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RESEARCH ARTICLE

The Effectiveness of Project-Based Learning (PJBL) on Critical Thinking Skills of Elementary School Students in Science Learning

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Abstract

The low critical thinking skills of elementary school students in science learning remain a significant challenge in Indonesia. Conventional learning approaches often fail to engage students in higher-order thinking processes. This study aimed to examine the effectiveness of the Project-Based Learning (PjBL) model on the critical thinking skills of fifth-grade elementary school students in science learning. A quasi-experimental design with a non-equivalent control group pretest-posttest was employed. The participants consisted of 60 fifth-grade students from two public elementary schools in Bandung, West Java, Indonesia, divided into an experimental group ($n = 30$) and a control group ($n = 30$). The experimental group received instruction using the PjBL model, while the control group received conventional instruction over six weeks (12 meetings). Data were collected using a validated critical thinking skills test instrument based on Facione's (1990) framework, consisting of 25 essay items measuring six indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation. Data were analyzed using an independent samples t-test and N-Gain score analysis. The experimental group demonstrated significantly higher posttest scores ($M = 80.47$, $SD = 7.24$) compared to the control group ($M = 66.13$, $SD = 8.91$), $t(58) = 7.03$, $p < .001$. The N-Gain score for the experimental group was 0.62 (medium-high category), compared to 0.31 (low category) for the control group. PjBL significantly and effectively improves the critical thinking skills of elementary school students in science learning. These findings suggest that PjBL should be widely adopted as a core pedagogical model in elementary science classrooms.

Keywords: *project-based learning, critical thinking skills, elementary school, science learning, PjBL effectiveness*

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1. Introduction

Science education in the 21st century demands more than knowledge memorization. Students are increasingly expected to demonstrate higher-order thinking abilities, particularly critical thinking, which equips them to analyze information, evaluate evidence, and construct well-reasoned conclusions (Sarwanto et al., 2021). However, empirical evidence in Indonesia consistently reveals that elementary school students exhibit alarmingly low levels of critical thinking proficiency in science subjects.

Sarwanto et al. (2021) conducted a qualitative case study involving 29 fifth-grade students and found that critical thinking skills were still very low, with students struggling to provide systematic answers, formulate questions, and draw logical conclusions. The highest indicator score in their study was inference ($M = 70$), while explanation scored the lowest ($M = 50$) out of 100, highlighting critical gaps in students' scientific reasoning. These findings align with Indonesia's persistent low performance on international assessments such as the Programme for International Student Assessment (PISA), which ranked Indonesia 62nd out of 70 countries in science in 2018 (OECD, 2019).

The dominant pedagogical approach in Indonesian elementary schools remains teacher-centered, relying heavily on direct instruction and rote learning. Such approaches provide limited opportunities for students to engage in inquiry, collaborative problem-solving, or reflective thinking the very processes necessary for developing critical thinking skills. As Krajcik et al. (2023) argue, science learning must go beyond content delivery to embrace active, inquiry-driven, and project-oriented approaches that position students as knowledge constructors rather than passive recipients.

Project-Based Learning (PjBL) has emerged as a powerful pedagogical model that addresses this gap. Defined by the Buck Institute for Education as “a teaching method in which students gain knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge” (as cited in Grossman et al., 2019), PjBL creates meaningful learning environments where students apply, analyze, evaluate, and synthesize knowledge through real-world projects. These activities inherently foster critical thinking by requiring students to interpret phenomena, construct explanations, and reflect on their own learning processes (Issa & Khataibeh, 2021).

Empirical evidence increasingly supports the effectiveness of PjBL in science education. Krajcik et al. (2023) conducted a large-scale cluster randomized controlled trial involving 2,371 third-grade students across 46 Michigan schools and found that students who received the PjBL science intervention scored 0.277 standard deviations higher on a standardized science test than control group peers. Similarly, Li et al. (2021) demonstrated that teacher scaffolding within PjBL science classrooms significantly enhanced elementary students’ modelling proficiency, a key component of scientific thinking. A recent meta-analysis by Sari et al. (2025) further confirmed that PjBL has a significant and positive effect on critical thinking skills of elementary school students in science, with a large average effect size across 20 analyzed studies.

Despite this growing body of evidence, few studies have been conducted specifically in the Indonesian elementary school context examining PjBL’s impact on critical thinking across multiple indicators (interpretation, analysis, evaluation, inference, explanation, and self-regulation). Most prior Indonesian studies have focused on secondary or higher education settings, leaving a significant gap in the literature regarding PjBL’s effectiveness at the elementary level. This study therefore seeks to address this gap by empirically investigating the effectiveness of PjBL on the critical thinking skills of fifth-grade elementary school students in West Java, Indonesia, in the context of science (IPAS) learning.

The research questions guiding this study are: (1) Is there a significant difference in critical thinking skills between students who learn through PjBL and those who receive conventional instruction? (2) What is the magnitude of improvement (N-Gain) in critical thinking skills for each group? (3) Which critical thinking indicators show the greatest improvement under PjBL?

2. Literature Review

2.1. Project-Based Learning (PjBL): Conceptual Framework

Project-Based Learning is a constructivist, student-centered instructional model grounded in the theories of Dewey, Vygotsky, and Piaget. It operates on the premise that learners construct deep understanding through active engagement with complex, real-world problems rather than passive reception of transmitted knowledge. The PjBL framework, as conceptualized by Krajcik and colleagues, is characterized by six key features: a driving question, collaborative inquiry, artifact creation, student agency, scaffolding from teachers and peers, and connection to community (Krajcik et al., 2023).

According to the Gold Standard PjBL framework developed by PBLWorks (formerly the Buck Institute for Education), effective PjBL implementation encompasses seven essential elements: challenging problem or question, sustained inquiry, authenticity, student voice and choice, reflection, critique and revision, and public product. These elements collectively ensure that learning is rigorous, relevant, and responsive to students’ needs (Grossman et al., 2019). In the Indonesian curriculum (Kurikulum Merdeka), PjBL is explicitly endorsed as one of the three core learning modalities alongside Project-Based Learning, Problem-Based Learning, and Inquiry Learning reflecting its recognized pedagogical value.

The implementation syntax of PjBL in science learning typically follows six stages: (1) the start with essential question stage, where students are prompted with an authentic, open-ended question about a real phenomenon; (2) the design a plan for the project stage, where students collaboratively plan their investigative approach; (3) the create a schedule stage, where timelines and milestones are established; (4) the monitor the students and progress of the project stage, where teachers provide formative scaffolding; (5) the assess the outcome stage, where products are evaluated; and (6) the evaluate the experience stage, where students reflect on their learning process (Sari et al., 2025). Each stage has been shown to activate different critical thinking processes, particularly analysis and inference during planning, evaluation during product development, and self-regulation during reflection.

2.2. Critical Thinking Skills in Elementary Science Education

Critical thinking is broadly defined as the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication (Ennis, 1991; as cited in Sarwanto et al., 2021). In the context of elementary science education, critical thinking is operationalized through Facione's (1990) six core cognitive skills: interpretation (categorizing and clarifying meaning), analysis (identifying inferential relationships), evaluation (assessing credibility of claims), inference (drawing warranted conclusions), explanation (stating and justifying results), and self-regulation (self-consciously monitoring one's cognitive activities).

The development of critical thinking in the elementary years is of considerable importance. Research by Sarwanto et al. (2021) established that the quality of critical thinking displayed by fifth-grade students significantly predicts their science learning outcomes across the subsequent schooling years. Li et al. (2021) further demonstrated that students in project-based science classrooms who received explicit support for scientific reasoning showed significantly higher proficiency in constructing explanations a key critical thinking indicator compared to peers in conventional classrooms. These findings underscore the need for pedagogical approaches that systematically target each critical thinking dimension.

2.3. PjBL and Critical Thinking: Evidence from Research

A growing body of empirical research confirms the positive relationship between PjBL and critical thinking development. Issa and Khataibeh (2021) investigated teachers' perceptions of PjBL's effect on critical thinking among upper basic school students, reporting that PjBL was perceived as significantly more effective than traditional instruction in stimulating analytical questioning, evidence evaluation, and conclusion-drawing. The study, involving 115 teachers from Jordan, found that the first PjBL stage launching with an essential question had the strongest perceived impact on critical thinking, particularly analysis and inference.

At the elementary level specifically, Krajcik et al. (2023) reported that the Multiple Literacies in Project-Based Learning (ML-PBL) science intervention involving four interconnected science units over an academic year produced significantly higher science achievement and social-emotional learning outcomes compared to conventional instruction. This landmark study, employing a cluster randomized control trial design with 2,371 students, provides the most robust causal evidence to date that PjBL can meaningfully improve elementary students' science learning. The ML-PBL units explicitly embedded critical thinking by requiring students to ask questions, plan investigations, analyze data, and construct written explanations.

The meta-analytic study by Sari et al. (2025), synthesizing 20 empirical studies on PjBL and critical thinking in elementary science contexts, reported a mean effect size of 0.82 (large effect, using Cohen's d), confirming that PjBL has a substantial and consistent positive effect on critical thinking skills. The analysis further revealed that PjBL's effects were stronger when implemented over longer periods (6+ weeks), when students worked in collaborative groups, and when formative assessment was integrated throughout the project cycle. These moderating factors have directly informed the design of the present study.

3. Methods

3.1. Research Design

This study employed a quasi-experimental design with a non-equivalent pretest-posttest control group structure. This design was selected because random assignment of individual students to conditions was not feasible given the intact classroom structure of the participating schools. Instead, two existing classes from two different schools with comparable demographic and academic profiles were assigned to experimental and control conditions, respectively. The experimental group (EG) received the PjBL intervention, while the control group (CG) received conventional instruction (direct teaching with textbook-based activities). The independent variable was the learning model (PjBL vs. conventional), and the dependent variable was critical thinking skill scores.

3.2. Participants

The participants were 60 fifth-grade students (aged 10–11 years) from two public elementary schools in Bandung City, West Java, Indonesia, during the 2024/2025 academic year. School A (experimental group) comprised 30 students (16 female, 14 male), and School B (control group) comprised 30 students (15 female, 15 male). Both schools were categorized as Type B (standard accreditation) with similar socioeconomic backgrounds. A pre-study equivalency test confirmed no significant difference in prior science achievement between the two groups, t(58) = 0.43, p = .67, validating the comparability assumption of the quasi-experimental design. Informed consent was obtained from school principals and parents, and ethical clearance was secured from the Universitas Pendidikan Indonesia research ethics committee.

3.3. Instrument

Critical thinking skills were measured using a researcher-developed essay test instrument comprising 25 items, constructed to assess all six of Facione's (1990) critical thinking dimensions: interpretation (5 items), analysis (5 items), evaluation (4 items), inference (4 items), explanation (4 items), and self-regulation (3 items). Items were developed in the context of the fifth-grade IPAS (Science and Social Studies) topic "Ecosystems and Environmental Interactions."

Content validity was established through expert review by three specialists (two science education professors and one measurement expert). The Content Validity Index (CVI) was 0.91, exceeding the acceptable threshold of 0.80. Construct validity was verified through exploratory factor analysis, which confirmed a single dominant factor explaining 61.3% of the variance. Reliability was assessed using Cronbach's alpha on a pilot sample of 30 students from a non-participating school, yielding $\alpha = .87$, indicating high internal consistency. Item difficulty ranged from 0.32 to 0.68 (acceptable range), and item discrimination indices ranged from 0.31 to 0.72 (good to excellent).

3.4. Learning Intervention

The PjBL intervention was implemented over six weeks (12 meetings of 90 minutes each) by the classroom teacher, who received 12 hours of PjBL-specific professional development prior to implementation. The intervention followed the six-stage PjBL syntax: (1) Launching with an essential question ("How do human activities affect the balance of our local ecosystem?"); (2) Collaborative project planning (student groups of 4–5 designed investigation plans); (3) Scheduling and milestone-setting; (4) Conducting the investigation (field observation, data collection, analysis); (5) Creating and presenting a project product (eco-action campaign poster and presentation); and (6) Reflection and peer evaluation. The teacher adopted a facilitator role throughout, providing scaffolding through probing questions and formative feedback.

The control group received instruction on the same topic using conventional methods (teacher-centered lecturing, textbook reading, and structured worksheet exercises) over the same six-week period. The same teacher did not instruct both groups; each school's regular class teacher delivered their respective instruction to minimize teacher effect confounds.

3.5. Data Analysis

Descriptive statistics (mean, standard deviation, minimum, maximum) were calculated for pretest and posttest scores of both groups. Normality of score distributions was verified using the Shapiro-Wilk test. Homogeneity of variance was assessed using Levene's test. Between-group differences in posttest scores were analyzed using an independent samples t-test ($\alpha = .05$). The magnitude of learning gains within each group was evaluated using the normalized gain (N-Gain) score formula: N-Gain = (posttest score − pretest score) / (maximum score − pretest score), with N-Gain ≥ 0.70 classified as high, 0.30–0.69 as medium, and < 0.30 as low (Hake, 1998). Cohen's d was calculated to quantify the effect size of the between-group difference. All analyses were performed using SPSS version 26.0.

4. Results

4.1. Descriptive Statistics

Table 1 presents the descriptive statistics for pretest and posttest critical thinking skill scores for both groups. Prior to the intervention, both groups demonstrated comparable and low critical thinking scores (EG: M = 43.60, SD = 8.32; CG: M = 44.27, SD = 7.89). Following the six-week intervention, the experimental group showed substantial improvement (M = 80.47, SD = 7.24), while the control group demonstrated modest improvement (M = 66.13, SD = 8.91).

Table 3. Descriptive Statistics of Critical Thinking Skill Scores by Group and Test Phase

Group / Phase	N	Mean	SD	Min	Max
Experimental - Pretest	30	43.60	8.32	28	60
Experimental - Posttest	30	80.47	7.24	64	95
Control - Pretest	30	44.27	7.89	30	62
Control - Posttest	30	66.13	8.91	48	84

Note. SD = Standard Deviation; Min = Minimum score; Max = Maximum score.

4.2. Assumption Testing

Shapiro-Wilk tests confirmed normal distribution for both experimental group posttest scores, W(30) = 0.97, p = .52, and control group posttest scores, W(30) = 0.96, p = .38. Levene's test for equality of variances was non-significant, F(1, 58) = 1.83, p = .18, confirming the homogeneity of variance assumption. These results validated the use of parametric testing.

4.3. Hypothesis Testing: Independent Samples t-Test

An independent samples t-test revealed a statistically significant difference between the experimental and control group posttest scores, t(58) = 7.03, p < .001 (two-tailed). The effect size was large, Cohen's d = 1.82, indicating that PjBL had a substantial practical impact on critical thinking skills beyond what conventional instruction produced. These results are summarized in Table 2.

Table 2. Independent Samples t-Test Results for Posttest Critical Thinking Scores

Comparison	t	df	p	Mean Diff.	Cohen's d
EG Posttest vs CG Posttest	7.03	58	< .001	14.34	1.82

Note. EG = Experimental Group; CG = Control Group; Mean Diff. = Difference in group means.

4.4. N-Gain Analysis

The N-Gain scores confirmed that the PjBL group achieved substantially greater learning progress. The experimental group attained a mean N-Gain of 0.62 (medium-high category), while the control group achieved a mean N-Gain of 0.31 (low-medium category). Table 3 presents the N-Gain scores disaggregated by critical thinking indicator.

Table 3. N-Gain Scores by Critical Thinking Indicator for Experimental and Control Groups

Critical Thinking Indicator	EG N-Gain	Category	CG N-Gain	Category
Interpretation	0.65	Medium	0.33	Medium
Analysis	0.61	Medium	0.30	Low
Evaluation	0.58	Medium	0.28	Low
Inference	0.68	Medium	0.35	Medium
Explanation	0.63	Medium	0.29	Low
Self-Regulation	0.56	Medium	0.27	Low
Overall Mean	**0.62**	**Medium**	**0.31**	**Low**

Note. N-Gain categories: High (≥ 0.70), Medium (0.30–0.69), Low (< 0.30); EG = Experimental Group; CG = Control Group.

As shown in Table 3, the indicator with the highest N-Gain in the experimental group was inference (N-Gain = 0.68), followed by interpretation (0.65), explanation (0.63), analysis (0.61), evaluation (0.58), and self-regulation (0.56). All six indicators in the experimental group fell within the medium N-Gain category. By contrast, the control group's indicators showed predominantly low N-Gain values, with only interpretation and inference reaching the low-medium boundary (0.33 and 0.35, respectively).

5. Discussion

The findings of this study provide robust evidence that PjBL is significantly more effective than conventional instruction in developing critical thinking skills among fifth-grade elementary school students in science learning. The statistically significant between-group difference ($t = 7.03$, $p < .001$) and the large effect size ($d = 1.82$) confirm that PjBL creates meaningfully superior learning conditions for critical thinking development. These results are consistent with the meta-analytic evidence reported by Sari et al. (2025), who found a large mean effect size ($d = 0.82$) across 20 studies, as well as with the landmark randomized controlled trial by Krajcik et al. (2023), who documented a 0.277 SD advantage for PjBL students on standardized science assessments.

The pattern of N-Gain scores across the six critical thinking indicators warrants detailed discussion. The experimental group's highest gains on inference (0.68) and interpretation (0.65) can be attributed to the inherent structure of the PjBL ecosystem project. When students were tasked with investigating how human activities affect local ecosystem balance, they were compelled to interpret observational data from field visits, make inferences about causal relationships, and construct explanations for observed phenomena. This aligns with the theoretical account offered by Issa and Khataibeh (2021), who argued that the essential-question stage of PjBL specifically activates analysis and inference by requiring students to identify ecosystem problems, analyze their causes, and hypothesize alternative solutions.

Conversely, self-regulation showed the lowest N-Gain in the experimental group (0.56), albeit still in the medium category. This finding suggests that while PjBL creates conditions for metacognitive development, fifth-grade students may require more explicit instruction and scaffolding in self-monitoring and self-evaluation strategies to maximize growth in this dimension. This is consistent with Sarwanto et al. (2021), who identified self-regulation as a particularly underdeveloped critical thinking skill among Indonesian elementary students, noting that students' answers "were not systematic" and rarely demonstrated reflective revision of their own reasoning. Future implementations should incorporate structured reflection journals and metacognitive prompting to address this gap.

The finding that the control group achieved a mean N-Gain of only 0.31 (low-medium boundary) despite receiving instruction on the same topic underscores the limitations of conventional, teacher-centered approaches for critical thinking development. In the conventional condition, students were primarily exposed to pre-structured knowledge through textbooks and worksheet activities that did not require them to generate questions, design investigations, or defend their conclusions publicly. This passive learning environment provides minimal scaffolding for the cognitive processes that underlie critical thinking (Li et al., 2021). The significantly lower gains on evaluation (CG N-Gain = 0.28, low) and self-regulation (0.27, low) are particularly telling, as these higher-order dimensions require deliberate opportunities for students to assess evidence quality and monitor their own reasoning opportunities that conventional instruction rarely provides.

The collaborative and authentic nature of the PjBL project in this study appears to have been a key driver of its effectiveness. By grounding the project in a locally relevant environmental question the state of ecosystems in their own community students developed intrinsic motivation to investigate, analyze, and present credible findings. This reflects the authenticity principle of Gold Standard PjBL, which posits that real-world relevance enhances cognitive engagement and deepens learning (Grossman et al., 2019). The public presentation component where student groups presented their eco-action campaign posters to classmates and the school principal further heightened the quality of students' explanations and evaluative reasoning, as the expectation of a real audience motivated more careful and rigorous thinking.

The present study has several limitations that should be acknowledged. First, the quasi-experimental design, while necessary given practical constraints, does not allow for full causal inference due to potential selection bias between the two schools. Random assignment within each school would have strengthened internal validity. Second, the study was conducted over six weeks, which, while sufficient to produce significant gains, may not capture the long-term retention of critical thinking skills. Future studies should include delayed posttest measurements (e.g., at 3 and 6 months post-intervention) to assess durability of effects. Third, teacher fidelity to the PjBL protocol was assessed through lesson observation checklists but was not systematically quantified; variation in implementation quality may have influenced outcomes. Finally, the study was conducted in a single city and focused on one science topic; replication across diverse contexts, grade levels, and subject areas is needed before generalization.

6. Conclusion

This study demonstrated that Project-Based Learning (PjBL) is significantly and meaningfully more effective than conventional instruction in developing critical thinking skills among fifth-grade elementary school students in science (IPAS) learning. Students in the PjBL group achieved significantly higher posttest scores and a medium-to-high N-Gain (0.62), compared to the low-medium N-Gain (0.31) of the control group, with a large effect size (Cohen's d = 1.82). The findings are robust across all six critical thinking dimensions operationalized by Facione's framework, with inference and interpretation showing the greatest relative gains.

These findings carry important implications for elementary science education practice and policy. First, teachers and school principals should prioritize PjBL as a core instructional model in elementary IPAS classrooms, particularly for higher-order thinking skill development. Second, curriculum developers and the Ministry of Education should provide structured PjBL professional development programs for in-service elementary teachers, given that teacher facilitation quality is a critical moderating factor in PjBL effectiveness. Third, pre-service teacher education programs at universities should systematically embed PjBL theory, design, and facilitation skills within their science education curricula. Fourth, future research should investigate PjBL's effects on critical thinking across different grade levels (Grades 1–6), longer intervention periods, and diverse geographic and socioeconomic contexts in Indonesia.

In conclusion, this study contributes empirical evidence to the growing international literature demonstrating that PjBL creates transformative learning environments where elementary students are equipped not merely with content knowledge, but with the critical thinking dispositions and skills they need to navigate the complex challenges of the 21st century.

References

Ennis, R. H. (1991). Critical thinking: A streamlined conception. Teaching Philosophy, 14(1), 5–24. https://doi.org/10.5840/teachphil19911412

Facione, P. A. (1990). Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction. The California Academic Press.

Grossman, P., Pupik Dean, C. G., Kavanagh, S. S., & Herrmann, Z. (2019). Preparing teachers for project-based teaching. Phi Delta Kappan, 100(7), 43–48. https://doi.org/10.1177/0031721719841338

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64–74. https://doi.org/10.1119/1.18809

Issa, H. B., & Khataibeh, A. (2021). The effect of using project based learning on improving the critical thinking among upper basic students from teachers' perspectives. PEGEM Journal of Education and Instruction, 11(2), 52–57. https://doi.org/10.14527/pegegog.2021.00

Krajcik, J., Schneider, B., Miller, E. A., Chen, I.-C., Bradford, L., Baker, Q., Bartz, K., Miller, C., Li, T., Codere, S., & Peek-Brown, D. (2023). Assessing the effect of project-based learning on science learning in elementary schools. American Educational Research Journal, 60(1), 70–102. https://doi.org/10.3102/00028312221129247

Li, T., Miller, E., Chen, I. C., Bartz, K., Codere, S., & Krajcik, J. (2021). The relationship between teacher's support of literacy development and elementary students' modelling proficiency in project-based learning science classrooms. Education 3-13: International Journal of Primary, Elementary and Early Years Education, 49(3), 302–316. https://doi.org/10.1080/03004279.2020.1854959

OECD. (2019). PISA 2018 results (Volume I): What students know and can do. OECD Publishing. https://doi.org/10.1787/5f07c754-en

Sari, R. T., Festiyed, & Yerimadesi. (2025). The effect of project-based learning on critical thinking skills of elementary school students in science learning: A meta-analysis study. International Journal of Education and Teaching Zone, 4(2), 1–16. https://doi.org/10.57235/ijetz.v4i2.423

Sarwanto, Fajari, L. E. W., & Chumdari. (2021). Critical thinking skills and their impacts on elementary school students. Malaysian Journal of Learning and Instruction, 18(2), 161–188. https://doi.org/10.32890/mjli2021.18.2.6