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Computational thinking in PjBL -STEM learning through arduino based-automated greenhouse project

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ABSTRACT

Computational thinking is one of the essential competencies required in the Society 5.0 era, particularly in STEM education. This study aimed to investigate the effectiveness of Project-Based Learning integrated with Science, Technology, Engineering, and Mathematics (PjBL-STEM), through an Arduino-based Automated Greenhouse project, in improving students' computational thinking skills in biology. The study employed a pre-experimental method with a one-group pretest-posttest design involving 27 students. Data were collected using a computational thinking test comprising 10 items that assessed indicators of abstraction, decomposition, pattern recognition, and algorithmic thinking. The data were analyzed using the Wilcoxon Signed-Rank Test due to non-normal data distribution. The results showed an N-gain score of 0.43, indicating a moderate improvement in computational thinking skills. The highest achievement was observed in the abstraction indicator (76%), while pattern recognition showed the lowest achievement (52%). The Wilcoxon test revealed a significant difference between pretest and posttest scores (Asymp. Sig.=0.001, $p<0.05$), indicating that the implementation of Arduino-based PjBL-STEM significantly improved students' computational thinking skills. These findings suggest that Arduino-based PjBL-STEM learning can serve as an innovative and effective instructional approach for developing computational thinking competencies in biology education.

INTRODUCTION

The challenges facing Indonesia's education sector in the 21st century continue to evolve since the advent of Industry 4.0 and the era of disruption (Fitrianti et al., 2024; Yanti et al., 2024). They are now entering the era of Society 5.0 (Legi et al., 2023). This era requires people who focus on integrating humans and technology, or the digital world, to solve various social problems, such as sustainability issues, global warming, and renewable energy (Bolis et al., 2025; Mondejar et al., 2021; Ogundipe et al., 2022). This era also requires 21st-century skills such as higher-order thinking, teamwork, effective use of technology, problem-solving, communication, and creativity (Baran et al., 2021).

Therefore, the era of Society 5.0 will not suffice if future students can only master basic skills such as reading, writing, and arithmetic. More advanced skills, such as understanding, analyzing, and utilizing information (big data) in the digital world, are required. Furthermore, skills in coding technologies, machine learning, artificial intelligence, biotechnology, and engineering principles need to be mastered (Ajibike, 2025; Legi et al., 2023). Due to the high demand for technological and scientific skills today, education must also equip students with STEM (science, technology, engineering, and mathematics) skills (Baran et al., 2021; Doly, 2024; Tavdgiridze et al., 2024).

STEM has been integrated into learning through various models, such as project-based learning (PBL) (Simamora, 2024), inquiry-based learning (Levin & Tsybulsky, 2017), problem-based learning (PBL) (Parno et al., 2019), and other learning models. However, PjBL is considered one of the most appropriate models for developing STEM skills because it produces products and is practice-oriented in the field (engineering) in STEM (Slough & Milam, 2013).

PjBL-STEM is a learning model that incorporates STEM into its design. The integration between PjBL-STEM can be used as an innovative learning approach. Students in PjBL are required to create projects or make tools, while STEM is a component that connects the disciplines of science, technology, engineering, and mathematics (Allanta & Puspita, 2021). The syntax of the PjBL-STEM learning model is (1) determining basic questions, (2) designing projects, (3) preparing project schedules, (4) monitoring project implementation, (5) testing project results, and (6) evaluating learning experiences (Thomas, 2000). PjBL-STEM through programming-based projects can be done using Arduino.

Arduino is a computing platform designed to facilitate electronics learning and programming for students and beginners. Arduino is a tool for measuring environmental parameters in everyday life, such as temperature and humidity. Arduino has a very simple microcontroller circuit (Michailidis et al., 2025; Tupac-Yupanqui et al., 2022). Arduino projects can be connected to a laptop via USB. One of the most important reasons Arduino is popular is that it uses open-source code that is easily accessible to anyone (Görgülü Arı & Meço, 2021). Arduino is highly relevant as an interactive learning medium across all science subjects (Yanto et al., 2025). Arduino-based learning tools have features that can help students develop motor skills, pedagogical skills, and computational thinking (Yudhistira et al., 2025).

Computational thinking is the ability to solve problems through reasoning using computational concepts, such as abstraction, generalization, pattern recognition, decomposition, and algorithms (Christi & Rajiman, 2023). Computational thinking focuses on the skills students develop through the practice of computer principles such as programming and algorithms. This enables the development of qualities such as abstract thinking, problem-solving, pattern recognition, and logical reasoning in students (Angeli & Giannakos, 2020; Nouri et al., 2019; Wang et al., 2026; Wu et al., 2024). These skills can be enhanced through technology-based learning, such as Arduino (Krishnan, 2021).

Several studies have been conducted on PjBL-STEM learning using Arduino. However, many of these studies are from physics (Kulsum, 2024), electronics (Yasin et al., 2018), and

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robotics (Jamzuri et al., 2024; Yudhistira et al., 2025) classes. For example, they study temperature and heat using a simple thermos with an Arduino temperature sensor (Kulsum, 2024). Research on the development and implementation of arduino-supported STEM activities in biology learning was conducted in Istanbul, Turkey (Görgülü Arı & Meço, 2021). The results showed that Arduino-supported STEM education improves students' abilities to establish cause-and-effect relationships. However, similar research with other variables remains difficult to find and is limited, including for computational thinking skills, specifically in Indonesia. Likewise, the school that was the subject of this research has not yet integrated computational thinking into STEM learning that uses Arduino or focuses on programming and automation. The school used simple projects without coding tools. Students had also never been specifically taught about computational thinking skills in learning. Therefore, this PjBL-STEM research on the development of an Arduino-based automated greenhouse was conducted to improve students' computational thinking skills in biology.

METHODS

Research Design

This study employed a quantitative pre-experimental with a one-group pretest-posttest design. The purpose of this design was to examine the effect of Project-Based Learning integrated with Science, Technology, Engineering, and Mathematics (PjBL-STEM) on students' computational thinking skills. Participants were assessed before and after the implementation of the learning intervention. The pretest was administered to assess students' initial computational thinking abilities, while the posttest was administered after the learning activities to measure changes resulting from the intervention.

Population and Samples

The study population consisted of students enrolled in Biology class at one of Secondary School Lembang. The sample comprised 27 students in 10th grade who participated in implementing PjBL-STEM learning activities. The students' ages range from 16 to 17 years. A total sampling technique was employed, as all students in 10th grade were involved in the study and completed the entire learning process, including the pretest, project implementation, and posttest activities.

Instruments

The primary instrument used in this study was a computational thinking skills test comprising 10 questions. The test was designed to measure students' abilities in key components of computational thinking, including decomposition, pattern recognition, abstraction, and algorithmic thinking (see Table 1). The same instrument was administered as both the pretest and posttest to ensure consistency in measuring students' performance before and after the intervention. The test items were aligned with the learning objectives and project activities related to plant growth and development through the construction of an Arduino-based automated greenhouse system.

Table 1

The indicators of instrument.

Indicator	Number	Score
Algorithmic thinking	1, 5, 8	1
Pattern recognition	2, 4, 7	1
Abstraction	3, 6	1
Decomposition	9, 10	1

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The instrument had undergone a process of expert validation, field testing, and item analysis, so the instrument had been deemed suitable and reliable for measuring computational thinking skills. The initial instrument consisted of 20 items; following item analysis and revision, 10 valid items were obtained, and these 10 items were used as the instrument to assess computational thinking skills. Table 2 presents the results of this analysis.

Table 2
Item analysis of the instrument.

N	Difficulty level	Discriminating power	Validity	Interpretation
3	0,280	0,762	0,601	Accepted
5	0,400	0,831	0,565	Accepted
7	0,280	0,688	0,543	Accepted
8	0,440	0,429	0,282	Accepted with revision
9	0,480	0,581	0,372	Accepted with revision
11	0,720	0,523	0,331	Accepted with revision
12	0,591	0,391	0,242	Accepted with revision
14	0,864	0,772	0,596	Accepted
15	0,455	0,487	0,318	Accepted with revision
16	0,455	0,922	0,602	Accepted
Reliability: 0,654				High

Procedures
The research procedure was conducted in several stages of PjBL syntax (determining basic questions, designing the project, compiling a project schedule, monitoring project implementation, and testing the project results) in four meetings. First, students were given a pretest to assess their initial computational thinking skills. Following the pretest, the PjBL-STEM learning intervention was implemented. During the intervention, students worked collaboratively to design and develop an Arduino-based automated greenhouse project. The project required students to integrate concepts from science, technology, engineering, and mathematics while solving authentic problems related to plant growth monitoring and environmental control. Throughout the project, students engaged in planning, designing, programming, testing, and evaluating the greenhouse system. Upon completion of the project activities, students were administered a posttest using the same computational thinking assessment instrument. The difference between the pretest and posttest scores was then used to determine the impact of the learning intervention. The evaluation of students' learning experiences is also measured through questionnaires regarding their response to the project.

Data Collection and Analysis
Data were collected through the administration of pretests and posttests. The pretest was conducted prior to the implementation of the PjBL-STEM learning activities to establish a baseline of computational thinking skills. The posttest was administered after students completed the Arduino-based automated greenhouse project. The scores obtained from both assessments were recorded and organized for further statistical analysis. These data served as the primary source for evaluating changes in students' computational thinking abilities following participation in the project-based learning activities.

Descriptive and inferential analysis was conducted using the N-gain and Wilcoxon tests. Table 3 shows the normality of the data. The data was not normally distributed so the Wilcoxon test was chosen as the inferential analysis.

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Table 3
Test of normality.

	df	Sig.
Pretest	27	0.51
Posttest	27	0.03

RESULTS AND DISCUSSION

The PjBL-STEM implemented in learning is an Arduino-based greenhouse project that uses a soil moisture sensor to measure soil temperature and humidity. This project was carried out over 4 meetings in 4 weeks. The 4 meetings included pretest-posttest and PjBL syntax 1, 2, 3, 4, and 5, which consisted of determining basic questions, designing the project, compiling a project schedule, monitoring project implementation, and testing the project results. The research data obtained were pretest and posttest scores, as shown in Figure 1.

Figure 1
Pretest-posttest score (0-100) (source: personal data).

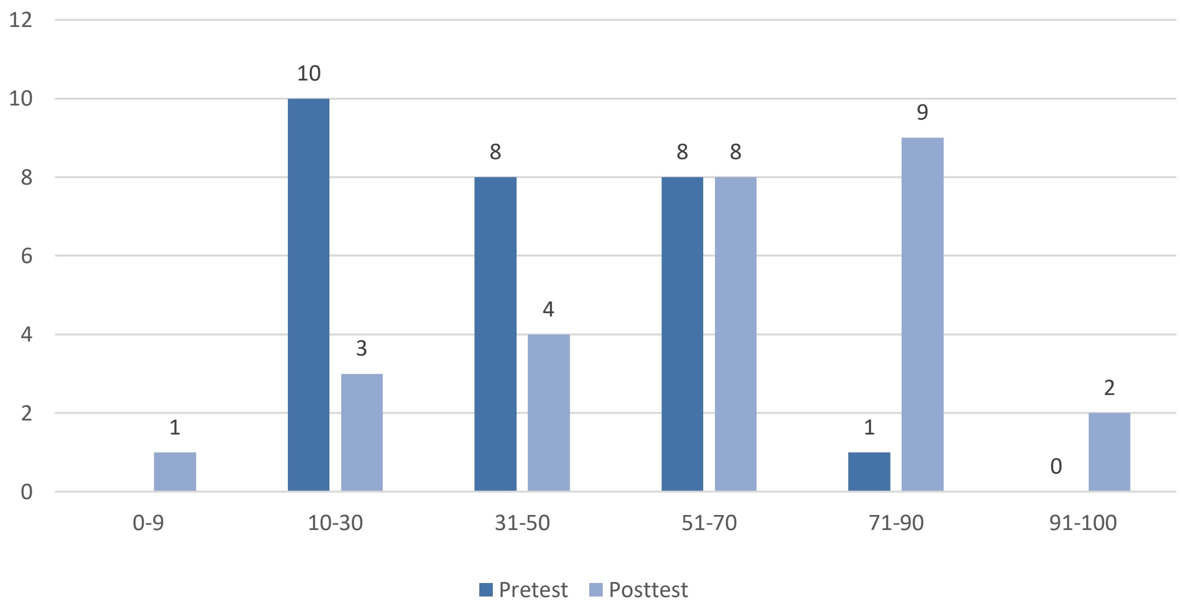

Table 4
N-Gain score

$$\text{N-Gain} = \frac{\sum \text{Posttest score} - \sum \text{Pretest score}}{\sum \text{Maximum possible score} - \sum \text{Pretest score}}$$

N-Gain = (66 – 40) / (100 - 40)
N-Gain = 26 / 60
N-Gain = 0,43 (moderate category)

The N-gain from the pretest-posttest was 0.43 as shown in Table 4, which falls in the moderate category. This shows that this research is quite effective in improving computational thinking skills. In line with Anggraini's research (2025), which found that the application of the PjBL-STEM model among high school students strongly improves students' computational thinking skills, with an N-gain value of 0.36. The effectiveness of PjBL-STEM learning in improving

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computational thinking skills was also observed among elementary school students, with an N-gain value of 0.56 (Rahma, 2026). Computational thinking focuses on skills that students develop through practice with computer principles such as programming and algorithms. This enables the development of qualities such as abstract thinking, problem solving, pattern recognition, and logical reasoning in students (Angeli & Giannakos, 2020). These abilities can be improved through technology-based learning, such as Arduino (Krishnan, 2021).

Computational thinking is a term used to describe a method for solving problems using the principles of computers. Computational thinking focuses on the skills children develop through the practice of computer principles such as programming and algorithms. This enables the development of qualities such as abstract thinking, problem-solving, pattern recognition, and logical reasoning in students (Angeli & Giannakos, 2020). Computational thinking can also be defined as the ability to solve problems by applying concepts from computing. For example, abstraction, pattern recognition, decomposition, and algorithms are indicators of computational thinking (Christi & Rajiman, 2023; Rosali & Suryadi, 2021).

Through designing projects, preparing project schedules activities (syntax 2 & 3), students can develop algorithmic skills in developing logical steps. Students design the project's implementation steps, determine the project schedule, and assemble the necessary tools and materials. This activity trains algorithmic skills, enabling students to develop logical and systematic steps to complete the project. Through determining basic questions activities (syntax 1), students can develop abstraction skills that focus on important information and ignore unimportant details. Through monitoring project implementation (syntax 4), students can develop decomposition skills, namely breaking large problems into smaller ones. Through student activities, they detail the list of suitability and completeness of the project they are making. Through testing project results activities (syntax 5), students can develop pattern recognition skills in identifying pattern similarities for more efficient results. Through the activity of recording observation data, reading data and drawing conclusions. Student achievement in each indicator is shown in Figure 2.

Figure 2

Percentage of computational thinking indicators (Source: personal data).

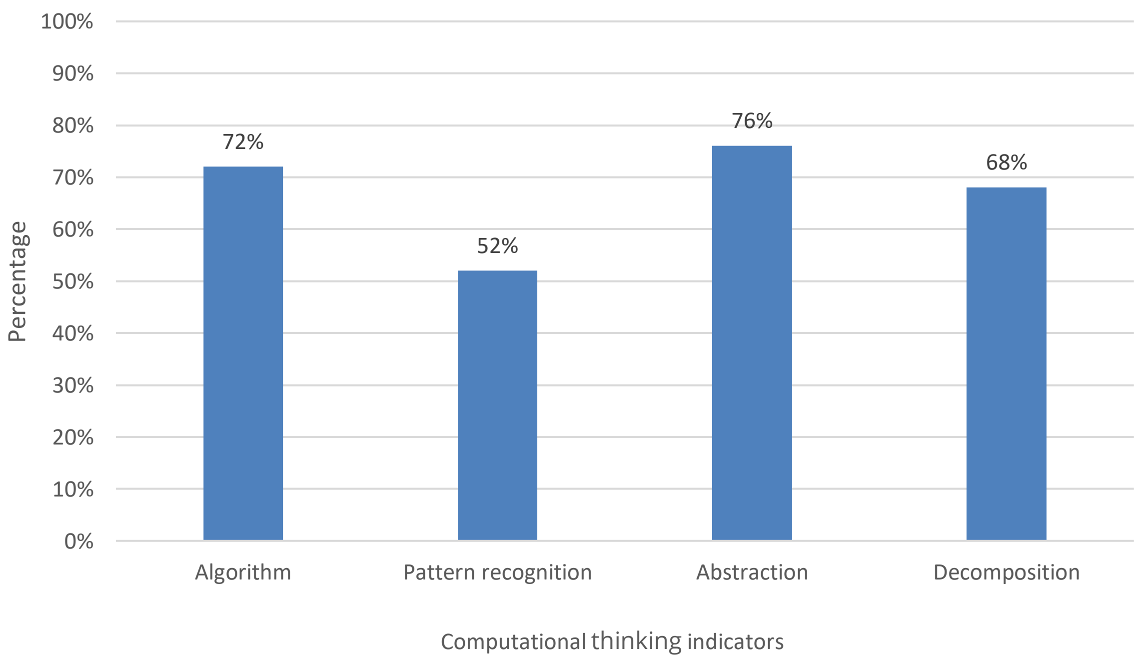

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Figure 2 shows the highest indicator achieved by students is abstraction (76% answered correctly), while the lowest was pattern recognition (52% answered correctly). Abstraction is an indicator of computational thinking that requires simplifying problems by eliminating unimportant details (Mardianto & Yahfizham, 2024). This indicator has a high level of achievement, meaning students can identify the most important information in a problem and ignore irrelevant information. Meanwhile, the computational thinking indicator with the lowest achievement is pattern recognition. Pattern recognition is the process of identifying patterns or similarities between existing problems (Barrón-Estrada et al., 2021). Students are not yet accustomed to reading complex data with more than one variable. For example, students are accustomed to measuring one variable, such as leaf length, from day to day, while this study uses more than one variable, such as light, temperature, and observation days. Basic mathematical skills need improvement, as evidenced by students' inability to properly complete problems involving repetitive pattern recognition, such as number sequences. This shows that 48% of students still have difficulty identifying patterns in a problem or data and applying them to similar conditions.

Two other indicators achieved success: 72% of students answered algorithm questions correctly, and 68% answered decomposition questions correctly. Algorithms are indicators of computational thinking that use a series of organized steps to solve problems. Meanwhile, 68% of students answered decomposition questions correctly. Decomposition involves dividing complex problems into simpler ones (Mardianto & Yahfizham, 2024).

Table 5

The statistical test.

Indicator	Score
N	27
α	5%
Z	-3.412
Median pretest & posttest	40 & 70
Average pretest & posttest	40 & 66
Interquartile Range	40
Effect size	0.61
Asymp. Sig. (2-tailed)	.001

The next research result comes from the statistical test the Wilcoxon shows the significance of the difference in the pretest and posttest averages. Table 5 shows that the Wilcoxon test result is 0.001 ($p<0.05$). The data indicate a significant average difference in computational abilities before and after learning. Then, the effect size value in this study was 0.61 (medium category), meaning that there was a learning effect of PjBL-STEM using Arduino that could be seen by observers. The median also shows the different value before (40) and after (70) the learning. This means that Arduino-based PjBL-STEM can improve students' computational thinking skills (Dat et al., 2025). In line with research by Pou (2022), which reveals a greater increase in computational concepts and skills with PjBL-STEM compared to other educational methodologies. Silaban et al. (2024) also stated that the STEM method was better than the PJBL, then PBL and last conventional methods. In addition, learning using STEM-PjBL can also improve collaboration, creativity, and students' computational thinking skills (Alkautsar, 2023).

Based on these results, it can be concluded that learning using Arduino-based PjBL-STEM not only helps students understand concepts but also develop computational thinking skills, which are among the important competencies in the 21st century. This is in line with Hsieh et al. (2022) that stated the 21st century can be considered the century of computing. In a world so

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saturated with computing, computational thinking is now recognized as a basic competency for becoming knowledgeable and successful citizens in STEM fields (Grover & Pea, 2013; Li et al., 2020; Pirzado et al., 2026). Therefore, the PjBL-STEM model has the potential to be an alternative, innovative learning model for improving students' computational thinking (Nabihah et al., 2025; Tariq et al., 2025).

Despite the widespread use of technology and programming platforms, the integration of computational thinking and educational robotics into the official secondary education curriculum has not become common practice (Alkautsar, 2023; Drakatos & Stavridis, 2023). Computational thinking is also still not widely implemented in K–12 education, and the availability of qualified K–12 teachers capable of teaching computing remains limited. In addition, preparing teachers to implement such integration should be considered a major priority (Killen et al., 2023; Knie et al., 2022; Lodi, 2020; Lye & Koh, 2014; Mohottige et al., 2024). The school that was the subject of this research also has not yet integrated computational thinking into STEM learning that uses Arduino or focuses on programming and robotics. Hence, this research is new and interesting for students. Therefore, further studies are needed to investigate effective ways to integrate computational thinking into education, particularly strategies to foster computational thinking skills among learners (Ogegbo & Ramnarain, 2021; Zhang et al., 2024).

CONCLUSION

The implementation of Project-Based Learning integrated with STEM, through an Arduino-based Automated Greenhouse project, effectively improved students' computational thinking skills in biology. The results demonstrated a moderate improvement with an N-gain score of 0.43 and a statistically significant difference between pretest and posttest scores ($p = 0.001$). Among the computational thinking indicators, abstraction achieved the highest level of student performance, whereas pattern recognition remained the most challenging skill. The findings indicate that Arduino-based PjBL-STEM learning not only facilitates students' understanding of biological concepts but also develops essential 21st-century competencies, including problem-solving and computational thinking. Therefore, Arduino-based PjBL-STEM can be considered an innovative alternative learning model to enhance computational thinking skills in education. Several recommendations is that future studies should employ larger sample sizes, include control groups, and explore the impact of Arduino-based PjBL-STEM on other higher-order thinking skills, such as critical thinking, creativity, and scientific literacy. Biology teacher can use this project with longer learning time and clear understanding in using Arduino. Students are expected to be able to learn research skills in terms of determining variables, processing and reading data, thus training their pattern recognition skills.

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