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Empowering critical thinking and self-awareness through biology learning mosquito larva control project

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ABSTRACT

This study investigates the effectiveness of a mosquito larva control project in enhancing students' critical thinking skills and self-awareness within biology learning. Contemporary biology education increasingly demands the integration of cognitive and affective competencies through authentic learning contexts. A mixed-methods experimental design was employed involving 27 high school students in Bandung. Quantitative data were collected through pretest–post-test measures of critical thinking and a self-awareness questionnaire, while qualitative data were derived from student experiments, reflections, and group-based project activities. The intervention was implemented through a Problem-Based Learning (PBL) framework, encompassing problem identification, field investigation, and the design and testing of mosquito larva control solutions. Quantitative analysis using N-Gain indicated a moderate improvement in critical thinking skills (N-Gain = 0.7) and a high level of self-awareness (mean = 4.29). Qualitative findings revealed that students actively engaged in data-driven discussions, demonstrated analytical reasoning, and developed reflective awareness of their role in environmental health contexts. Most student groups successfully designed and implemented functional larval control strategies based on empirical observations. These findings suggest that the mosquito larva control project is effective in simultaneously strengthening students' higher-order thinking skills and ecological self-awareness. The effectiveness of this approach may be further enhanced through extended project duration, structured reflective activities, and targeted teacher facilitation focusing on analytical and evaluative processes.

INTRODUCTION

21st-century biology education increasingly emphasizes the development of higher-order thinking skills and scientific character rather than mere content acquisition. Among these competencies, critical thinking is widely recognized as a fundamental capacity that enables students to analyze information, evaluate evidence, and construct reasoned, data-driven arguments when addressing complex scientific problems (Facione, 2011). Beyond factual recall, critical thinking involves higher-level cognitive processes such as interpretation, inference, evaluation, and self-regulation, particularly when individuals are confronted with uncertainty and diverse information sources (Dwyer et al., 2014). However, empirical findings consistently indicate that many students still struggle to formulate investigative questions, construct coherent arguments, and critically assess the reliability of scientific information (Facione, 2011; Lai, 2011). This suggests that current biology instruction has not yet fully provided meaningful opportunities for evaluative and reflective engagement, which are essential for the development of critical thinking (Fatmawati et al., 2019). Critical thinking is not only about assessing the accuracy of information but also about constructing evidence-based scientific arguments (Widodo et al., 2016). In addition, this scientific argumentation may involve skilled interpretation and evaluation of observational results, communication, and clear information to practice structured argumentation.

In addition to cognitive competencies, biology learning also requires attention to the affective dimension, particularly the development of students' self-awareness regarding biological and ecological issues. Self-awareness refers to an individual's capacity to recognize, monitor, and reflect upon internal states and their implications for behavior and the surrounding environment (Wicklund, 1972). Within the context of environmental and health education, this concept extends to students' awareness of their ecological roles, personal habits, and the consequences of their actions on collective well-being (Lee et al., 2015; Tokshylyk., 2025). Despite its importance, self-awareness remains insufficiently operationalized in science education, even though it plays a critical role in fostering ecological responsibility and preventive behavior. Previous studies have reported that low levels of biological risk awareness and weak self-regulation contribute to the persistence of environmentally risky practices and the increased transmission of vector-borne diseases (Savery, 2015; Wong et al., 2015). This indicates a gap in instructional approaches that simultaneously address cognitive and affective learning outcomes.

The limited development of both critical thinking and self-awareness is closely linked to the predominance of teacher-centered, concept-oriented instructional practices. Such approaches tend to position students as passive recipients of knowledge, resulting in abstract understanding that is disconnected from real-life contexts (Goodale, et.al., 2024). Consequently, students often encounter difficulties in applying biological concepts to authentic situations, such as understanding ecological interactions and environmental dynamics (Aidoo, 2024). Moreover, laboratory activities are frequently procedural and rigid, offering limited opportunities for inquiry, reasoning, and reflection (Windschitl., et.al, 2008). This condition highlights the urgent need to transform biology learning into authentic, inquiry-based experiences that actively engage students in constructing knowledge while developing reflective awareness.

One contextual issue that offers significant potential for such transformation is the prevalence of vector-borne diseases, particularly those transmitted by mosquitoes in tropical regions. In Indonesia, mosquito-borne diseases remain a persistent public health challenge, influenced by environmental changes, urbanization, and human mobility (Kraemer et al., 2019). Despite ongoing prevention efforts, these strategies are often reactive and short-term, reflecting limited public awareness of ecological risks and preventive practices (Glanz et al., 2015). This situation underscores the importance of integrating environmental health issues into educational contexts, allowing students to develop both critical thinking and ecological self-awareness through meaningful engagement with real-world problems (Nutbeam, 2008; Paakkari & Okan, 2020).

From a biological perspective, mosquito larvae serve as sensitive ecological indicators and provide a concrete entry point for understanding environmental conditions and disease dynamics. Their presence can be directly observed, analyzed, and interpreted, enabling students to connect theoretical concepts with empirical evidence. As such, mosquito larvae not only represent a public health concern but also function as a powerful pedagogical medium for promoting inquiry, scientific reasoning, and reflective thinking (Rueda, 2008). In this context, Problem-Based Learning (PBL) offers a promising approach to facilitate active learning and inquiry. PBL engages students in solving authentic, illstructured problems, thereby promoting higher-order thinking, collaboration, and self-directed learning (Barrows, 1996; Jaganathan et al., 2024). Previous studies have demonstrated the effectiveness of PBL in improving critical thinking skills and conceptual understanding (Martínez-Barciela et al., 2024; Yulfi et al., 2025). However, most studies focus primarily on cognitive outcomes and rarely examine the simultaneous development of affective dimensions, such as self-awareness, particularly in environmental health contexts.

To address this gap, this study integrates Problem-Based Learning with a mosquito larva control project as a contextual and experiential learning strategy. This approach allows students to engage in the full cycle of scientific inquiry, including problem identification, field investigation, solution design, and evaluation, while reflecting on the ecological implications of their actions. The mosquito larva control project is designed as an adaptive and innovative learning platform in which students actively function as designers and implementers of contextual solutions.

By engaging in the full cycle of scientific inquiry, ranging from problem identification and environmental analysis to solution development and evaluation, students are encouraged to construct knowledge through direct interaction with real-world phenomena (Zebua et al, 2025). At the same time, this project is innovative because it encourages students to design, test, and evaluate various mosquito larvae control strategies in a creative, simple, and sustainable manner (Fortuin & van Koppen, 2016). Through the mosquito larva control project, students are involved in the entire scientific problem-solving cycle, from identifying and mapping mosquito breeding sites and analyzing environmental factors to developing and evaluating prototype solutions.

The novelty of this study lies in integrating cognitive (critical thinking) and affective (ecological self-awareness) competencies within a single intervention framework grounded in real environmental issues. Therefore, this study aims to examine the effectiveness of a mosquito larva control project integrated with Problem-Based Learning in improving students' critical thinking skills and ecological self-awareness in biology learning. This research is expected to contribute to the development of adaptive and innovative biology education that is both contextually relevant and pedagogically meaningful, particularly in addressing environmental health challenges.

METHODS

Research Design

This study employed a mixed-methods experimental design to examine the effectiveness of a mosquito larva control project in improving students' critical thinking skills and self-awareness (Creswell & Guetterman, 2019). The quantitative component used a pretest–post-test design to measure changes in students' critical thinking and self-awareness, while the qualitative component explored students' learning processes, reflections, and experimental experiences during the intervention. The mosquito larva control project served as the core learning activity, generating both quantitative data from pretest and post-test scores and qualitative data from student reflections, observations, and experimental outcomes. This integrated approach enabled a comprehensive analysis of both the intervention's effectiveness and the underlying learning processes that contributed to changes in students' critical thinking and self-awareness within a problem-based learning (PBL) framework.

Population and Samples

Table 1.

Demographic Characteristics of Participants

Variable	Category	n	Percentage (%)
Gender	Male	12	44.4
	Female	15	55.6
Age	15–16 years	27	100
Grade	10th Grade	27	100

The study population consisted of tenth-grade students at SMAN 15 Bandung. The sample was selected using purposive sampling based on the following criteria: (1) the school environment supported the implementation of a mosquito larva control project, (2) students had not previously experienced project-based learning in a similar context, and (3) the school and teachers were willing to participate in the research process. The sample consisted of 27 students. Detailed demographic characteristics of the participants are presented in Table 1.

Instrument

Critical thinking assessment tools are developed based on critical thinking frameworks. Facione (2015), which includes six indicators, namely interpretation, analysis, inference, evaluation, explanation, and self-regulation. This instrument has been tested for validity and reliability among students. The final instrument (valid and reliable) consists of six multiple-choice items and has an alpha of 0.73. The students' critical thinking scores are converted to a 0–100 scale based on the instrument's maximum score before descriptive and inferential analyses are performed. Table 2 presents the blueprint of the critical thinking skills instrument used in this study, which is based on six core indicators, namely interpretation, analysis, inference, evaluation, explanation, and self-regulation. Each indicator is represented by one item, yielding a total of 6 items designed to comprehensively measure students' critical thinking skills.

Table 2.
Critical thinking skills instrument blueprint

Indicator	Description of Indicators	Item Number	Number of Items
Interpretation	Students can understand and interpret environmental messages logically.	1	1
Analysis	Students can analyze the cause-and-effect relationships among environmental variables.	2	1
Inference	Students can draw logical inferences from empirical phenomena.	3	1
Evaluation	Students can evaluate solutions based on sustainability principles.	4	1
Explanation	Students can explain ideas using rational reasoning and social and environmental values.	5	1
Self-Regulation	Students can regulate their personal actions through reflection and critical awareness.	6	1
Total	Description of Indicators		6

The instrument for mapping students' self-regulation was developed by combining four main dimensions, including biological risk awareness, personal habits, self-role, and self-reflection and self-regulation, with an alpha value of 0.77, consisting of 16 items on a 1-5 Likert scale. The development of each dimension is conceptualized within psychological, environmental behavior, and metacognitive frameworks (Flavell, 1979; Hmelo-Silver, 2004; Zimmerman, 2000). The self-awareness data were analyzed using descriptive statistics, including the mean and standard deviation. The questionnaire scores were interpreted according to the guidelines for descriptive analysis of Likert-scale data, using evenly spaced intervals on a five-point Likert scale. Table 3 presents the blueprint of the self-awareness instrument used in this study. The instrument consists of four main dimensions, namely biological risk awareness, personal habit awareness, self-role awareness, and reflective awareness. Each dimension is represented by 4 items, resulting iyielding 16 items designed to comprehensively measure students' ecological self-awareness.

Table 3.
Self-awareness instrument blueprint

Dimension	Measured Indicators	Number of Items
A. Biological Risk Awareness (Understanding and awareness of biological threats related to mosquito larvae)	1. Knowledge of the mosquito/larva life cycle 2. Awareness of where mosquito larvae develop 3. Understanding health consequences 4. Perception of flood risk	4
B. Personal Habit Awareness (Personal awareness and behavior related to mosquito breeding potential)	1. Inspection of containers filled with water 2. Action of closing/emptying the container 3. Frequency of personal hygiene	4

Dimension	Measured Indicators	Number of Items
	4. Personal responsibility for hazardous containers	
C. Self-Awareness (Sense of responsibility, initiative, and social role in mosquito larvae prevention)	1. A sense of responsibility prevents mosquito larvae 2. Initiative to invite others 3. The belief that individual actions have an impact 4. Expansion of social roles in prevention	4
D. Reflective Awareness (The ability to evaluate one's own actions and change behavior based on reflection)	1. Evaluation of the effectiveness of preventive measures 2. The desire to change habits after reflection 3. Connecting biological knowledge with real-world action 4. Reflections on the influence of knowledge on daily actions	4
Total		16

Qualitative Instruments

Qualitative data were collected through three supporting instruments, namely (1) Student reflection journal, each student is required to write and/or present a structured reflection at the end of each session that covers their understanding of the concepts learned, their thought process during problem-solving, their awareness of their role in mosquito larval prevention, and a plan for further action that provides a solution or an experimental design. (2) Student worksheets are designed to capture students' thinking processes and self-awareness during learning. Worksheets include several components, namely: Problem identification (Participants write down their field observations, describe environmental conditions, and formulate problems related to mosquito larvae, students identify and analyze environmental factors, solution design (Students describe their innovation designs, explain the working principles, and create experimental designs with solutions), data and observation results, analysis, and evaluation. And (3) Documentation, (including photos, videos, project reports, and innovative products produced by students as evidence of the learning process and learning achievements).

Procedure

This study was conducted in three main stages, namely the preparation stage, the implementation stage, and the reporting stage (Figure 1). The preparation stage began with a literature review focusing on Problem-Based Learning (PBL) in biology, critical thinking skills, self-awareness, and mosquito larval control as a context for environmental learning. Next, learning tools were developed in the form of a mosquito larva control project scenario, student worksheets, and experiment guidelines. At this stage, research instruments were also developed and adapted, including a Facione indicator-based critical thinking skills test for pretest and post-test, as well as a self-awareness questionnaire modified from relevant instruments.

The research implementation stage began with a pretest to measure the students' initial critical thinking skills. Next, learning was carried out through a PBL-based mosquito larva control project that included activities such as identifying environmental problems related to mosquito larvae, conducting field investigations, engaging in data-based discussions, and designing and implementing mosquito larva control experiments in groups. During the learning process, students were actively involved in direct observation, analysis of environmental factors, testing of solutions, and reflection on the effectiveness and ecological implications of the solutions developed. The students' thinking and reflection processes were documented through their answers on the worksheets and the results of group discussions. After the entire project was completed, students were given a post-test of critical thinking skills and a self-awareness questionnaire.

The reporting stage includes the processing and analysis of quantitative data in the form of pretest and post-test scores for critical thinking skills and the results of the self-awareness questionnaire, as well as the analysis of qualitative data from student worksheets and documentation of the experiment results. The analysis results are then discussed to assess the effectiveness of the mosquito larva control project in developing students' critical thinking skills and self-awareness. The final stage involves compiling and reporting the research results in accordance with the conventions of scientific writing.

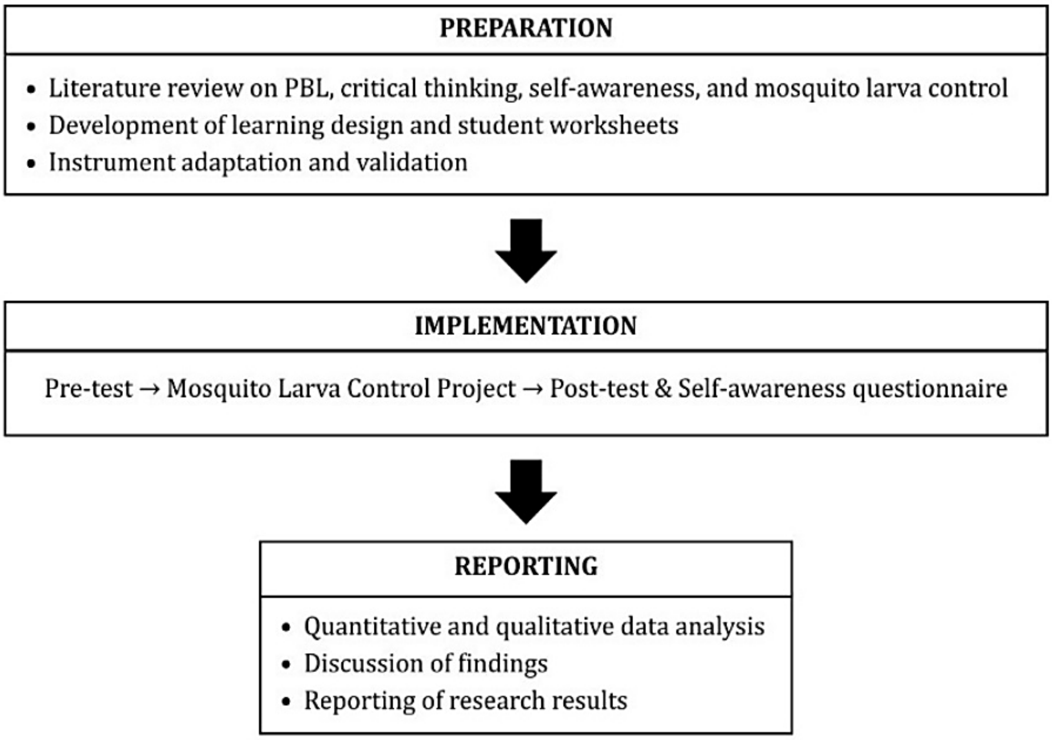

Figure 1. Research procedure diagram mosquito larva control project

Learning was conducted according to the Problem-Based Learning (PBL) framework, integrated with the mosquito larva control project. The entire learning process is described in Table 4.

Table 4.
Description of PBL-based activities: mosquito larva control project

Meeting	Activities
1	Learning activities are carried out in accordance with the stages of Problem-Based Learning (PBL): Problem Orientation 1) Students identify environmental problems, such as mosquito larvae in school ditches and surrounding areas, through direct exploration. 2) Students analyze the causes of environmental problems through the presence of mosquito larvae. 3) Students design ideas in the form of temporary hypotheses regarding the problem of mosquito larvae.
2	Experimental Plan 1) Students designed a project-based experiment called mosquito larva control project using literature and AI, working in groups on mobile devices. 2) Students engage in discussions by evaluating each group's solution designs. 3) Students revise the designs they have prepared.
3	Solution Development with Practice 1) Students carried out a mosquito larva control project using creative solutions developed by each group. 2) Students measured the pH of the water before and after the experiment using pH paper and counted the number of mosquito larvae using the Count Things AI Object Counter app. 3) Students can assess the effectiveness of experimental solutions implemented to reduce mosquito larvae. 4) Students summarize the findings from the mosquito larva control project.
4	Presentation 1) Students communicate the results of the mosquito larva control project scientifically and identify the strengths and weaknesses of their project design.

Meeting	Activities
	2) Students continuously apply their understanding of mosquito larvae control in their daily lives.

Data Analysis Techniques

All quantitative data, in the form of pretest and posttest scores for critical thinking skills, were analyzed using the (N-Gain) to measure learning improvement. The N-Gain calculation refers to Hake's formula and is classified into low, medium, and high categories (Hake, 1998). Quantitative data from the pretest and posttest were also analyzed using descriptive and advanced statistical methods. Meanwhile, the self-awareness questionnaire scores were analyzed using a five-point Likert scale. The interpretation of respondent categories was determined using the class interval technique, as recommended by Azwar, (2012), with a range from very low to very high. Qualitative data in this study were obtained from students' worksheet answers generated during the implementation of the mosquito larva control project. Qualitative data analysis was conducted using a thematic analysis approach, with stages including data reduction, initial coding, grouping codes into themes, and interpretation of findings based on predetermined indicators of critical thinking and self-awareness.

The analysis began by reading all student responses to identify patterns in reasoning, self-reflection, and awareness of the individual's role in mosquito larval control. Next, student responses were systematically coded to map the emergence of critical thinking aspects, such as the ability to identify problems, provide evidence-based reasoning, and evaluate solutions, as well as aspects of self-awareness, including self-reflection, ecological responsibility, and awareness of the impact of personal actions. The validity of qualitative data was maintained through triangulation across indicators and through discussions among researchers during the interpretation of the results.

RESULTS AND DISCUSSION

The implementation of the mosquito larva control project improved students' critical thinking skills. The improvement in students' critical thinking skills will be discussed in more detail for each indicator. The descriptive analysis showed an increase in students' critical thinking scores following the intervention. The data results are shown in Table 4 below.

Table 5.
Results of Statistical Analysis of Critical Thinking Skills

Analysis Components	Results
Number of students (N)	27
Descriptive Statistics	
Pretest (Mean ± SD)	64.17 ± 21
Posttest (Mean ± SD)	90.17 ± 13.33
Normality Test (Shapiro–Wilk)	
Pretest (p-value)	0,111 (normal)
Posttest (p-value)	0,000 (abnormal)
Difference Test	
Type of test	Wilcoxon Signed Rank Test
Z-score	−3.980
p-value	< 0.001
Effect Size	
r value	0.77
Effect category	Large

The results indicate a moderate improvement in students' critical thinking skills, as reflected by an N-Gain score of 0.7. This finding suggests that implementing the mosquito larva control project within a problem-based learning framework was effective in facilitating meaningful cognitive development, although the level of improvement has not yet reached its full potential. The observed improvement reflects a shift in students' learning processes, from initial conceptual understanding toward more advanced analytical and evaluative thinking. This progression can be attributed to students' active engagement in identifying real environmental problems, analyzing mosquito breeding conditions, and evaluating the effectiveness of proposed control strategies. Such activities are consistent with the principles of PBL, which emphasize inquiry, problem-solving, and reflective thinking as key drivers of higher-order cognitive development (Loyens et al., 2023; Yu., & Zin, 2023). However, variation in students' reasoning depth suggests that the development of critical thinking skills was not uniformly achieved across participants.

This disparity may be influenced by differences in students' prior knowledge, engagement levels, and the extent of scaffolding provided during the learning process. Limited time allocation and variations in teacher facilitation during the reflection and evaluation stages may have constrained students' opportunities to fully develop evidence-based reasoning and argumentation skills. These findings highlight that while PBL-based contextual learning can effectively support the development of critical thinking, its impact depends heavily on the quality of its implementation. Therefore, optimizing learning outcomes requires extended project duration, more structured reflective activities, and targeted teacher guidance that emphasizes analytical reasoning, evidence-based argumentation, and evaluative thinking (Anggraeni et al., 2023).

The results of the nonparametric statistical analysis using the Wilcoxon Signed Rank Test revealed a significant difference between students' pretest and post-test scores, indicating that the mosquito larva control project had a measurable impact on the development of critical thinking skills. The use of the Wilcoxon test was appropriate, given that the post-test data were not normally distributed, thereby ensuring the robustness and validity of the statistical conclusions. Beyond statistical significance, these findings suggest that the observed improvement reflects a systematic change in students' cognitive processes rather than random variation. The magnitude of this change is further supported by the effect size analysis, which indicates a strong intervention effect on students' critical thinking skills. According to Cohen (1988), an effect size of $r \geq 0.50$ indicates a substantial impact, suggesting that the learning experience not only produced statistically significant outcomes but also meaningful educational effects. This finding implies that the mosquito larva control project facilitated a learning environment that actively engaged students in higher-order cognitive processes.

From a pedagogical perspective, the strength of this effect can be understood through the nature of the learning activities implemented. The project required students to engage in problem identification, environmental analysis, and the evaluation of alternative solutions, all of which are central components of critical thinking. This aligns with the view that meaningful learning occurs when students are challenged to construct knowledge through inquiry, reflection, and evidence-based reasoning (Widodo et al., 2016). Furthermore, integrating real-world environmental issues into the learning process appears to deepen students' cognitive engagement. By situating learning in an authentic context, students are encouraged to move beyond procedural understanding toward more reflective and evaluative thinking (Bester & Pretorius, 2022). Therefore, the effectiveness of the mosquito larva control project can be interpreted not merely as an outcome of instructional design, but as the result of a learning process that fosters sustained cognitive engagement and meaningful knowledge construction.

A significant increase in post-test scores was accompanied by a higher average critical thinking score and a lower standard deviation. This pattern indicates that the learning intervention not only improved students' overall performance but also contributed to a more even distribution of critical thinking skills across the group. In other words, the learning process appears to have reduced the gap between students with varying initial abilities, suggesting that the intervention supported more equitable cognitive development. This finding is consistent with previous studies indicating that Problem-Based Learning (PBL) can produce relatively stable learning outcomes among students with diverse prior knowledge by promoting active participation and sustained cognitive engagement (Naenggolan, 2023).

The reduction in score variability suggests that the learning environment enabled a broader range of students to engage in higher-order thinking processes, rather than benefiting only high-performing individuals. In the context of the mosquito larva control project, students were actively involved in identifying larval sources, mapping environmental factors, designing intervention strategies, and evaluating the effectiveness of their proposed solutions. These activities positioned students as central actors in the scientific inquiry process, thereby requiring continuous engagement in analysis, evaluation, and evidence-based reasoning. Such involvement is critical in supporting the development of higher-order thinking skills, as students are not merely receiving information but actively constructing and applying knowledge in meaningful contexts (Pimdee., et.al, 2024).

Furthermore, direct observation of mosquito larvae and their interaction with environmental conditions provided students with authentic empirical experiences that strengthened their scientific reasoning. This supports previous findings that learning grounded in local organisms and real environmental issues enhances students' analytical abilities, as they are required to interpret complex and dynamic biological phenomena (Almulla & Al-Rahmi, 2023). The contextual nature of the learning experience thus appears to play a key role in deepening students' understanding and facilitating the application of abstract concepts to real-world situations.

In addition, the reflection stage embedded in the PBL cycle contributed to the development of self-regulation, a critical component of established critical thinking frameworks (Facione, 2015). Through structured reflection on their investigation processes and outcomes, students were encouraged to evaluate data quality, assess the strength of their arguments, and consider the ecological implications of their decisions. This reflective dimension is particularly important in the context of mosquito larval control, where effective and sustainable solutions require not only cognitive understanding but also the integration of ecological awareness and responsible decision-making (Savery, 2015).

Overall, the mosquito larva control project integrates field observation, solution design, simple experimentation, and systematic reflection into a coherent learning sequence. This integration fosters deep cognitive engagement by requiring students to apply data-driven analysis, evaluation, and decision-making in addressing real environmental problems. These findings reinforce existing evidence that project-based and real-world problem-based biology learning has strong potential to develop students' critical thinking skills in a meaningful and sustainable manner. Beyond its statistical effectiveness, the mosquito larva control project also contributes to the development of contextual biology pedagogy oriented toward strengthening 21st-century competencies. A more detailed analysis of each critical thinking indicator is presented in Figure 1.

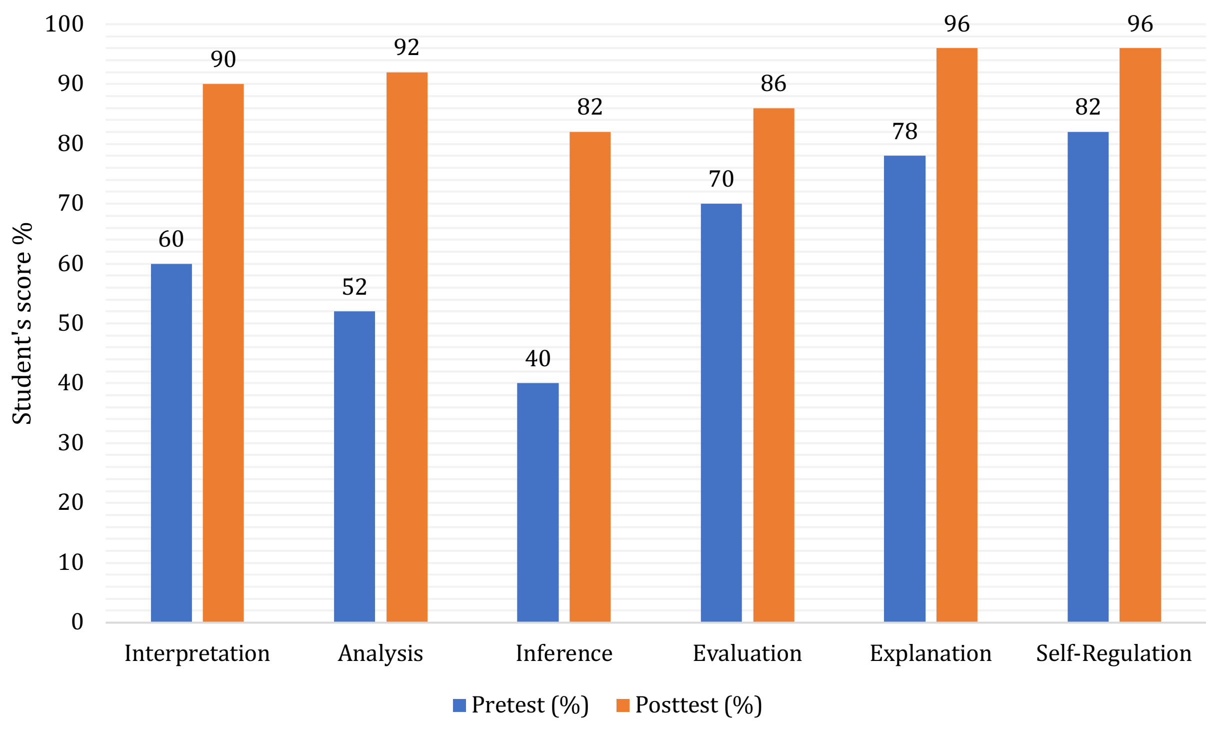

Figure 2. Distribution of Pretest and Post-test Scores for Students' Critical Thinking Ability

Based on Figure 2, all critical thinking indicators show higher average posttest scores than pretest scores, indicating that the mosquito larva control project contributed to consistent improvement in students' overall critical thinking development. This pattern suggests that the learning intervention not only enhanced general performance but also supported the development of multiple dimensions of critical thinking in an integrated manner. The most substantial improvement was observed in the interpretation indicator, reflecting students' increased ability to interpret messages, environmental phenomena, and actions in a logical and meaningful way. This improvement can be understood as stemming from students' direct engagement in field observations, analysis of community behaviors, and evidence-based discussions, which required them to construct meaning from real ecological contexts.

Such learning experiences encourage students to move beyond surface-level understanding toward deeper conceptual interpretation (Affandy et al., 2024). From a theoretical perspective, this finding is consistent with Facione's (2015) framework, which identifies interpretation as a foundational component of critical thinking. Interpretation enables individuals to understand and organize information accurately before engaging in more complex processes such as analysis and evaluation. Therefore, the observed improvement in this indicator reflects the development of a more mature, contextually grounded conceptual understanding, which serves as a basis for advancing higher-order thinking skills.

Analysis and inference indicators also showed significant improvement, reflecting students' enhanced ability to identify cause-and-effect relationships and draw logical conclusions from empirical data. This development indicates that students were increasingly able to process information in a more structured and evidence-based manner when engaging with environmental problems. Within the context of the mosquito larva control project, students were actively involved in analyzing the relationships between environmental variables such as standing water, sanitation conditions, and human activities, as well as predicting their implications for the presence of mosquito larvae.

The processes of field observation, comparison across different locations, and hypothesis formulation within the Problem-Based Learning (PBL) framework required students to engage in more complex and integrative cognitive processing. These activities encouraged students to synthesize multiple sources of information and construct logically coherent explanations. In addition, group discussions and collective reflection played a significant role in strengthening students' analytical and inferential reasoning. Through these collaborative processes, students were required to evaluate alternative explanations, compare evidence, and select conclusions most strongly supported by the data. Such interactions not only enhanced reasoning accuracy but also promoted deeper cognitive engagement.

This finding is consistent with previous studies demonstrating that active involvement in real-world phenomena can effectively improve students' analytical and inferential abilities (Fortuin & van Koppen, 2016; Hmelo-Silver, 2004; Savery, 2015). Furthermore, the project-based learning environment provided students with opportunities to assess the effectiveness and sustainability of their proposed solutions, develop coherent, evidence-based scientific explanations, and reflect on decisions based on experimental results. Activities such as presentations, scientific argumentation, and structured reflection encouraged students to articulate their reasoning more clearly and justify their conclusions in a logical and systematic manner (Rehman et al., 2023). This suggests that well-designed learning environments that integrate inquiry, collaboration, and reflection can effectively support the development of evaluative and self-regulatory skills. In line with this, previous research has shown that authentic learning experiences that provide space for scientific argumentation and reflection are essential for strengthening higher-order thinking processes (Blumenfeld et al., 1991; Savery, 2015).

Self-awareness is considered an important component in the development of ecological behavior, as it reflects students' ability to understand biological risks, evaluate their personal habits, recognize their role in the environmental system, and reflect on their actions (Chang, Tu, & Jiang, 2025). The measurement of self-awareness was conducted after the entire series of mosquito larva control projects had been completed, so the scores obtained reflected the level of internalization of self-awareness among students regarding mosquito larvae and their ecological consequences. The results of the descriptive analysis for each dimension of self-awareness are presented in Table 5, providing an overview of students' affective achievements. This presentation serves as a starting point for understanding students' self-awareness development before discussing the findings in more depth.

Table 6.
Descriptive Statistics Self-Awareness After Learning

Indicator	Mean	SD	Category
Biological Risk Awareness	4.30	0.48	Very High
Personal Habit Awareness	4.24	0.53	Very High
Self-Role Awareness	4.32	0.50	Very High
Reflective Awareness	4.31	0.54	Very High
Average	4.30		Very High

The descriptive analysis results (Table 5) indicate that all dimensions of students' self-awareness fall within the very high category, suggesting a comprehensive strengthening of self-awareness following participation in the mosquito larva control project-based learning. These findings demonstrate that the learning intervention influenced not only the cognitive domain but also the affective dimensions related to understanding biological risks, evaluating personal habits, and developing ecological responsibility. Self-awareness plays a critical role in environmental education, as it underpins preventive behaviour and responsible decision-making. In the context of mosquito larval control, high levels of self-awareness reflect students' ability to connect their learning experiences with broader public health implications.

This is consistent with finding which show that mosquito control integrated with health education effectively enhances understanding of mosquito habitats and promotes more sustainable environmental practices. Through Problem-Based Learning, students are encouraged to recognize the relevance of environmental issues and develop self-awareness through reflective engagement with their daily behaviours, rather than relying solely on cognitive responses. Conceptually, the four dimensions of self-awareness, biological risk awareness, personal habit awareness, self-role awareness, and reflective awareness demonstrate strong integration through authentic, experience-based learning processes.

Direct interaction with ecological phenomena strengthens students' perceptions of environmental risks, consistent with the Health Belief Model's emphasis on perceived threats in promoting preventive behavior. Students' involvement in environmental observation and behavior monitoring also encourages self-observation processes (Carver & Scheier, 1981). Making them more aware of the impact of their daily habits. In addition, project-based learning fosters a sense of agency, defined as the awareness that individuals play an active role in ecological change. At the same time, repeated reflection throughout the learning process supports the development of self-regulation, in line with the principles of metacognition and self-regulated learning (Flavell, 1979; Zimmerman, 2000). In addition to the quantitative analysis of students' critical thinking skills and self-awareness profiles, this study also incorporates qualitative data to provide a deeper understanding of the learning process. The qualitative analysis focuses on how critical thinking and self-awareness are developed and manifested during students' participation in the mosquito larva control project. Specifically, the analysis examines group discussions, student involvement in designing and implementing experiments, and reflections on the effectiveness of the solutions produced. The results of this qualitative analysis, derived from students' worksheets and group experiment reports, are presented in Table 6.

Table 7.
Description of the mosquito larvae control experiment and larval response

Group	Types of Experimental Solutions	Observed Environmental Changes	Mosquito Larval Response
1	Environmental chemical modification (a mixture of laundry soap, salt, vinegar, and water)	Decrease in water pH from initial conditions to a more acidic condition	Larval activity decreased dramatically and died within a relatively short period of time.
2	Environmental chemical modification (salt solution)	Increased salinity and changes in water pH	The larvae exhibit irregular movements and gradually die.
3	Physical modification of the habitat (a simple eco-filter made from bottles, charcoal, and cotton)	The filtered water becomes clearer; the larvae are trapped in the filter media.	No larvae were found in the filtered water.
4	Environmental chemical modification (lemon water solution)	Decrease in water pH, becoming more acidic	Most larvae experience decreased activity leading to immobilization and death.

The data in Table 6 are presented descriptively to illustrate the diversity of students' solutions and learning processes, rather than to quantitatively compare biological effectiveness. These findings highlight that the mosquito larva control project fosters active student involvement across all stages of scientific inquiry. Students not only carry out experimental procedures, but also engage in discussion, decision-making, and reflection on the impact of the solutions they design.

This pattern indicates that problem-based learning facilitates the development of critical thinking skills through direct engagement with real biological phenomena (Hmelo-Silver, 2004). Such authentic experiences play a crucial role in supporting the construction of meaningful and contextually grounded understanding. Through this process, students can connect biological concepts with the conditions of their surrounding environment in a more integrated manner. These findings further suggest that learning occurs not as a passive transfer of knowledge, but as an active process of knowledge construction in which students continuously interpret, evaluate, and refine their understanding based on experience.

Analysis of group discussions and experimental decision-making shows that students' critical thinking skills are clearly manifested during the formulation and evaluation of mosquito larva control solutions. Students actively compared various alternative strategies, including environmental chemical modification and physical habitat modification, while considering observed environmental changes and corresponding larval responses. This process required students to analyze cause-and-effect relationships between environmental variables and biological responses, which constitutes a central component of critical thinking (Cujba & Pifarré, 2024; Facione, 2015). Group discussions also revealed variations in participation levels; however, most groups reached consensus on solutions grounded in experimental evidence (Portilla et al., 2025). These findings are consistent with previous research showing that project-based learning supports students in organizing information, evaluating arguments, and making data-driven decisions (Blumenfeld et al., 1991; Fortuin & van Koppen, 2016). The qualitative evidence further indicates that critical thinking develops progressively through dialogue and the negotiation of meaning within collaborative settings, rather than emerging instantaneously. In this context, the experimental activities served as a key mechanism for strengthening students' analytical and evaluative abilities by providing opportunities to test, refine, and justify their reasoning using empirical evidence.

In addition to cognitive aspects, qualitative data reveal the development of students' self-awareness during the implementation of the mosquito larva control project. Reflections documented in students' worksheets indicate that they increasingly recognized the relationship between daily habits, microenvironmental conditions, and the presence of mosquito larvae. This awareness extends beyond conceptual understanding to a more personal level, as students reflect on their role in either contributing to or preventing mosquito breeding habitats. This reflective process is consistent with the concept of self-awareness, which emphasizes individuals' capacity to evaluate themselves in relation to environmental and social standards (Ayerbe & Perales-Palacios, 2023).

Problem-based learning provides a meaningful context for fostering ecological awareness, as students are directly confronted with the consequences of human actions on the environment (Agustira et al., 2025). The analysis further suggests that self-reflection becomes more pronounced when students engage in cross-group comparisons of experimental results. Such interactions encourage students to reassess their assumptions and refine their understanding. Therefore, self-awareness in this study can be understood as developing through authentic, reflective, and dialogical learning experiences.

Qualitative findings also reveal that student participation within groups plays a crucial role in the development of critical thinking and self-awareness. Group discussions demonstrated a diversity of roles, with some students actively expressing ideas and others contributing through observation and data recording. These interactions encouraged students to reevaluate group decisions and revise strategies based on experimental results, reflecting the development of self-regulation. Self-regulation is a key component of critical thinking, as it enables individuals to consciously monitor and improve their thinking processes (Facione, 2015; Zimmerman, 2000). Group reflection activities conducted at the end of the experiment further reinforced this process, as students were required to identify the strengths and limitations of their proposed solutions. Previous studies have shown that project-based learning effectively supports the development of self-regulation through collaborative and reflective experiences (Flavell, 1979; Hyytinen et al., 2021; Savery, 2015). Thus, group dynamics function as a social context that enriches learning and supports the development of higher-order thinking skills

Overall, the qualitative data indicate that the various experimental solutions designed by students contributed significantly to both the learning process and its outcomes. All four groups successfully demonstrated that their strategies suppressed and controlled mosquito larval populations, though through different mechanisms and response times. In environmental chemical modification experiments, students observed decreased activity and increased larval mortality in response to changes in habitat conditions. In contrast, in the filtration approach, larvae were no longer detected because they were physically trapped in the filter media. These findings encouraged students not only to evaluate the effectiveness of the solutions but also to consider their sustainability and ecological impact.

Students' reflections further indicate that habitat-based physical modifications, such as filtration, were perceived as more sustainable than chemical approaches, even though both proved effective within the experimental context. This pattern of reasoning reflects the development of more advanced evaluative abilities and ecological awareness, as students began to consider not only immediate outcomes but also long-term environmental implications. This is consistent with the goals of environmental education, which emphasize integrating knowledge, attitudes, and ecological responsibility (UNESCO, 2017). By integrating experimental activities, self-reflection, and collaborative discussion, the mosquito larva control project successfully facilitated holistic and context-based biology learning. Therefore, these qualitative findings reinforce the quantitative results and confirm that project-based learning can simultaneously enhance students' critical thinking skills and self-awareness.

CONCLUSION

The results of this study demonstrate that the mosquito larva control project is effective in improving students' critical thinking skills while strengthening their ecological self-awareness. This improvement is reflected in the moderate N-Gain score, consistent development across all Facione indicators, and very high levels of self-awareness across all dimensions. These findings indicate that students not only achieved cognitive gains but also developed a deeper sense of ecological responsibility and awareness. The integration of quantitative and qualitative findings confirms that Problem-Based Learning (PBL) oriented toward authentic environmental problems can simultaneously support cognitive and affective development. These results imply that contextual, project-based biology learning can serve as an effective pedagogical approach for developing 21st-century competencies, particularly critical thinking and ecological awareness. For educators, this approach offers a practical framework for designing meaningful, real-world learning experiences. Future research may further explore the long-term impact of such interventions across diverse educational contexts.

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