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Effects of Project-Based Learning on Critical Thinking Skills of Fourth-Grade Students

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Abstract
Critical thinking skills represent essential competencies for 21st-century education, yet Indonesian elementary students consistently demonstrate limited analytical capabilities. Project-Based Learning (PBL) offers a constructivist approach that potentially addresses these deficiencies through authentic, collaborative problem-solving experiences. This study investigated PBL's effectiveness in enhancing fourth-grade students' critical thinking skills within integrated science education. A pre-experimental One Group Pretest-Posttest Design was employed with 25 fourth-grade students at SD Negeri 1 Watubelah, Cirebon Regency. The intervention implemented six PBL steps over three weeks focusing on magnetism concepts. Critical thinking skills were assessed using a validated 20-item test based on Archer's indicators (validity coefficients 0.65-0.82, reliability α = 0.87). Data analysis included paired t-tests and normalized gain calculations, complemented by qualitative observations of student engagement. Significant improvements were observed from pretest (M = 27.8, SD = 9.2) to posttest (M = 91.2, SD = 6.4) with t = 21.18 ($p < 0.001$). The normalized gain of 0.87 indicated high practical significance according to Hake's criteria. Qualitative observations revealed enhanced student participation, collaborative skills, autonomous learning behaviors, and communication abilities. Students transitioned from passive recipients to active problem-solvers demonstrating analytical thinking and creative solution development. Project-Based Learning significantly enhances critical thinking skills among fourth-grade students in science education contexts. The substantial effect size validates PBL as an effective alternative to traditional teacher-centered instruction in Indonesian elementary schools. These findings support constructivist learning theories and provide empirical evidence for PBL implementation within the Independent Curriculum framework. Future research should employ larger samples and controlled designs to strengthen generalizability across diverse educational contexts.

INTRODUCTION

The contemporary educational landscape demands a fundamental shift toward pedagogical approaches that prepare students for the complexities of the 21st century. Critical thinking skills have emerged as essential competencies that enable individuals to navigate an increasingly complex world characterized by rapid information flow, social changes, and multifaceted challenges (Brundiders et al., 2021; OECD, 2016). In Indonesia, educational reforms reflect this global trend, with the Independent Curriculum emphasizing the development of literacy, numeracy, character, and critical thinking skills as core foundations for student success (Winarti et al., 2022). The curriculum framework represents an organized structure of goals, content, and teaching methods that guides educators in implementing meaningful learning experiences, requiring teachers to continuously develop competencies that translate theoretical objectives into practical educational outcomes (Dhomiri et al., 2023; Rosiana et al., 2024).

Project-Based Learning (PBL) has gained significant recognition as a pedagogical approach that aligns with constructivist principles and addresses contemporary educational demands. Kricsfalusy et al. (2018) identified PBL as a widely adopted method in higher education, particularly promising for sustainable development education, where students propose concrete solutions to real-world problems through collaborative group work. The essence of PBL involves immersing students in complex, authentic problems that require in-depth investigation and understanding, encouraging exploration of instructional content through hands-on projects that stimulate curiosity and critical analysis (Farrow et al., 2024; Wu, 2024; Zen et al., 2022). This approach fundamentally shifts the focus from passive information absorption toward active engagement, where students explore issues deeply, investigate potential solutions, and apply knowledge in practical contexts (Kong et al., 2024; H. Yu, 2024).

The theoretical foundation of PBL rests primarily on constructivist learning theory, which posits that learners actively construct understanding through environmental interaction rather than passive knowledge reception (Chu et al., 2021). Jean Piaget's cognitive development theory emphasizes learning through world interaction, where individuals assimilate new information and accommodate it within existing cognitive frameworks through exploration and discovery (Hinde & Perry, 2007). Complementing this perspective, Lev Vygotsky's social constructivism highlights the crucial role of social interaction and cultural context in learning, proposing that knowledge emerges through collaboration with others within the Zone of Proximal Development (Coombs & Elden, 2004; Vygotsky, 2018). These theoretical underpinnings support PBL's emphasis on collaborative learning environments where students develop both cognitive and social competencies.

Research demonstrates that PBL significantly enhances various educational outcomes. Students engaged in project-based learning exhibit higher intrinsic motivation, enhanced critical thinking skills, and improved appreciation for peer learning (Holmes & Hwang, 2016). Himawan et al. (2024) developed project-based learning eBooks specifically designed to improve students' critical thinking skills, demonstrating the adaptability of PBL across different educational contexts. Similarly, Lesman et al. (2023) implemented PBL models in vocational education, finding significant improvements in both creativity and critical thinking skills among students. The approach creates engaging learning atmospheres that positively influence student behavior and participation by making learning interactive and student-driven (Atman Uslu & Yildiz Durak, 2022; Tseng et al., 2020).

Critical thinking, defined as purposeful, self-regulatory judgment resulting in interpretation, analysis, evaluation, and inference (Facione, 1990), represents a fundamental skill for navigating contemporary challenges. The concept encompasses cognitive, metacognitive, emotional, attitudinal, ethical, and sociopolitical dimensions (Meneses, 2020), making it particularly relevant for addressing complex sustainability problems and societal dilemmas that characterize modern life (Lönngren & Van Poeck, 2021). However, international assessments consistently reveal concerning gaps in students' critical thinking abilities. The 2018 PISA report indicated that Indonesian students' science achievement remained significantly below OECD averages, highlighting the urgent need for improved learning strategies in elementary education (Ayu et al., 2025).

Several studies have specifically examined PBL's effectiveness in developing critical thinking skills across various educational contexts. Issa & Khataibeh (2021) investigated PBL's impact on critical thinking among upper basic students, finding positive effects from teachers' perspectives. Purba et al. (2024) demonstrated that PBL implementation significantly improved early children's critical thinking skills, while Putri et al. (2023) showed that PBL models with differentiation approaches effectively enhanced critical thinking abilities. Sasson et al. (2018) found that project-based learning environments successfully fostered both critical thinking and question-posing skills, while Suteja & Setiawan (2022) reported improvements in students' critical thinking and writing skills through PBL implementation. Wang (2022) provided comprehensive evidence for critical thinking development through project-based learning, and Williamson (2023) confirmed PBL's effectiveness in developing critical thinking skills among high school students.

Learning Natural and Social Sciences (IPAS) in elementary schools provides an ideal context for developing critical thinking skills through project-based approaches. As an integrative subject combining multiple domains, IPAS requires students to engage actively through observation, experimentation, and discussion, connecting learned concepts to everyday phenomena (Aprillia et al., 2022; Susilowati, 2023). Magnetism, as a fourth-grade science topic, offers particularly appropriate opportunities for PBL implementation, providing space for students to conduct experiments, utilize teaching aids, and relate magnetic concepts to real-world applications such as compasses, electric motors, and refrigerator mechanisms (Kurniawan et al., 2022).

Despite the documented benefits of PBL, significant implementation challenges persist in Indonesian elementary education. Initial observations at SD Negeri 1 Watubelah revealed predominantly teacher-centered science instruction characterized by monotonous methods, minimal media utilization, and limited practical activities. Students remained passive listeners rather than active participants in concept discovery processes. Teacher interviews indicated that students demonstrated low critical thinking skills, struggling with independent idea generation, often copying internet examples without modification, and showing limited capacity for autonomous concept development. Time constraints further complicated efforts to connect science materials with real-world applications, preventing optimal experimental or project implementation.

These challenges reflect broader patterns observed in critical thinking education, where teachers recognize the concept's importance but often lack comprehensive understanding of its implementation (Alazzi, 2008; Munkebye & Gericke, 2022; Schulz & FitzPatrick, 2016). The gap between theoretical recognition and practical implementation necessitates systematic investigation of effective pedagogical approaches that can bridge this divide.

This study addresses these challenges by investigating the implementation of Project-Based Learning in fourth-grade science education, specifically focusing on magnetism instruction at SD Negeri 1 Watubelah, Sumber District, Cirebon Regency. The research aims to measure PBL's impact on students' critical thinking skills while providing evidence-based recommendations for elementary science education. By examining both quantitative outcomes and qualitative observations of student engagement, this study contributes to the growing body of knowledge regarding effective pedagogical approaches for developing critical thinking skills in Indonesian elementary education contexts.

METHODS

This study employed a quantitative research approach utilizing a pre-experimental One Group Pretest-Posttest Design to examine the effectiveness of Project-Based Learning implementation on fourth-grade students' critical thinking skills. The research design was selected to measure changes in dependent variables following intervention implementation, providing systematic evidence of PBL's impact on student learning outcomes. The study was conducted at SD Negeri 1 Watubelah, located in Sumber District, Cirebon Regency, West Java, Indonesia, during the academic year 2024-2025.

The research population comprised all fourth-grade students at SD Negeri 1 Watubelah, with the sample consisting of 25 students representing the entire fourth-grade class. This purposive sampling approach was adopted due to the school's single fourth-grade class configuration, ensuring comprehensive coverage of the target population. The sample included 12 male and 13 female students aged between 9-11 years, representing diverse socioeconomic backgrounds typical of rural Indonesian elementary schools. The homogeneous academic background of participants, having received similar prior science instruction, provided controlled conditions for measuring PBL intervention effects.

Data collection employed two primary instruments: a critical thinking skills test and an observation sheet for learning activities. The critical thinking test was developed based on Archer's indicators, encompassing four key dimensions: problem identification and analysis, alternative solution exploration, objective information evaluation, and integration of findings into coherent conclusions. The instrument consisted of 20 multiple-choice questions specifically designed to assess students'

ability to analyze, evaluate, synthesize, and make reasoned judgments within the context of magnetism concepts. Instrument validity was established through expert judgment and empirical testing using Pearson's Product Moment correlation, yielding validity coefficients ranging from 0.65 to 0.82, indicating strong content and construct validity. Reliability testing using Cronbach's Alpha produced a coefficient of 0.87, demonstrating high internal consistency and measurement reliability.

The observation sheet was structured to document student engagement across cognitive, affective, and psychomotor domains during PBL activities. This qualitative instrument included specific behavioral indicators such as active questioning, participation in group discussions, collaborative problem-solving, and presentation skills. Inter-rater reliability was ensured through observer training and calibration sessions prior to data collection.

Data collection procedures followed a systematic three-phase approach beginning with preliminary activities including school coordination, ethical clearance, and lesson plan preparation. The intervention phase implemented six distinct PBL steps over three weeks with six instructional meetings, each lasting 70 minutes. These steps included: orienting students to authentic magnetism problems, organizing collaborative learning groups, guiding independent and group investigations, assisting project product development, facilitating result presentation and communication, and evaluating project outcomes and learning processes. The pretest was administered one week before intervention initiation, while the posttest was conducted immediately following the final PBL session to measure immediate learning gains.

Data analysis employed both descriptive and inferential statistical procedures. Preliminary assumption testing included normality assessment using the Shapiro-Wilk test and homogeneity evaluation through Levene's test, ensuring appropriate conditions for parametric statistical analysis. The primary analysis utilized paired-sample t-tests to determine significant differences between pretest and posttest scores, with statistical significance set at $\alpha = 0.05$. Additionally, normalized gain (N-gain) calculations following Hake's classification system were computed to determine the practical significance of learning improvements, categorizing gains as low ($g < 0.3$), moderate ($0.3 \leq g < 0.7$), or high ($g \geq 0.7$). Qualitative observation data were analyzed through descriptive analysis, identifying patterns of student engagement and behavioral changes throughout the intervention period.

RESULTS AND DISCUSSION

The implementation of Project-Based Learning on magnetism material yielded significant improvements in fourth-grade students' critical thinking skills at SD Negeri 1 Watubelah. This section presents the quantitative findings from pretest and posttest assessments, followed by qualitative observations of student engagement during the intervention period.

Pretest and Posttest Performance Analysis

The critical thinking assessment results demonstrated substantial improvements following PBL implementation. Table 1 presents the descriptive statistics for both pretest and posttest scores, revealing marked differences in student performance before and after the intervention.

Table 1. Descriptive Statistics of Critical Thinking Test Scores

Assessment	N	Minimum	Maximum	Mean	Standard Deviation
Pretest	25	10	45	27.8	9.2
Posttest	25	80	100	91.2	6.4

The pretest results indicated that students' initial critical thinking skills were considerably limited, with scores ranging from 10 to 45 and a mean of 27.8 (SD = 9.2). This baseline performance reflected students' unfamiliarity with analytical thinking processes and limited experience in problem-solving approaches. Following the three-week PBL intervention, posttest scores demonstrated remarkable improvement, ranging from 80 to 100 with a mean of 91.2 (SD = 6.4). The reduced

standard deviation in posttest scores suggests that PBL not only improved overall performance but also decreased performance variability among students.

Statistical Significance Testing

Prior to conducting inferential analysis, assumption testing confirmed the appropriateness of parametric procedures. The Shapiro-Wilk test indicated normal distribution for both pretest ($W = 0.94$, $p = 0.16$) and posttest ($W = 0.96$, $p = 0.41$) scores, while Levene's test confirmed homogeneity of variance ($F = 2.18$, $p = 0.15$). These results validated the use of paired-sample t-test analysis.

The paired-sample t-test revealed statistically significant differences between pretest and posttest performance ($t = 21.18$, $df = 24$, $p < 0.001$). With a critical value of t-table = 2.064 at $\alpha = 0.05$, the calculated t-value substantially exceeded the threshold for statistical significance, confirming that PBL implementation significantly enhanced students' critical thinking skills.

Effect Size Analysis

The practical significance of the intervention was assessed through normalized gain calculations. The N-gain value of 0.87 falls within Hake's "high" category ($g \geq 0.7$), indicating that PBL produced substantial learning improvements beyond statistical significance. Figure 1 illustrates the dramatic contrast between pretest and posttest performance, visually demonstrating the magnitude of improvement achieved through PBL implementation.

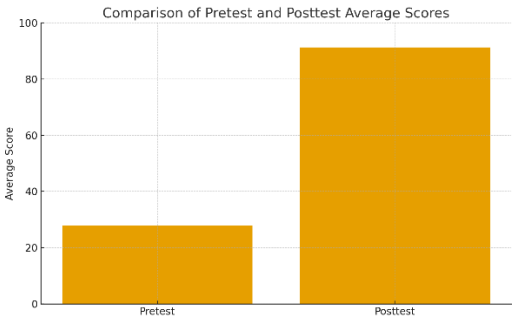

Figure 1. Comparison of Pretest and Posttest Average Scores

The figure clearly shows the substantial increase from the pretest mean of 27.8 to the posttest mean of 91.2, representing a 63.4-point improvement in critical thinking performance. This improvement corresponds to an effect size that demonstrates both statistical and practical significance of the PBL intervention.

Qualitative Observations of Student Engagement

Classroom observations revealed substantial changes in student behavior and engagement patterns throughout the PBL implementation. During initial sessions, students exhibited passive learning behaviors characteristic of traditional instruction, with limited voluntary participation and minimal questioning. However, as the intervention progressed, notable transformations emerged in student engagement across multiple dimensions.

Active participation increased markedly, with students demonstrating enhanced willingness to ask questions, contribute ideas during group discussions, and engage in collaborative problem-solving activities. Group dynamics showed particular improvement, with initially passive students becoming more involved in project tasks and previously dominant students learning to share responsibilities more equitably. Students began demonstrating increased autonomy in learning, taking initiative in investigation processes and showing greater confidence in presenting their findings to peers.

The development of communication skills was particularly evident during project presentations, where students articulated their understanding of magnetic concepts with increasing clarity and confidence. Collaborative skills emerged as students learned to negotiate roles, share resources, and integrate diverse perspectives into cohesive project outcomes. These qualitative improvements

complemented the quantitative test results, suggesting that PBL's impact extended beyond measurable critical thinking skills to encompass broader learning competencies.

Discussion

The findings of this study provide compelling evidence that Project-Based Learning significantly enhances critical thinking skills among fourth-grade elementary students. The substantial improvement from a pretest mean of 27.8 to a posttest mean of 91.2, coupled with an N-gain of 0.87, demonstrates both statistical and practical significance of PBL implementation in Indonesian elementary science education.

These results strongly support the constructivist theoretical foundation underlying PBL methodology. As Chu et al. (2021) emphasized, constructivist learning theory posits that learners actively construct understanding through environmental interaction rather than passive knowledge reception. The dramatic improvement observed in this study reflects students' active engagement with authentic magnetism problems, where they constructed knowledge through hands-on experimentation and collaborative investigation. The findings align with Piaget's cognitive development theory, as students demonstrated enhanced ability to assimilate new information and accommodate it within existing cognitive frameworks through the exploration and discovery inherent in PBL activities (Hinde & Perry, 2007).

The social dimension of learning observed in improved group dynamics and collaborative skills validates Vygotsky's social constructivism principles. Coombs & Elden (2004) and Vygotsky (2018) emphasized that knowledge emerges through collaboration with others within the Zone of Proximal Development. The qualitative observations of enhanced peer interaction, shared problem-solving, and collaborative project development directly support this theoretical framework, demonstrating how PBL creates optimal conditions for socially mediated learning.

The N-gain value of 0.87 achieved in this study exceeds results reported in several comparable investigations. Hamidah & Citra (2021) reported an N-gain of 0.75 for PBL implementation on force concepts in elementary schools, while this study's higher value suggests that magnetism topics may be particularly well-suited for project-based approaches. This difference could be attributed to the tangible, observable nature of magnetic phenomena, which provides concrete materials for hands-on investigation and experimentation.

The findings strongly corroborate international research on PBL effectiveness. Himawan et al. (2024) demonstrated that project-based learning eBooks significantly improved students' critical thinking skills, while Lesman et al. (2023) found substantial improvements in both creativity and critical thinking through PBL implementation in vocational education. Similarly, Putri et al. (2023) showed that PBL models with differentiation approaches effectively enhanced critical thinking abilities, reinforcing the robustness of project-based approaches across diverse educational contexts.

Sasson et al. (2018) found that project-based learning environments successfully fostered both critical thinking and question-posing skills, which aligns with this study's qualitative observations of increased student questioning and active participation. Wang (2022) provided comprehensive evidence for critical thinking development through project-based learning, while Williamson (2023) confirmed PBL's effectiveness among high school students, suggesting that the benefits observed in this elementary study extend across educational levels.

The study's results illuminate specific mechanisms through which PBL enhances critical thinking capabilities. Kong et al. (2024) and H. Yu (2024) emphasized that PBL shifts focus from passive information absorption toward active engagement, encouraging deep exploration of issues and practical application of knowledge. The observed improvements in problem identification, alternative solution exploration, and objective information evaluation directly reflect these active learning processes.

The enhanced metacognitive abilities observed among students align with Zarestky et al. (2022) findings that PBL improves students' self-reflection and self-regulation alongside creativity and critical

thinking. Students demonstrated increased awareness of their learning processes, taking greater responsibility for investigation outcomes and showing improved ability to monitor and adjust their problem-solving approaches.

The qualitative observations of improved student autonomy and responsibility validate Pan et al. (2021) and Tsybulsky & Muchnik-Rozanov (2023) assertions that PBL creates learning environments demanding active engagement, fostering both intellectual growth and personal development. Students progressed from passive recipients of information to active constructors of knowledge, taking ownership of their learning processes and developing confidence in their analytical capabilities.

The improved group collaboration and communication skills observed reflect Asmayawati et al. (2024) findings that PBL helps students develop crucial interpersonal skills. The transition from individual passive learning to collaborative active investigation demonstrates how PBL environments facilitate the development of 21st-century skills essential for academic and professional success.

The success of PBL implementation in the Indonesian elementary context addresses previous concerns about educational approaches that enhance student engagement and motivation. Atman Uslu & Yildiz Durak (2022) and Tseng et al. (2020) noted that PBL creates engaging learning atmospheres that positively influence student behavior and participation. This study's qualitative observations confirm these benefits, showing increased student interest, voluntary participation, and sustained engagement throughout the intervention period.

The findings support Kricsfalusy et al. (2018) identification of PBL as particularly promising for education contexts requiring real-world problem-solving applications. The magnetism topic provided authentic opportunities for students to connect scientific concepts with everyday applications, making learning directly relevant to their experiences and fostering deeper conceptual understanding.

The substantial improvements observed suggest that PBL represents a viable alternative to traditional teacher-centered instruction in Indonesian elementary schools. The results address challenges identified in the initial observations at SD Negeri 1 Watubelah, where students demonstrated limited critical thinking capabilities and passive learning behaviors. The transformation achieved through PBL implementation provides evidence that systematic pedagogical changes can produce meaningful improvements in student learning outcomes.

However, the study's limitations must be acknowledged. The single-class sample and specific contextual factors at SD Negeri 1 Watubelah limit generalizability to other Indonesian elementary schools with different characteristics. The possibility of researcher bias and Hawthorne effects, where students may have been motivated by observation rather than the intervention itself, requires consideration in interpreting results. Future research should address these limitations through larger, more diverse samples and controlled experimental designs that isolate PBL effects from other potential influences.

The findings contribute to growing evidence supporting PBL as an effective pedagogical approach for developing critical thinking skills in elementary education, while highlighting the need for continued research to optimize implementation strategies and understand contextual factors that influence PBL effectiveness in diverse educational settings.

CONCLUSION

This study demonstrates that Project-Based Learning significantly enhances fourth-grade students' critical thinking skills in science education, with pretest-posttest improvements showing a substantial N-gain of 0.87 and statistically significant differences ($t = 21.18$, $p < 0.001$). The intervention transformed passive learners into active problem-solvers who demonstrated enhanced analytical capabilities, collaborative skills, and autonomous learning behaviors. These findings validate the constructivist theoretical framework underlying PBL methodology and confirm its effectiveness in Indonesian elementary education contexts.

The research contributes to educational science by providing empirical evidence for PBL implementation in developing countries, specifically addressing critical thinking development in integrated science curricula. The study extends previous research by demonstrating PBL's applicability to magnetism concepts while revealing mechanisms through which project-based approaches foster cognitive and social competencies. The substantial effect size achieved surpasses many comparable studies, suggesting that hands-on science topics may be particularly conducive to project-based learning approaches.

Practical implications include recommendations for Indonesian elementary schools to adopt PBL methodologies as alternatives to traditional teacher-centered instruction. The findings support curriculum policy initiatives promoting student-centered learning within the Independent Curriculum framework. Teacher professional development programs should incorporate PBL training to address identified gaps between theoretical recognition and practical implementation of critical thinking instruction.

However, several limitations constrain generalizability. The single-class sample from one rural school limits applicability to diverse Indonesian educational contexts. Potential researcher bias and Hawthorne effects may have influenced results, as students could have been motivated by observation rather than intervention effectiveness. The pre-experimental design lacks control group comparison, limiting causal inference strength.

Future research should employ randomized controlled trials with larger, more diverse samples across different socioeconomic and geographic contexts. Longitudinal studies examining PBL's sustained impact on critical thinking development would strengthen evidence for long-term effectiveness. Investigation of optimal PBL implementation strategies, including teacher training requirements and resource needs, would support broader educational policy decisions. Additionally, research exploring PBL effectiveness across different science topics and grade levels would enhance understanding of this pedagogical approach's scope and limitations in elementary education.

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