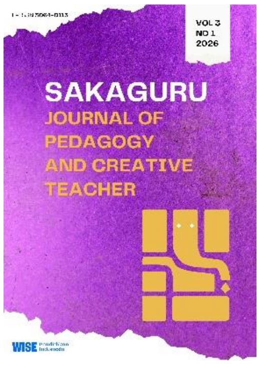

WISE Pendidikan Indonesia

SAKAGUR U
JOURNAL OF PEDAGOGY AND CREATIVE TEACHER
VOL. 3 NO. 1 (2026)

ISSN: 3064-0113

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To cite this article R. Oktafiani, D. Fernandilla, A. Novitasari, A. D. Kesumawardani, and M. D. Solviana, “The effect of Project Based Learning model on creative thinking ability and emotional intelligence of Grade X students in biology,” *SAKAGURU J. Pedagog. Creat. Teach*, vol. 3, no. 1, pp. 22–34, May 2026. https://doi.org/10.70211/sakaguru.v3i1.648

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SAKAGURU: Journal of Pedagogy and Creative Teacher Vol 3 No 1 (2026)

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Research Article

The Effect of Project Based Learning Model on Creative Thinking Ability and Emotional Intelligence of Grade X Students in Biology

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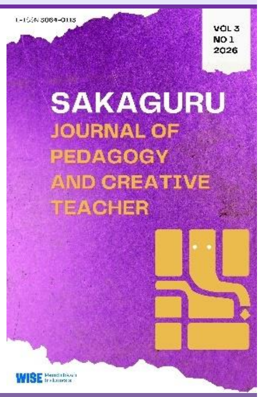
Received : January 20, 2026	Revised : March 14, 2026	Accepted : March 22, 2026	Online : May 10, 2026

Abstract

Creative thinking and emotional intelligence are essential competencies for students facing the demands of twenty-first-century biology learning. Preliminary data at SMA Negeri 12 Bandar Lampung showed that Grade X students' creative thinking ability was still in the less creative category (average 36%), while emotional intelligence was categorized as poor (average 40%). This study examined the effect of the Project Based Learning (PjBL) model on students' creative thinking ability and emotional intelligence in Grade X Biology, particularly on the topic of environmental pollution. A quantitative quasi-experimental method with a pretest-posttest control group design was employed. The population comprised all Grade X students in the even semester of the 2024/2025 academic year ($N = 337$). Through cluster random sampling, Class X.4 ($n = 34$) was assigned as the experimental group and Class X.1 ($n = 34$) as the control group. Data were collected using a validated creative thinking essay test, an emotional intelligence questionnaire, and observation sheets. Instrument reliability was very high for both the creative thinking test (Cronbach's alpha = 0.821) and the emotional intelligence questionnaire (Cronbach's alpha = 0.877). Data were analyzed using descriptive statistics, N-gain, prerequisite testing, and independent samples t-tests through SPSS version 25. The findings showed significant differences between experimental and control groups in creative thinking ability, $t(66) = 13.844$, $p < 0.05$, and emotional intelligence, $t(66) = 15.440$, $p < 0.05$. The experimental group achieved N-gain scores of 80.91% for creative thinking and 80.51% for emotional intelligence, both in the excellent category, whereas the control group obtained 35.18% and 45.23%, respectively. Visualized indicator-level data further showed that all creative thinking indicators and all emotional intelligence indicators reached very high categories in the experimental group. These results indicate that PjBL is more effective than direct instruction in strengthening creative thinking and emotional intelligence in biology learning. The study contributes empirical evidence for integrating authentic environmental projects into secondary biology instruction.

Keywords: Creative Thinking Ability; Emotional Intelligence; Environmental Pollution; Project Based Learning; Quasi-Experimental



INTRODUCTION

Education plays a fundamental role in shaping students' knowledge, skills, values, and character. In Indonesia, Law No. 20 of 2003 on the National Education System defines education as a conscious and planned effort to create learning conditions that enable students to develop spiritual, intellectual, emotional, and social potential [1]. In biology education, this mandate requires learning experiences that go beyond factual recall and procedural explanation. Biology classrooms need to help students interpret living systems, analyze environmental problems, make evidence-based decisions, and act responsibly toward their surroundings [2], [3]. Therefore, biology learning should intentionally develop both cognitive competencies and socio-emotional competencies that support students' participation in real-life scientific and environmental problem solving.

Creative thinking is one of the central competencies required in twenty-first-century learning. It enables students to generate diverse ideas, formulate alternative solutions, develop original responses, and elaborate ideas into meaningful products [4], [5], [6]. In biology, creative thinking is particularly relevant because environmental and ecological issues are complex, contextual, and open-ended. The topic of environmental pollution, for example, requires students to identify sources of pollution, examine ecological impacts, design possible solutions, and communicate persuasive environmental messages. Such tasks cannot be optimally developed through memorization alone; they require inquiry, collaboration, product development, and reflective evaluation [3], [7].

Alongside creative thinking, emotional intelligence has become an important learning outcome in contemporary education. Emotional intelligence refers to students' capacity to recognize, regulate, and use emotions constructively in academic and social situations [8], [9], [10]. Goleman's framework consists of self-awareness, self-regulation, motivation, empathy, and social skills [8]. These dimensions are highly relevant to biology learning because students frequently work in groups, respond to environmental issues, present ideas publicly, and negotiate different opinions during learning. Recent research on social-emotional learning also shows that structured classroom interventions can improve students' social skills, prosocial attitudes, and academic adjustment [9], [10], [11]. Thus, emotional intelligence should not be separated from academic learning but should be integrated into meaningful instructional activities.

Preliminary assessment at SMA Negeri 12 Bandar Lampung revealed that Grade X students still experienced difficulties in both competencies. The average creative thinking score reached only 36%, categorized as less creative, with fluency, flexibility, originality, and elaboration all below the expected level. The emotional intelligence questionnaire also showed an average score of 40%, categorized as poor, especially in motivation, self-regulation, and social skills. Classroom observations and teacher interviews indicated that instruction was still predominantly teacher-centered, relying on lectures, note-taking, and worksheet completion. Although this approach can deliver content efficiently, it provides limited opportunities for students to formulate original ideas, make project decisions, collaborate intensively, manage frustration, and reflect on emotional responses during learning [12], [13], [14].

Project Based Learning (PjBL) offers a relevant instructional alternative because it positions students as active learners who investigate authentic problems and produce meaningful learning products [3], [15], [16]. The PjBL process generally involves presenting a fundamental driving question, planning the project, arranging a schedule, monitoring project progress, evaluating products, and reflecting on the learning experience [17], [18]. These stages are theoretically aligned with creative thinking because students are required to produce ideas, select strategies, design products, revise work, and present original solutions. They are also aligned with emotional intelligence because students must negotiate roles, regulate emotions, listen to peers, respond to feedback, and take collective responsibility for a shared product [19], [20].

Previous studies have reported the contribution of PjBL to creative thinking, science achievement, collaboration, and affective development [21], [22], [23], [24], [25], [26]. International reviews and meta-analyses also indicate that PjBL tends to produce stronger learning outcomes when projects are authentic, sufficiently scaffolded, connected to clear learning objectives, and assessed through both process and product evidence [7], [18], [27]. However, studies that simultaneously examine creative thinking ability and emotional intelligence in Grade X biology learning remain limited, especially within the context of environmental pollution learning in Indonesian senior high schools. Many studies focus only on cognitive achievement or creative thinking, while fewer studies analyze emotional intelligence as a parallel learning outcome [28], [29], [30].

Based on this gap, the present study aims to determine the effect of the PjBL model on (1) creative thinking ability and (2) emotional intelligence of Grade X students in biology. The topic of environmental pollution was selected because it provides authentic, contextual, and socially meaningful problems for project-based inquiry. The novelty of this study lies in integrating cognitive and affective outcomes within one quasi-experimental biology learning design and in presenting indicator-level visualized evidence as substantive research findings rather than as supplementary documentation. In this way, the study contributes not only to the empirical literature on PjBL but also to practical biology pedagogy that connects scientific understanding, creativity, collaboration, and emotional development [3], [7], [9], [31].

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental pretest-posttest control group design. The design was selected because intact classes were used while still enabling comparison between an experimental group and a control group. The experimental group received instruction using the Project Based Learning model, whereas the control group received conventional direct instruction on the same biology topic, namely environmental pollution.

Table 1. Quasi-Experimental Pretest-Posttest Design

Group	Pretest	Treatment	Posttest
Experimental (X.4)	B1	X1: Project Based Learning	B2
Control (X.1)	B3	X2: Direct Instruction	B4

Note: B1/B3 = pretest scores; B2/B4 = posttest scores; X1 = PjBL treatment; X2 = conventional instruction

Population and Sample

The population consisted of all Grade X students at SMA Negeri 12 Bandar Lampung in the even semester of the 2024/2025 academic year, totaling 337 students across ten classes. Cluster random sampling was used to select two intact classes. Class X.4, consisting of 34 students, served as the experimental group, and Class X.1, consisting of 34 students, served as the control group. The study was conducted at SMA Negeri 12 Bandar Lampung, located at Jl. Hi. Endro Suratmin, Harapan Jaya, Sukarame, Bandar Lampung. Data collection took place in April 2025 during the environmental pollution unit.

Research Procedure and Instruments

The experimental group learned through six PjBL stages. First, students were oriented to a real-world driving question concerning environmental pollution in their surrounding environment. Second, students planned projects by selecting pollution subtopics, determining outputs such as posters, models, pamphlets, or short campaigns, and distributing group roles. Third, students developed a schedule for completing each project component. Fourth, the teacher monitored group progress, provided guidance, and observed emotional intelligence behaviors. Fifth, groups evaluated and presented their products. Sixth, students and the teacher reflected on conceptual understanding, creative processes, emotional challenges, collaboration, and improvement strategies. The control group learned the same content through direct instruction involving lectures, note-taking, and worksheet completion.

Two main instruments were used. The creative thinking essay test consisted of ten items mapped to four indicators: fluency, flexibility, originality, and elaboration. Items were scored using a 0-4 rubric. The emotional intelligence questionnaire consisted of 24 Likert-scale items aligned with five Goleman indicators: self-awareness, self-regulation, motivation, empathy, and social skills. An observation sheet containing nine behavioral indicators was also used to document students' emotional and collaborative behaviors during PjBL implementation. The instruments were piloted on Grade XI students at the same school before the main study.

Instrument validity was examined using Pearson Product Moment correlation with $r_{xy} > 0.30$ as the validity criterion. Seven of ten creative thinking items were valid, while sixteen of twenty-four emotional intelligence items were valid. Reliability was assessed using Cronbach's Alpha. The creative thinking test obtained alpha = 0.821 and the emotional intelligence questionnaire obtained alpha = 0.877, indicating very high reliability. The difficulty and discrimination analyses were also used to ensure that the essay test was appropriate for measuring students' creative thinking.

Data Analysis Techniques

Descriptive statistics were used to summarize pretest and posttest results. N-gain analysis was applied to measure the magnitude of improvement from pretest to posttest using the formula: N-gain = (posttest - pretest) / (maximum score - pretest) x 100%. The categories were interpreted as poor (0.00-0.19), fair (0.20-0.39), good (0.40-0.69), and excellent (0.70-1.00). Hypothesis testing used the independent samples t-test after normality testing through Kolmogorov-Smirnov and homogeneity testing through Levene's Test. All statistical analyses were conducted using SPSS version 25 with a significance level of 0.05. The visualization of N-gain and indicator achievement was integrated into the Results section as substantive data to clarify the magnitude and pattern of the intervention effect.

RESULT AND DISCUSSIONS

Result

Instruments Validity and Reliability

Before the main study, the research instruments were piloted on Grade XI students. The validation results demonstrated that the instruments were sufficiently reliable for the main data collection. The creative thinking essay test reached a Cronbach's Alpha of 0.821, while the emotional intelligence questionnaire reached 0.877. These values indicate very high internal consistency.

Table 2. Validity and Reliability Summary of Research Instruments

Instrument	Total items	Valid items	Reliability (alpha)	Category
Creative thinking essay test	10	7	0.821	Very high
Emotional intelligence questionnaire	24	16	0.877	Very high

The item difficulty analysis showed that three creative thinking items were in the difficult category and seven were in the moderate category. No item was classified as easy, indicating that the instrument provided sufficient challenge for measuring creative thinking. The discrimination index ranged from fair to excellent, suggesting that the items were able to distinguish students with different levels of performance.

Prerequisite Analysis

Kolmogorov-Smirnov normality testing showed that all pretest and posttest data for creative thinking and emotional intelligence in both groups had significance values greater than 0.05. Levene's homogeneity test also confirmed equal variance between groups for creative thinking (sig. = 0.222) and emotional intelligence (sig. = 0.590). These results indicate that the assumptions for independent samples t-test were satisfied.

Table 3. Summary of normality and homogeneity assumptions

Analysis	Variable	Result	Interpretation
Kolmogorov-Smirnov	Creative thinking pretest and posttest	All sig. > 0.05	Normally distributed
Kolmogorov-Smirnov	Emotional intelligence pretest and posttest	All sig. > 0.05	Normally distributed
Levene's Test	Creative thinking	sig. = 0.222	Homogeneous
Levene's Test	Emotional intelligence	sig. = 0.590	Homogeneous

Hypothesis Testing

The independent samples t-test was performed to compare posttest means between experimental and control groups. The results showed that PjBL produced statistically significant effects on both creative thinking ability and emotional intelligence.

Table 4. Independent Sample T-Test Results

Variable	t	df	Sig. (2-tailed)	Mean difference	Decision
Creative thinking ability	13.844	66	0.000	36.45	H0 rejected
Emotional intelligence	15.440	66	0.000	23.71	H0 rejected

For creative thinking ability, $t(66) = 13.844$ with $p < 0.05$, confirming a significant difference between the experimental and control groups. For emotional intelligence, $t(66) = 15.440$ with $p < 0.05$, also confirming a significant difference. Thus, both hypotheses were accepted: PjBL significantly influenced students' creative thinking ability and emotional intelligence in Grade X biology learning.

N-Gain Analysis and Visualization

N-gain analysis was used to clarify the magnitude of improvement. The experimental group reached an N-gain of 80.91% for creative thinking and 80.51% for emotional intelligence, both categorized as excellent. The control group reached 35.18% for creative thinking and 45.23% for emotional intelligence. These differences show that PjBL not only produced statistically significant results but also generated educationally meaningful improvement.

Table 5. Comparison of N-gain scores

Outcome	Experimental pretest	Experimental posttest	Experimental N-gain	Control pretest	Control posttest	Control N-gain
Creative thinking ability	30.25	87.18	80.91% (Excellent)	22.27	55.74	35.18% (Fair)
Emotional intelligence	44.21	89.84	80.51% (Excellent)	37.22	43.75	45.23% (Good)

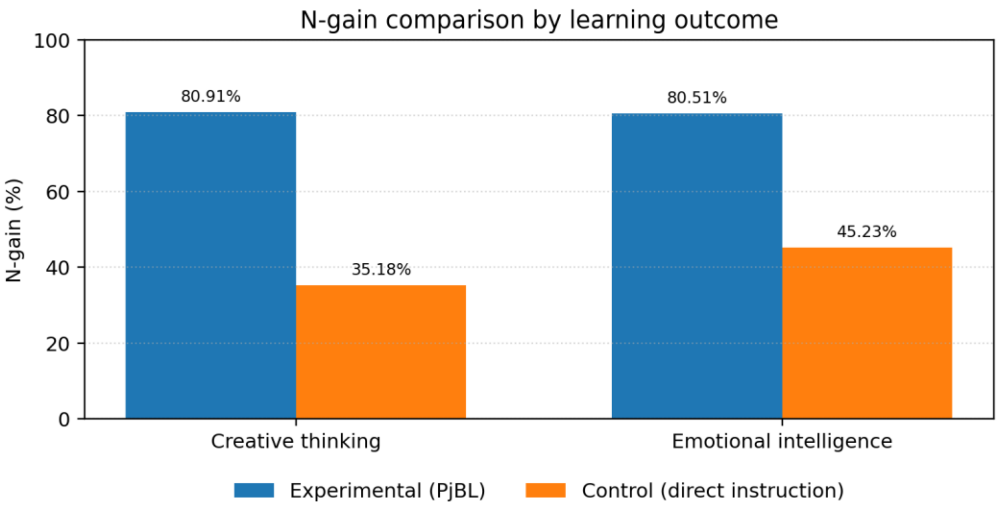


Figure 1. N-Gain Comparison of Creative Thinking Ability and Emotional Intelligence

Figure 1 is included as substantive result evidence because it displays the comparative magnitude of learning improvement between the PjBL and direct instruction groups. The visualization confirms that the experimental group consistently outperformed the control group across cognitive and affective outcomes.

Creative Thinking Indicator Achievement

The indicator-level analysis showed that all four creative thinking indicators in the experimental group reached the very creative category. Fluency reached 87%, flexibility 84%, originality 88%, and elaboration 89%. In contrast, the control group remained in the moderately creative category, with an average of 50.5%.

Table 6. Creative thinking indicator achievement by group

No	Indicator	Experimental (%)	Category	Control (%)	Category
1	Fluency	87	Very creative	47	Moderately creative
2	Flexibility	84	Very creative	55	Moderately creative
3	Originality	88	Very creative	47	Moderately creative
4	Elaboration	89	Very creative	53	Moderately creative
	Average	87	Very creative	50.5	Moderately creative

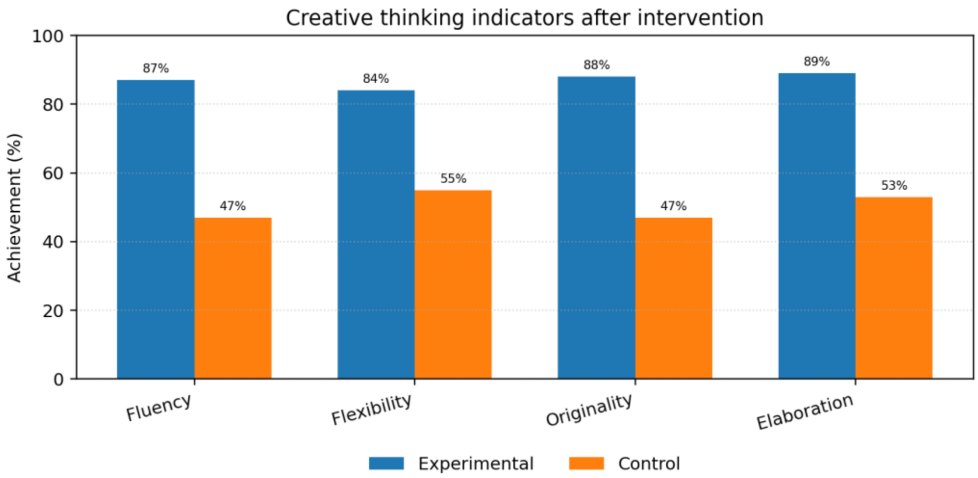


Figure 2. Visual Comparison of Creative Thinking Indicators

Figure 2 demonstrates that the strongest experimental result appeared in elaboration, followed by originality and fluency. The pattern indicates that PjBL provided students with opportunities to expand, refine, and present ideas through project products rather than merely memorizing content.

Emotional Intelligence Indicator Achievement

The emotional intelligence results showed that all five indicators in the experimental group reached the very good category. Self-awareness reached 90%, self-regulation 87%, motivation 88%, empathy 86%, and social skills 84%. In contrast, the control group averaged 58.6%, with empathy and social skills remaining in the poor category.

Table 7. Emotional intelligence indicator achievement by group

No	Indicator	Experimental (%)	Category	Control (%)	Category
1	Self-awareness	90	Very good	65	Fair
2	Self-regulation	87	Very good	64	Fair
3	Motivation	88	Very good	67	Fair
4	Empathy	86	Very good	54	Poor
5	Social skills	84	Very good	43	Poor
	Average	87	Very good	58.6	Fair

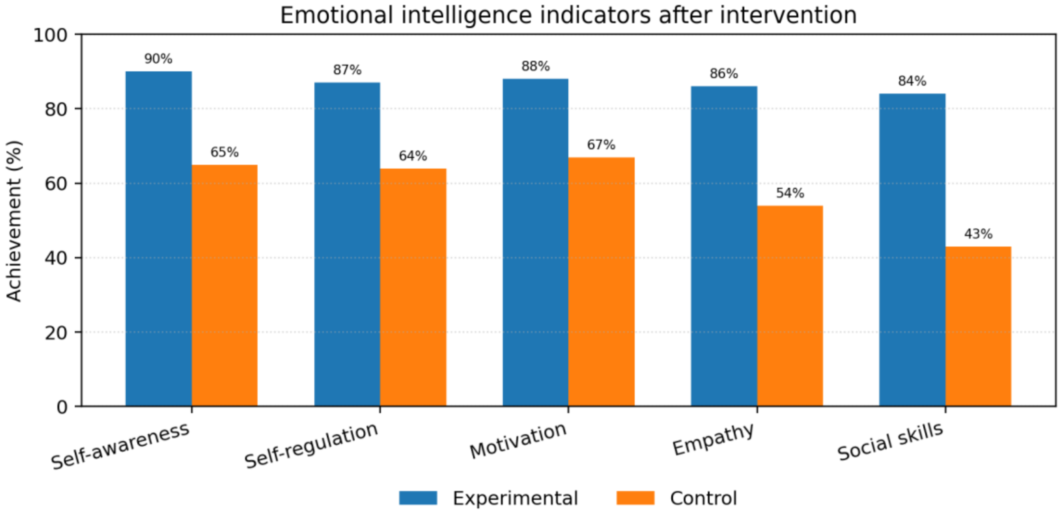


Figure 3. Visual Comparison of Emotional Intelligence Indicators

Figure 3 is presented in the Results section to emphasize that emotional intelligence was measured and analyzed as a substantive learning outcome. The visualization shows that PjBL had the strongest contribution to self-awareness, while empathy and social skills showed particularly meaningful differences compared with the control group.

Substantive Visualization of the PjBL Learning Process

The learning process was documented and analyzed as part of the research results because the implementation of PjBL is central to explaining why the experimental group improved. Therefore, the visualization of the process should not be placed in an appendix. It functions as substantive process evidence showing how the treatment was operationalized in the classroom.

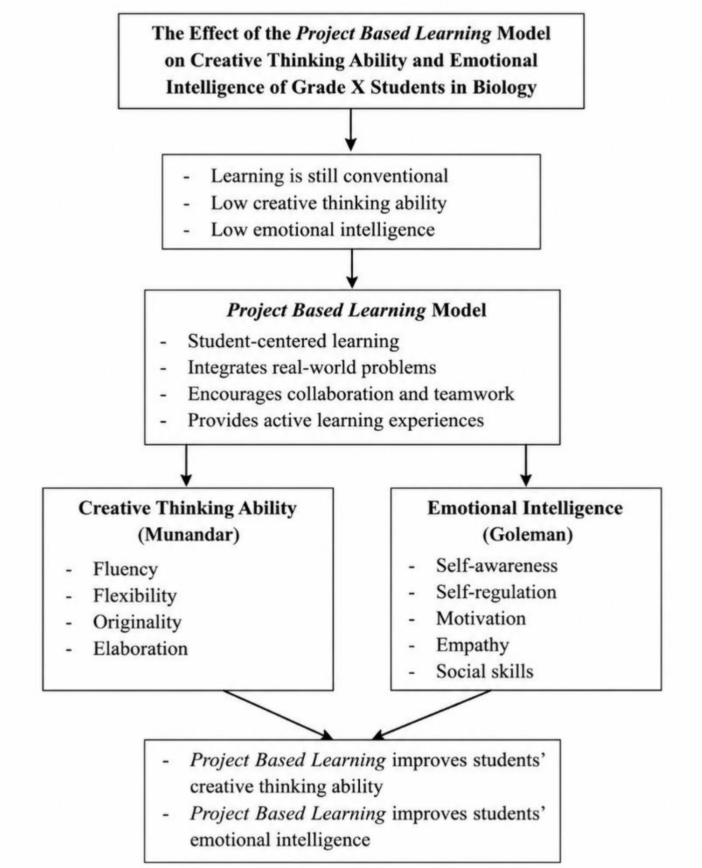


Figure 4. Conceptual framework of PjBL effects on creative thinking and emotional intelligence

Figure 4 illustrates the conceptual framework of this study. The conventional teacher-centered approach was identified as the root cause of low creative thinking and poor emotional intelligence. The PjBL model was hypothesized to address both variables through its student-centered, project-based, and collaborative characteristics.

Figure 5. Stage 1: Project Initiation – Fundamental Question

Figure 6. Stage 2: Project Planning and Role Assignment

In Stage 1, the teacher posed a real-world driving question about environmental pollution: 'Why is our river getting more and more polluted, and what can we do about it as biology students?' This provocative question immediately stimulated students to share ideas and propose diverse solutions—directly engaging the fluency and originality dimensions of creative thinking. In Stage 2, student groups collaboratively planned their projects: choosing a specific pollution sub-topic (air, water, soil, or waste), deciding on a project output format (poster, short video, model, or pamphlet), and assigning roles within the team. This collaborative planning stage was crucial for developing social skills and self-regulation components of emotional intelligence.

Figure 7. Stage 3: Teacher Monitoring and Student Guidance

Figure 8. Stage 4: Product Presentation to Class

Stage 3 (monitoring) was identified as particularly transformative for emotional intelligence development. As the teacher circulated between groups to check progress, students were required to articulate their thinking, receive critical feedback, and manage any inter-group disagreements—situations that exercised self-awareness, self-regulation, and empathy simultaneously. Stage 4 (product presentation) required each group to stand before their classmates and present their environmental pollution project. This public presentation moment cultivated confidence, communication skills, and awareness of self performance relative to group expectations.

Discussions

The results show that the experimental group achieved substantially higher creative thinking outcomes than the control group. The experimental group obtained an N-gain of 80.91% in the excellent category, while the control group obtained 35.18% in the fair category. This finding indicates that the PjBL model provided a stronger learning structure for developing fluency, flexibility, originality, and elaboration than direct instruction. The superiority of the experimental group can be explained by the authentic and open-ended nature of the environmental pollution project. When students were asked to investigate pollution problems and create products such as posters, models, video campaigns, or pamphlets, they were required to generate ideas, compare alternative solutions, refine designs, and communicate their reasoning to others [3], [7], [18].

The indicator-level visualization strengthens this interpretation. Fluency reached 87%, flexibility 84%, originality 88%, and elaboration 89% in the experimental group, all categorized as very creative. These findings demonstrate that PjBL did not merely increase the total creative thinking score but improved each dimension of creativity. Fluency developed when students proposed many possible causes and solutions related to environmental pollution. Flexibility developed when students selected different project topics, formats, and presentation strategies. Originality emerged when groups created unique products based on their own interpretations of local environmental problems. Elaboration developed as students refined initial ideas into complete products with explanations, visuals, and recommendations. This pattern is consistent with prior studies showing that PjBL can strengthen idea generation, problem solving, and product-based creativity when students are given meaningful tasks and sufficient scaffolding [5], [22], [27].

The control group received the same biology content but had fewer opportunities to create products, make decisions, negotiate alternatives, or revise solutions. Consequently, students in the control group remained in the moderately creative category. This confirms that creative thinking requires more than exposure to content; it requires learning activities that invite students to think divergently, test ideas, and transform concepts into visible products. From a biology teaching perspective, the findings suggest that environmental pollution is a suitable topic for PjBL because it is close to students' lived experiences and naturally encourages scientific inquiry, ecological reasoning, and social action [2], [31].

The findings also show that PjBL had a strong effect on students' emotional intelligence. The experimental group achieved an N-gain of 80.51% in the excellent category, while the control group achieved 45.23% in the good category. This result indicates that the project process supported not only cognitive development but also students' ability to recognize emotions, regulate responses, maintain motivation, demonstrate empathy, and build social skills. PjBL created repeated social situations in which students had to divide responsibilities, manage disagreements, respond to teacher feedback, and present group products. These situations provided authentic opportunities for practicing emotional intelligence in ways that are difficult to achieve through lecture-based instruction [8], [9], [10], [11].

The emotional intelligence indicator visualization shows that self-awareness reached 90%, self-regulation 87%, motivation 88%, empathy 86%, and social skills 84% in the experimental class. Self-awareness was strengthened through reflection activities because students evaluated their own contributions, emotional responses, and learning progress. Self-regulation developed as students managed time, handled obstacles, and adjusted group strategies during the project. Motivation increased because students worked on meaningful environmental problems and produced tangible outputs. Empathy and social skills developed through peer interaction, role negotiation, discussion, and presentation. The large gap between experimental and control groups in empathy and social skills is especially meaningful because these two indicators depend heavily on direct interpersonal experience [9], [10], [29].

These findings support the argument that emotional intelligence can be developed through academic instruction when learning activities are intentionally social, reflective, and collaborative. The role of PjBL in this study is therefore not limited to improving achievement; it also functions as a pedagogical environment for social-emotional learning. This interpretation is consistent with research showing that emotional intelligence and social-emotional competencies contribute to students' academic performance, school adjustment, and interpersonal relationships [9], [10], [11], [32].

A major contribution of this study is the simultaneous examination of creative thinking and emotional intelligence within one biology learning intervention. In many classroom studies, cognitive outcomes and affective outcomes are treated separately. The present findings show that both can develop together when learning is designed around authentic environmental projects. The environmental pollution topic allowed students to combine scientific concepts with social concerns, creative product development, and group communication. As a result, the project became a bridge between biology content, twenty-first-century skills, and character development [2], [3], [31].

The visualization of PjBL stages should therefore be treated as substantive research evidence rather than decorative documentation. The conceptual framework, implementation-stage visuals, N-gain comparison, and indicator-level charts help explain how the intervention operated and why the outcomes improved. For example, the visual comparison of N-gain scores clearly shows the magnitude of the treatment effect, while the indicator charts demonstrate which creative and emotional dimensions were most strongly developed. Including these figures in the Results and Discussion sections improves the transparency of the article and helps readers connect statistical findings with the actual instructional process.

The statistical results support the effectiveness of PjBL. The independent samples t-test showed significant differences between experimental and control groups for creative thinking ability, $t(66) = 13.844$, $p < 0.05$, and emotional intelligence, $t(66) = 15.440$, $p < 0.05$. The N-gain results further confirm that the improvement in the experimental group was educationally meaningful. Nevertheless, the findings should be interpreted within the limits of the quasi-experimental design. Although cluster random sampling was used to select intact classes, individual random assignment was not possible. Therefore, the study demonstrates a strong instructional effect in the observed context, but broader causal generalization requires replication with larger samples, multi-school settings, longer duration, and follow-up measurement [7], [18], [33].

Another important methodological point is the need to clarify how observation data complemented questionnaire and test data. The observation sheet was useful for capturing visible emotional-intelligence behaviors during project implementation, such as participation, cooperation, confidence, and peer interaction. Future research should strengthen this aspect by reporting inter-rater reliability, including examples of observation indicators, and triangulating test, questionnaire, product, and observation data. Such improvements would provide stronger evidence regarding how PjBL influences both learning products and learning processes [7], [19], [33].

The findings have several implications for biology teachers. First, PjBL should be planned as a structured learning model rather than as an incidental product-making activity. Teachers need to formulate authentic driving questions, prepare clear project rubrics, monitor group processes, and facilitate reflection. Second, creative thinking assessment should include indicator-based rubrics so that teachers can evaluate fluency, flexibility, originality, and elaboration more precisely. Third, emotional intelligence should be assessed through multiple sources, including questionnaires, observations, peer feedback, and reflective journals. Fourth, environmental pollution and similar contextual biology topics should be used to connect scientific literacy with students' local realities, enabling learning to become cognitively challenging, socially meaningful, and emotionally formative.

From a curriculum perspective, the results are aligned with the Merdeka Belajar orientation, which emphasizes student agency, collaboration, creativity, and character development. PjBL provides a practical pathway for translating these curriculum goals into biology classroom practice. However, teachers require professional support in designing authentic projects, managing classroom time, guiding group dynamics, and developing assessment tools that capture both cognitive and socio-emotional growth.

Therefore, school-level support, teacher collaboration, and continuous reflection are necessary for sustainable implementation.

CONCLUSION

This study demonstrates that Project Based Learning has a statistically significant and educationally meaningful effect on both creative thinking ability and emotional intelligence of Grade X students in biology learning at SMA Negeri 12 Bandar Lampung. The experimental group achieved N-gain scores of 80.91% for creative thinking and 80.51% for emotional intelligence, both in the excellent category, while the control group achieved 35.18% and 45.23%, respectively. Indicator-level visualization showed that all four creative thinking indicators and all five emotional intelligence indicators reached very high categories in the experimental class. These outcomes confirm that PjBL, through authentic problem-solving, collaborative project work, product development, presentation, and reflection, is more effective than conventional direct instruction in developing cognitive creativity and socio-emotional competence. The study provides evidence that environmental pollution learning can be used as a meaningful biology context for integrating creative thinking and emotional intelligence development.

LIMITATIONS

This study was conducted in one school using two intact classes, which may limit generalizability to broader school contexts. The research focused on one biology topic, environmental pollution, and the long-term retention of creative thinking and emotional intelligence outcomes was not examined. External factors that may influence students' emotional intelligence outside the classroom were also not fully controlled. Future studies should involve larger and more diverse samples, randomized or stronger quasi-experimental designs, multiple biology topics, longitudinal follow-up, and mixed-method data to strengthen causal interpretation and explore students' learning experiences in greater depth.

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AUTHOR CONTRIBUTION

DF: conceptualization, data collection, data analysis, manuscript writing, and revision. AN, MDS: research supervision, manuscript review, and methodology guidance. RO, ADK: research supervision, instrument development, and manuscript review.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

DECLARATION OF USE OF AI IN SCIENTIFIC WRITING

During the preparation of this revised manuscript, artificial intelligence tools may have been used only to support language refinement, grammar checking, sentence restructuring, and proofreading. AI tools were not used to generate research data, conduct statistical analysis, fabricate findings, or draw research conclusions. All conceptualization, methodology, data collection, data analysis, interpretation, and final manuscript approval remain the responsibility of the authors.

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