advancements in technology and the proliferation of digital tools, fundamentally transforming the global landscape of education. In this dynamic era, students are expected to acquire not only subject-specific knowledge but also adaptable skills that enable them to navigate technological complexities and real-world challenges effectively (Dishon & Gilead, 2021; Oliveira & de Souza, 2022). Among these essential skills, computational thinking (CT) stands out as a cornerstone for success in science, technology, engineering, and mathematics (STEM) fields. Wing (2006) famously introduced computational thinking as a problem-solving framework characterized by abstraction, pattern recognition, algorithmic thinking, and systematic decomposition. These skills are not confined to computer science but are applicable across various disciplines, making them invaluable for students in an increasingly technology-driven society.

Computational thinking serves as a bridge between theoretical concepts and practical applications, enabling students to approach problems methodically, develop logical solutions, and implement strategies effectively (Barr & Stephenson, 2011). In physics education, for example, computational thinking allows students to simulate physical phenomena, analyze complex data, and develop predictive models, thereby fostering deeper conceptual understanding and scientific reasoning. Despite its significance, however, fostering computational thinking skills remains a persistent challenge in many educational systems.

One major barrier is the limited understanding of computational thinking concepts among students and educators alike. While the term itself has gained recognition, its practical integration into everyday teaching practices is often inconsistent or poorly executed (Barr & Stephenson, 2011). Additionally, traditional teaching methodologies, which often rely on rote memorization and passive learning, fail to provide students with opportunities to engage in the type of active problem-solving required for computational thinking development (Yadav et al., 2011). The lack of well-designed curricula and instructional models further compounds this issue, leaving students inadequately prepared to develop these critical skills.

A preliminary study conducted at a public high school in Banjar City, West Java, highlighted the extent of this problem. In assessments using computational thinking-based questions from the BEBRAS platform (www.bebras.or.id), students demonstrated significant struggles in answering the questions accurately. These findings align with previous research, where similar trends have been observed. Kamil (2021) found that students' computational thinking abilities remained underdeveloped across multiple assessment domains. Likewise, Jamna et al. (2022) reported that 35% of students scored in the low computational thinking category, another 35% fell into the medium category, while only 10% and 5% were categorized as high and very high, respectively. These results suggest a systemic issue in the cultivation of computational thinking skills within traditional teaching environments.

Various efforts have been undertaken to address this challenge, including initiatives such as introducing basic programming courses (Santoso et al., 2020) and incorporating interactive animation media into teaching practices (Satria et al., 2022). While these approaches have shown promise, they often require substantial infrastructure, advanced technological resources, and specialized teacher training, which pose significant barriers to widespread implementation. As a result, there is an increasing demand for more accessible and scalable learning models that can effectively nurture computational thinking skills across diverse educational contexts (Putri et al., 2022).

One such promising approach is the problem-solving laboratory (PSL) learning model. Rooted in problem-based learning principles, the PSL model emphasizes active student engagement in identifying, analyzing, and solving real-world problems through structured, hands-on laboratory activities (Batul et al., 2022). By integrating theoretical knowledge with experimental practice, the PSL model fosters not only computational thinking but also critical thinking, creativity, and collaborative skills. In physics education, where abstract concepts often pose significant learning barriers, the PSL model offers an interactive and inquiry-based approach that aligns well with the principles of computational thinking (Malik et al., 2019).

The PSL model also encourages students to develop higher-order thinking skills by guiding them through distinct problem-solving stages, including problem identification, hypothesis formulation, experimentation, data analysis, and conclusion drawing. These stages provide a clear structure for students to engage with complex problems while cultivating essential computational thinking indicators such as decomposition, abstraction, algorithmic thinking, and pattern recognition. Research has shown that such structured approaches are highly effective in improving students' computational skills and overall academic performance in STEM subjects (Malik et al., 2019).

Despite the potential of the PSL model, empirical evidence on its implementation and impact on computational thinking in physics education remains limited. Most existing studies have focused on general problem-solving skills without delving deeply into computational thinking indicators or measuring their development systematically. Therefore, there is a critical need to evaluate how the PSL model specifically supports computational thinking and whether it can serve as a scalable framework for enhancing these skills in physics classrooms.

This study seeks to address these gaps by evaluating the implementation of the PSL learning model and assessing its impact on improving students' computational thinking abilities, specifically in the context of alternating current electricity topics. The study aims to determine whether the PSL model effectively fosters computational thinking indicators, including decomposition, abstraction, algorithmic thinking, pattern recognition, and data analysis. By doing so, this research aspires to contribute to the growing body of knowledge on effective instructional strategies for computational thinking in physics education while providing actionable insights for educators and curriculum developers.

In summary, as education continues to evolve in response to technological advancements, equipping students with computational thinking skills is no longer optional but essential. The PSL learning model offers a promising pathway for achieving this goal, providing an interactive and problem-oriented framework that aligns well with the demands of modern education. This study aims to shed light on the practical effectiveness of the PSL model in fostering computational thinking and to offer recommendations for its broader application across educational settings.

II. METHODS

This study employed a pre-experimental design with a one-group pretest-posttest approach, as illustrated in Table 1.

Table 1. One group pretest-posttest design

O_1	X	O_2

with:
O_1 = pretest
X = PSL learning model
O_2 = post test

The sample consisted of 35 Grade XII students from a high school in Banjar City, West Java, Indonesia. The research procedure is depicted in Figure 1.

Two key types of data were collected in this study: (1) the implementation of the PSL model learning process, and (2) the improvement in students' computational thinking skills. Data on the implementation of the PSL model were collected using an Authentic Assessment based on the Teaching and Learning Trajectory with Student Activity Sheets (AABTLT with SAS) (Rochman et al., 2017). Improvement in computational thinking skills was measured through a descriptive computational thinking test focused on alternating current electricity. The computational thinking indicators assessed included decomposition, abstraction, pattern recognition, algorithmic thinking, and data collection and analysis (Parlons, 2018).

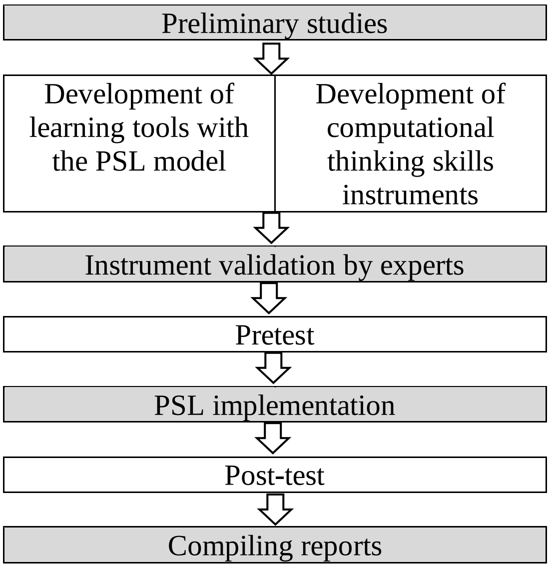

Figure 1. Research procedure

Data on the implementation of AABTLT with SAS, which contains students' responses, are then calculated according to the assessment rubric as follows (Nasrudin et al., 2017).

Table 2. Rubric of AABTLT with SAS

Score	Criteria
0	If the respondent does not provide an answer
1	If the respondent gives a wrong answer
2	If the respondent gives a correct but incomplete answer.
3	If the respondent answers correctly and completely but not as expected.
4	If the respondent's answer is correct, complete, and as expected.

Assessed SAS sheets were accumulated for each stage of learning. The assessment results were converted into percentages using Equation 1.

$$\% = \frac{\textit{The score obtained}}{\textit{Maximum score}} \times 100\% \qquad 1)$$

(Nasrudin et al., 2017)

The calculated percentages were interpreted using the learning effectiveness criteria shown in Table 3 (Nasrudin et al., 2017).

Table 3. The interpretation of AABTLT with SAS

Percentage (%)	Interpretation
<55	Not effective
55 - 70	Less effective
71 – 85	Effective
>85	Very effective

Improvements in computational thinking skills were measured using the average normalized gain value (<g>) calculated using Equation 2.

$$< g > = \frac{\% < G >}{\% < G >_{max}}$$

$$= \frac{\% < S_f > - \% < S_i >}{(100 - \% < S_i >)} \qquad (2)$$

(Hake, 1998)

Here S_f and S_i represent the final (post-test) and initial (pre-test) class averages, respectively. The calculated $<g>$ alues were categorized based on the criteria proposed by Hake, (1998) as detailed in Table 4.

Table 4. Criteria for average normalized gain

<g>	Criteria
(<g>) > 0.7	High
0.7 > (<g>) > 0.3	Medium
(<g>) < 0.3	Low

III. RESULTS AND DISCUSSION

This study addressed two key research questions: the effectiveness of implementing the PSL model and its impact on improving students' computational thinking skills. The findings related to the first question are summarized in Table 5, while the results addressing the second question are provided in Tables 6 and 7.

Table 5. The implementation of PSL

Lear.to	The implementation of PSL (%)	Interpretation
1	76.3	Effective
2	78.7	Effective
3	80.1	Effective
Avg.	78.4	Effective

The data in Table 5 represent the processed results of the SAS sheets, assessed using the rubric in Table 2, calculated with Equation (1), and interpreted based on the criteria in Table 3. The findings in Table 5 indicate that the implementation of the PSL learning model was effective, achieving an average success rate of 78.4%.

Several key factors contributed to the effectiveness of the PSL model implementation. First, the PSL model employs a problem-solving approach that actively fosters critical and analytical thinking among students. In the laboratory setting, students are encouraged to participate in hands-on experiments and investigations, which deepen conceptual understanding and build practical skills in knowledge application (Gürses et al., 2007). Second, the 78.4% achievement rate demonstrates that most students met or exceeded the established learning objectives. This finding highlights the PSL model's adaptability to students' learning needs and its effectiveness in supporting their academic progress. Active student engagement in the learning process is likely a crucial factor driving this high success rate (Wilujeng & Suliyanah, 2022).

However, there remains room for further enhancement of the model. For instance, incorporating technology or diversifying learning materials could improve the model's overall effectiveness. Future improvements could include project-based experiments to foster creativity (Sari et al., 2020), enhanced student activity sheets (Rahayu et al., 2018), or Android-based pocketbooks as supplemental guides (Mulhayatiah et al., 2019).

The study involved three lessons employing the PSL model, which is structured into three stages: pre-experimental activities, experimental (core) activities, and post-experimental closing activities (Heller & Heller, 2012). Field observations revealed challenges during the initial implementation of the PSL model, as students were unfamiliar with its structure, particularly the experimental phase.

Students' difficulties in adapting to the PSL model during the experimental phase can be attributed to several factors. First, the PSL model diverges from traditional teaching methods, leading to challenges in understanding its approach and expectations. The PSL model demands active engagement in problem-solving and experimentation, which may represent a novel experience for many students.

Additionally, the complexity of the experimental phase may stem from students' limited practical skills and laboratory experience. This phase often involves laboratory equipment and data collection techniques unfamiliar to the students. Consequently, it requires a strong foundation in scientific principles and technical skills that students might not yet possess.

To address these challenges, educators should offer targeted support, particularly during the initial implementation phases. Support measures could include an introduction to PSL concepts, demonstrations of laboratory equipment usage, and guidance in problem-solving strategies. Constructive feedback and fostering collaboration among students can further create a supportive and effective learning environment (Kadir et al., 2020).

Table 6 presents data on the improvement in students' computational thinking skills after employing the PSL model. These results, processed using Equation (2), are confirmed against the criteria outlined in Table 4.

Table 6. Improvement of students' computational thinking skills

Average Pre-test	Average Post-test	Average N-gain
40.00	82.97	0.73

As shown in Table 6, the improvement in students' computational thinking skills falls within the high category. Computational thinking encompasses logical reasoning, problem-solving, and the systematic resolution of complex problems. The PSL model creates a learning environment that actively engages students in solving real-world problems through hands-on experimentation.

By employing the PSL model, students transition from passive recipients of information to active participants, encouraged to think critically and systematically during problem-solving activities. This approach requires students to decompose problems, analyze them, and apply diverse methodologies to derive solutions (Asdar et al., 2020). This method aligns seamlessly with the foundational principles of computational thinking.

The implementation of the PSL model enables educators to establish a more interactive and practical learning environment. This approach not only enhances student engagement but also develops critical skills essential for success in today's technology-driven society. The results in Table 6 underscore the PSL model's effectiveness in cultivating these invaluable computational thinking skills among students. These findings reinforce previous studies highlighting the benefits and advantages of the PSL model. The PSL model has been shown to enhance student creativity (Azizah & Edie, 2014), problem-solving skills (Leite & Dourado, 2013), scientific literacy (Muhajir et al., 2015), and metacognitive skills (Mariati, 2012).

Table 7 presents the average pre-test, post-test, and N-gain results for each Computational Thinking Skills (CTS) indicator.

Table 7. Improvement of each CTS indicator

CTS Indicator	Average		
	Pre-Test	Post-Test	N-gain
Decomposition	48.20	86.50	0.74
Abstraction	42.50	87.90	0.79
Pattern Recognition	34.30	79.20	0.68
Algorithmic Thinking	36.90	80.10	0.68
Data Analysis	38.10	81.10	0.70

The data in Table 7 reveal considerable variation among the computational thinking skill components. Abstraction emerges as the strongest skill, while pattern recognition and algorithmic thinking exhibit lower levels of improvement. Abstraction involves simplifying complex problems into more manageable forms, which aids understanding and problem-solving. This result is encouraging, as abstraction is a fundamental skill in computational processes (Kramer, 2007). Conversely, pattern recognition entails identifying and understanding recurring patterns in data or problems, while algorithmic thinking involves devising systematic steps to address these problems.

The strong performance in abstraction suggests that students can grasp higher-level concepts, though they may struggle with applying systematic processes and identifying patterns in information. This indicates a need to emphasize the development of pattern recognition and algorithmic thinking within the curriculum and instructional methods. Reworking thinking skills, considered a novel domain in science education, could be effectively embedded through accessible learning tools, such as instructional videos (Irwansyah et al., 2019; Suhendi et al., 2023).

These findings have broad implications for physics education. The study demonstrates that the PSL model is an effective tool for enhancing computational thinking skills. Considering the growing significance of computational thinking in the digital era, the PSL model offers a valuable approach to equipping students with essential 21st-century skills. Physics teachers are encouraged to adopt the PSL model, particularly for topics like alternating current and potentially other subjects, to foster students' computational thinking skills effectively.

IV. CONCLUSION AND SUGGESTION

This study demonstrates that the implementation of the PSL model effectively enhances students' computational thinking skills in the context of alternating current electricity. The PSL model achieved an average implementation rate of 78.4%, which is categorized as effective. The N-gain analysis shows a significant improvement in computational thinking skills, with a score of 0.73, categorized as high.

However, this study has certain limitations, particularly its use of a pre-experimental design without a control group. Future research should address these limitations by incorporating a control group and broadening the study's scope to provide a more comprehensive evaluation of the PSL model's effectiveness in improving students' computational thinking skills. Additionally, further studies are encouraged to investigate the PSL model's applicability to other physics topics and academic disciplines.

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