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Enhancing Fifth-Grade Students' Critical Thinking Skills through Project-Based Learning Integrating STEM Elements in Science

Endang Wahyudiana[1]*, I Made Astra[2] , Iva Sarifah[3]
[1,2,3]Post-Graduate Of Elementary School Education, The State University Of Jakarta, Jakarta, Indonesia
*EndangWahyudiana_9919919012@mhs.unj.ac.id

Abstract

This research is motivated by the demand for the development of critical thinking skills as the main competency of the 21st century in science learning in elementary schools. Science learning practices that are still dominated by a teacher-centered approach lead to low student involvement and lack of facilitation of high-level thinking skills. The purpose of this article is to conceptually examine the potential of Project-Based Learning (PjBL) integrated with STEM (Science, Technology, Engineering, and Mathematics) elements in developing critical thinking skills of grade V elementary school students. The method used is a literature review with a qualitative descriptive approach to internationally reputable journal articles that are relevant to PjBL, STEM, and critical thinking in science education. Data were analyzed through thematic synthesis to identify the role of the PjBL stages and the integration of STEM elements in stimulating critical thinking indicators, including analysis, inference, evaluation, explanation, and self-regulation. The results of the study show that STEM-integrated PjBL provides a contextual, cross-disciplinary, and authentic problem-solving oriented learning environment, so it has a strong potential in supporting the development of students' critical thinking. STEM integration acts as a conceptual and procedural reinforcement in science learning projects. This article emphasizes that STEM-integrated PjBL has a strong theoretical foundation to be used as a framework for 21st century science learning in elementary schools.

Keyword: Critical Thinking; Project-Based Learning; STEM Integration; Science Learning; Elementary School

1 INTRODUCTION

Critical thinking is one of the key competencies that is increasingly urgent to be developed, especially in science learning, along with the increasing complexity of scientific phenomena, technological developments, and real-world problem-solving demands. These skills allow students to analyze evidence, evaluate arguments, and apply the logical and systematic reasoning that is the foundation of scientific inquiry and responsible decision-making (Saikia & Roy, 2024). In the context of science education, critical thinking is not just a supporting skill, but a core part of science literacy that plays an important role in helping students design experiments, interpret data, and build scientific explanations based on empirical evidence (Gobert et al., 2015; Janoušková et al., 2023). A number of studies have shown that students' critical thinking skills can be significantly improved through active learning approaches, such as inquiry-based learning, problem-based learning, and project-based learning (PjBL), which place students on an authentic and meaningful problem-solving process (Arsal, 2017; Sasson et al., 2018; Zhang & Ma, 2023)

However, science learning in elementary schools is still faced with various fundamental problems, especially the dominance of the teacher-centered approach and the low development of students' Higher-Order Thinking Skills (HOTS). This condition is inseparable from the limitations of mastery of content and teacher science pedagogy, which causes learning to focus on one-way information transmission and minimally involves student inquiry and exploration activities (Watson, 2024). Other findings show that the scientific approach that should be the main feature of science learning has not been optimally applied in elementary schools, resulting in a low reasoning and analytical thinking ability of students (Kodirun et al., 2025). In addition, the limitations of teachers in designing HOTS-based assessment instruments have resulted in learning evaluations that measure lower-level thinking skills, so that the development of students' critical thinking has not been systematically facilitated (Rahayu & Alsulami, 2024).

The low critical thinking skills of elementary school students are also reflected in the lack of use of learning strategies that require analysis, evaluation, and problem-solving. Studies have shown that the application of innovative learning models, such as problem-based learning and project-based learning contextualized with real problems, can significantly improve students' HOTS and science literacy (Guerrero-Hernández et al., 2023; Krajcik et al., 2023; Penuel et al., 2022). Learning strategies that emphasize open discussion, experimentation, and authentic problem-solving have proven effective in developing students' critical thinking skills and high-level thinking disposition (Arviat et al., 2023). However, the limitations of teachers' conceptual and practical understanding are still the main obstacles, so learning strategies oriented towards the development of critical thinking have not been applied consistently (Andreucci-Annunziata et al., 2023; Khalid et al., 2021; Li et al., 2025).

The use of learning technology is one of the alternative solutions to strengthen the development of critical thinking in science learning. The use of interactive simulations, such as PhET, has been shown to improve students' conceptual understanding and problem-solving abilities through visual and exploratory learning experiences (Diab et al., 2024). The integration of other technologies, such as virtual reality and virtual labs, also has a positive impact on students' scientific inquiry and reasoning skills (Gobert et al., 2015; Wu et al., 2021). A technology-enabled collaborative learning environment further strengthens the development of critical thinking through interaction, discussion, and shared problem-solving, which is an important competency in STEM education (Xinh et al., 2025). However, the implementation of learning that explicitly targets critical thinking still faces challenges, especially related to the difference in teachers' understanding of the concept of critical thinking and the limitations of its integration in the curriculum (Ghahremani et al., 2017), so that continuous professional development of teachers is needed (Day et al., 2013).

The urgency of developing critical thinking in science learning is not only related to academic achievement, but also to students' readiness to face the challenges of the global community. Critical thinking equips students with the ability to make rational decisions, solve problems creatively, and adapt to uncertainty (Funke, 2025). By making critical thinking the main achievement of learning through the right pedagogical model and technological integration, science education can play a strategic role in shaping students who are scientifically literate, reflective, and responsible as citizens (Toheri et al., 2020).

Grade V elementary school students are in a phase of cognitive and social development characterized by increased learning independence, ability to set goals, and awareness of their own thought processes, although there are still variations between individuals (Suryana et al., 2020). At this stage, students begin to demonstrate divergent thinking skills that are the basis for HOTS development and problem-solving (Fauziah et al., 2020). Grade V student engagement tends to increase when learning is actively designed, contextual, and meaningful, as such approaches are able to increase cognitive engagement and in-depth conceptual understanding (Fadilah & Alwi, 2020). Therefore, students at this level need a learning model that is relevant to real experience and encourages their active participation (Polivanova et al., 2017).

In this context, Project-Based Learning (PjBL) is seen as an approach that is in line with the characteristics and developmental needs of grade V students. PjBL is able to increase learning engagement through collaborative activities and real-world problem-based project completion, which has a positive impact on problem-solving skills and 21st century skill mastery (Chhabra and Gawande, 2025; N. Rehman et al., 2025). Furthermore, PjBL contributes to the development of critical thinking, creativity, collaboration, and communication through a student-centered, product-oriented learning process (Al-Kamzari & Alias, 2025). Involvement in real projects allows students to relate theoretical knowledge to practice, thereby strengthening conceptual understanding and relevance of learning (Moreira & Marques, 2025).

Strengthening PjBL through the integration of STEM (Science, Technology, Engineering, and Mathematics) elements is a strategic approach to provide authentic and cross-disciplinary science learning. STEM-integrated PjBL engages students in real-world projects that demand the application of multidisciplinary knowledge in an integrated manner, thus encouraging complex problem-solving and critical thinking (Selimi et al., 2025; Tsutsumi, 2025). Based on these conditions, this study is designed to examine the effectiveness of Project-Based Learning integrated with STEM in improving the critical thinking skills of grade V students in science learning. This research is expected to make a theoretical contribution to the development of elementary school science learning models through strengthening the integration of STEM and critical thinking as the main learning achievements. Practically, the results of this research are expected to be a reference for teachers and policy makers in designing innovative, meaningful science learning, while supporting the improvement of the quality of science education in elementary schools.

2 RESEARCH METHODS

This study uses a qualitative descriptive approach based on literature review (*qualitative literature-based study*). This approach aims to analyze, synthesize, and interpret theoretical findings and previous research results that are relevant to the application *Project-Based Learning* (PjBL) integrated STEM elements in science learning and the development of critical thinking skills of elementary school students. Qualitative descriptive studies allow the author to understand concepts, models, and relationships between variables in depth without collecting empirical data in the field (Creswell & Poth, 2018).

The data sources in this study are in the form of articles from reputable international journals indexed by academic books, as well as research reports relevant to the topics of critical thinking, Project-Based Learning, and the integration of STEM in science education. Articles are selected based on the following criteria: (1) published in internationally reputable journals, (2) discussing PjBL, STEM, or critical thinking in the context of science education, and (3) relevant to the primary education level. Source selection was carried out purposively to ensure the depth and relevance of the study (Snyder, 2019).

The analysis of the study was carried out using a conceptual framework that related: (1) the characteristics and stages of Project-Based Learning, (2) the integration of STEM (Science, Technology, Engineering, and Mathematics) elements, and (3) indicators of critical thinking ability (analysis, inference, evaluation, explanation, and self-regulation). This framework is used to organize the findings of the literature and identify patterns, fits, and differences between the results of previous research (Krajcik et al., 2023). The data was analyzed using qualitative content analysis techniques. The analysis stages include: (1) grouping of the main themes from the literature, (2) reduction and categorization of concepts, (3) synthesis of findings, and (4) drawing conceptual conclusions related to the role of STEM-integrated PjBL in supporting the development of students' critical thinking. The analysis process is carried out iteratively to ensure consistency and depth of interpretation (Miles & Huberman, 1984). The validity of the study is maintained through the consistency of reference sources, the use of internationally reputable journals, and comparisons across research findings to avoid interpretation bias. Transparency of the selection process and literature analysis is used to improve *credibility* and *dependability* kajian (Guba & Lincoln, 1994).

3 RESULT AND DISCUSSION

3.1 Project-Based Learning as a Student-Centered Approach in Science Learning

Based on the results of a study of internationally reputable literature, *Project-Based Learning* (PjBL) is consistently positioned as a student-oriented learning approach (*student-centered*) and based on authentic problem-solving. The findings of the study show that PjBL places students as the main actors in the learning process through exploration activities, problem formulation, planning, and meaningful product development. With these characteristics, science learning no longer focuses on the transmission of knowledge by teachers, but on the process of actively and collaboratively constructing knowledge by students (Bell, 2025; Krajcik et al., 2023). In addition, PjBL allows for differentiation of learning activities according to students' abilities and interests, which contributes to increased involvement and motivation of elementary school students (Kokotsaki et al., 2016; Silverman, 2016).

The results of the study show that PjBL has several main characteristics that support science learning. First, PjBL encourages student autonomy and inquiry by providing space to formulate questions, conduct investigations, and develop solutions independently. This process strengthens students' cognitive engagement and fosters a sense of responsibility for their own learning (Sahin, 2013; Sánchez-García & Reyes-de-Cózar, 2025). Second, PjBL emphasizes collaboration and communication through group work. The literature synthesis shows that teamwork in PjBL helps students develop social skills, argumentative skills, and joint reflection on learning processes and outcomes. This collaborative aspect is crucial in science learning, which demands collective discussion, exchange of ideas, and problem-solving (Felipe et al., 2016; Haatainen & Aksela, 2021). Third, PjBL is often associated with the use of technology as a means of supporting learning. The use of digital tools and technological media in science projects enriches students' learning experiences and makes learning more contextual and relevant to modern life (S. U. Rehman, 2023; Shpeizer, 2019).

In addition, PjBL plays an important role in the development of 21st century skills, particularly critical thinking, problem-solving, and cooperation. This study shows that student involvement in projects that demand problem analysis, solution design, and outcome evaluation provides a sustained cognitive stimulus. Thus, PjBL has great potential to support science learning goals in elementary schools that are not only oriented towards cognitive learning outcomes, but also on the development of higher-level thinking competencies (Leite et al., 2016). Although it has various advantages, the results of the study also identified a number of challenges in the implementation of PjBL. The main challenges include the need for teacher readiness in designing projects, limited learning time, availability of resources, and complexity in assessing student learning processes and products. Assessment in PjBL not only assesses the final results, but also the learning process, so it requires the right evaluation instruments and strategies (Shspeizer, 2019). In addition, the cultural context and learning habits of students also affect the success of PjBL. In an educational environment that is still dominated by traditional learning approaches, the transition to PjBL requires institutional support, teacher mentoring, and gradual adaptation so that students can participate optimally (Hunt et al., 2007).

3.2 Integration of STEM Elements in Project-Based Learning in Science Education

Based on the results of a study of various internationally reputable literature, the integration of STEM elements in *Project-Based Learning* (PjBL) has been proven to enrich the science learning context through a cross-disciplinary approach that is interconnected. The findings of the study show that each STEM element has a specific and complementary pedagogical role within the framework of PjBL. Science elements serve as a conceptual foundation that builds students' scientific understanding, while Technology and Engineering facilitate the application of science concepts in the form of real solutions or products. The Mathematics element supports the measurement process, data analysis, and evidence-based decision-making. This integration makes learning projects more authentic, contextual, and relevant to real-world problems (Jiau, n.d.; Laur, 2013). The results of the literature synthesis also show that STEM-integrated PjBL allows students to face complex and multidimensional problems, thus encouraging the use of various scientific perspectives in the problem-solving process.

The literature review conceptually distinguishes between STEM-based learning in general and PjBL that integrates STEM elements. In STEM-based learning, disciplinary integration is often the primary goal of learning. On the other hand, in STEM-integrated PjBL, projects act as the core framework of learning, while STEM elements function as conceptual and procedural reinforcements in the project process. This difference confirms that STEM-integrated PjBL does not demand rigid integration of disciplines, but rather emphasizes the functional linkage between fields of science according to the needs of the project (Bybee, 1997). This approach is considered more flexible and realistic to be applied at the elementary school level, considering the characteristics of students' cognitive development that still requires concrete and structured learning experiences.

The results of the study show that the integration of STEM in PjBL contributes to the development of various important competencies of students. The literature emphasizes that STEM integrated project-based learning encourages the development of students' critical thinking, problem-solving, collaboration, communication, and self-regulation skills. These skills develop through students' active involvement in designing solutions, testing ideas, evaluating outcomes, and reflecting on the learning process (Akmal et al., 2025; Yusuf et al., 2023). In addition, the integration of STEM in PjBL has also been reported to increase student engagement and learning motivation. Projects that are based on real problems and close to students' lives make learning more meaningful and interesting, so that students are encouraged to actively participate in every stage of learning (Fatin & Sudira, 2023).

3.3 PjBL Integrating STEM Elements and the Development of Critical Thinking

Based on the results of a literature review of internationally reputable articles, the integration of STEM elements in Project-Based Learning (PjBL) shows strong potential in developing students' critical thinking skills. Literature synthesis indicates that STEM-integrated PjBL provides a learning environment that requires students to analyze real problems, design solutions, test ideas, and reflect on learning processes and outcomes. The process is aligned with critical thinking indicators that include analysis, inference, evaluation, explanation, and self-regulation. The findings of the study show that STEM-integrated project-based learning encourages deep student cognitive engagement. Project activities that are contextual and cross-disciplinary require students to relate science concepts to the application of technology, engineering principles, and mathematical reasoning. This condition encourages students to not only understand concepts declaratively, but also to use them in decision-making and problem-solving, which is at the core of critical thinking (Pan & Allison, 2010; Rahmawati et al., 2021). The results of the study revealed that the development of critical thinking in STEM integrated PjBL occurred through pedagogical mechanisms at each stage of the project. At the problem formulation stage, students are trained to identify and analyze problems based on real phenomena. The project planning and execution stages encourage students to develop inferences, design solutions, and evaluate alternatives based on existing evidence and limitations.

4 CONCLUSION

Based on the results of the literature review, it can be concluded that Project-Based Learning (PjBL) integrated with STEM elements has strong conceptual potential in supporting the development of critical thinking skills in science learning in elementary schools. The characteristics of PjBL are student-centered, authentic problem-based, and emphasize the process of exploration and reflection in line with the needs of 21st century learning that demand high-level thinking skills. The integration of Science, Technology, Engineering, and Mathematics elements in the project framework enriches the learning process by presenting an applicable cross-disciplinary context. Each stage of PjBL provides opportunities for students to practice the ability to analyze, infrere, evaluate, explain, and self-regulate on an ongoing basis. Thus, STEM-integrated PjBL not only serves as an innovative learning strategy, but also as a pedagogical framework that supports meaningful and contextual science learning. However, the implementation of STEM-integrated PjBL requires careful learning planning, teacher readiness, and curriculum support and assessment systems that are in accordance with the characteristics of project-based learning. Therefore, further research is recommended to test the application of this approach empirically in the context of primary schools in order to strengthen conceptual findings and provide more comprehensive practical recommendations

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