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Implementation of Project-Based Learning-Oriented STEM Education to Enhance Primary School Students' Creativity and Problem-Solving Skills

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Abstract
Conventional memorization-based instruction in elementary schools often struggles to cultivate 21st-century competencies, while empirical research integrating Science, Technology, Engineering, and Mathematics (STEM) with geological disaster mitigation for lower-grade students remains scarce. Addressing this gap, this study provides novel empirical insights by implementing Project-Based Learning (PjBL)-oriented STEM education tailored to the concrete operational stage of third-grade students to foster creativity, problem-solving skills, and conceptual understanding. A qualitative descriptive approach supported by quantitative learning outcome data was employed, involving 23 third-grade students at SDN Sadagori 1 during the 2024/2025 academic year. Data were collected through pre-tests, post-tests, observations, and performance assessments during a contextual water-filtration project addressing post-disaster turbid water. Within this project, students integrated Science by analyzing water properties and filtration mechanisms, Technology by utilizing measuring instruments and instructional media, Engineering by designing functional filter prototypes, and Mathematics by calculating water volumes and filter layer thicknesses. Findings revealed substantial classical and individual score improvements, notably among low-performing students, while iterative design nurtured creativity, problem-solving, and collaboration. Practically, educators can adopt low-cost, contextual PjBL-STEM modules to bridge theoretical science with disaster preparedness in under-resourced classrooms, cultivating resilient learners.

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Introduction

The rapid transformation of the global landscape amid technological disruption and climate change demands that primary education systems transition from rote memorization toward the holistic cultivation of 21st-century competencies. From an early age, learners must be equipped with creative thinking, critical reasoning, and the capacity to solve complex real-world problems in order to adapt effectively to future challenges (Kennedy & Sundberg, 2020). However, instructional practices in many primary school classrooms remain dominated by conventional, teacher-centered, and siloed disciplinary approaches that restrict students' exploratory space (Dare et al., 2021). Over-reliance on unidirectional content delivery frequently fails to foster divergent thinking fluency or student resilience when confronting ill-structured, contextual problems (Wahono et al., 2020). Furthermore, limited hands-on, inquiry-based learning experiences hinder students from connecting theoretical concepts taught in school with real phenomena in their immediate environment (Margot & Kettler, 2019; Nadelson & Seifert, 2021). Left unaddressed, this creates a significant skill gap unless remedied through pedagogical innovations aligned with children's stages of cognitive development (Slavin, 2018; Wan et al., 2021). Consequently, reforming instructional strategies at the primary education level is an urgent prerequisite for preparing a generation of innovative, solution-oriented learners (Li et al., 2022).

In response to these pedagogical demands, the Science, Technology, Engineering, and Mathematics (STEM) approach has emerged prominently as a 21st-century educational paradigm bridging academic theory and real-world practice. Conceptually, STEM education integrates these four disciplines into a cohesive, applied learning experience oriented toward inquiry, exploration, and solution engineering (Kelley & Knowles, 2016; Wan et al., 2021). At the primary school level, STEM integration has proven effective in building foundational scientific literacy, self-confidence, and learner autonomy from an early age through student-centered activities (Guzey et al., 2016; Wahono et al., 2020). Synergizing the STEM approach with the Project-Based Learning (PjBL) model further amplifies instructional efficacy by requiring students to design tangible artifacts through ideation, collaboration, and design iteration (Larmer et al., 2015; Rohman et al., 2022). Through the stages of the engineering design process (EDP), students move beyond passive information reception, learning instead from trial-and-error failures to modify prototypes and generate alternative solutions (Syukri et al., 2018; Thibaut et al., 2018). Recent empirical studies also affirm that teacher preparedness in implementing project-based STEM correlates positively with heightened student motivation and cognitive achievement (English, 2016; Tucker et al., 2024). Thus, the STEM-PjBL model occupies a strategic position in contemporary educational research as a catalyst for simultaneously cultivating creativity and problem-solving capabilities (Li et al., 2022).

The successful implementation of STEM-PjBL depends heavily on selecting authentic problem contexts closely tied to learners' lived realities and environmental needs. One critical issue highly relevant to Indonesia's geographical vulnerability is geological disaster mitigation and its secondary impacts, such as clean water scarcity resulting from post-disaster water contamination and turbidity (Kartini et al., 2021). Historically, disaster education in primary schools has been delivered normatively through the memorization of evacuation procedures without engaging students in post-disaster technical problem-solving (Amri et al., 2022). Yet integrating geological disaster mitigation into a STEM framework offers an authentic avenue for

students to apply environmental science concepts, simple technologies, and engineering principles to construct emergency water filtration devices (Rohman et al., 2022; Suryani et al., 2023). Direct involvement in designing solutions for turbid water assists third-grade students, who operate within Piaget's concrete operational stage, in comprehending cause-and-effect relationships in a tangible and meaningful manner (Bell, 2010; Piaget, 1972). Beyond raising environmental awareness, simple water-filtration engineering projects train students to think systematically, test the efficacy of local materials, and collaborate effectively within teams (Han et al., 2014; Kartini et al., 2021). Accordingly, combining geological disaster mitigation contexts with STEM-PjBL represents a high-potential pedagogical strategy for constructing both conceptual understanding and social sensitivity among young learners (English, 2016).

Despite the expanding body of literature on STEM education, empirical investigations combining STEM-PjBL with geological disaster mitigation among lower-grade primary school students still exhibit notable research gaps. First, Kartini et al. (2021) examined STEM Project-Based Learning on Earth's layers and disaster topics to enhance problem-solving skills, but their study focused on junior high school students who had already reached the formal operational stage of abstract reasoning, thereby failing to capture the cognitive dynamics of lower-grade primary learners. Second, Rohman et al. (2022) explored STEM-PjBL integration utilizing local environmental materials to build scientific understanding and creativity, yet the problem context was not specifically oriented toward geological disaster preparedness or mitigation. Third, Suryani et al. (2023) investigated geological disaster mitigation education at the elementary level, but their approach remained confined to conceptual instructional material development without incorporating project-based engineering design activities to jointly measure creativity and problem-solving. Collectively, these prior studies demonstrate a lack of targeted research examining simple water-filtration engineering projects within a STEM-PjBL framework for third-grade primary students in the context of geological disaster mitigation. Bridging this empirical gap is vital given that the psychological profile of 8- to 9-year-old learners requires concrete project scaffolding distinct from that used in higher educational tiers (Piaget, 1972; Slavin, 2018). Addressing this void, the present study provides empirical evidence illustrating how simple project design processes in STEM-PjBL foster creativity and problem-solving in lower primary grades.

Psychologically, third-grade primary school students (aged 8–9 years) are situated in the concrete operational stage, which limits their capacity for abstract mathematical modeling or overly intricate mechanical manipulation; consequently, the Engineering Design Process (EDP) must be streamlined into cycles of visual observation, simple material assembly, and direct testing (English, 2016; Piaget, 1972). Adapting the EDP sequence in this manner functions as cognitive scaffolding that accommodates children's working-memory constraints as they progressively link physical filtration principles to the structural arrangement of filter media (Slavin, 2018; Wan et al., 2021). Moreover, employing coarse-textured, easily handled materials, such as gravel, sand, and plastic bottles. It aligns with the fine motor coordination levels of lower-grade students, ensuring that prototype iteration proceeds safely, independently, and meaningfully (Guzey et al., 2016; Syukri et al., 2018).

The urgency of this study is driven by the pressing need to equip primary school students in disaster-prone regions with practical mitigation literacy from an early age. Without instructional interventions that cultivate engineering reasoning and problem-solving, students

risk remaining passive bystanders when confronting post-disaster environmental crises such as clean water shortages (Amri et al., 2022; Kartini et al., 2021). Furthermore, many lower-grade primary teachers remain hesitant to adopt STEM-PjBL due to misconceptions that engineering integration is overly complex for third graders and requires costly laboratory facilities (Margot & Kettler, 2019; Tucker et al., 2024). This investigation is therefore crucial in demonstrating that STEM-PjBL projects utilizing readily available, low-cost environmental materials can be implemented effectively even within resource-constrained school settings (Margot & Kettler, 2019; Wan et al., 2021). Theoretically, the findings enrich STEM pedagogy at the concrete operational stage. A developmental phase frequently marginalized in science and technology education discourse (Dare et al., 2021). Practically, the study offers an operational model for primary educators to design contextual instruction that seamlessly integrates the science curriculum with disaster preparedness (Suryani et al., 2023). Thus, this research holds strategic value both for elevating classroom instructional quality and for strengthening youth resilience against geological hazards.

Grounded in the aforementioned background, empirical gaps, and urgency, this study focuses on implementing Project-Based Learning (PjBL)-oriented STEM instruction within the context of geological disaster mitigation through a simple water-filtration device project in Grade III at SDN Sadagori 1. To guide the inquiry systematically, three primary research questions were formulated: (1) How is the implementation process of PjBL-based STEM instruction carried out on geological disaster mitigation material for third-grade primary school students? (2) How does students' creativity develop in terms of generating ideas, modifying designs, and discovering alternative solutions during the execution of the simple water-filtration project? and (3) How do students' problem-solving skills and learning outcomes improve following PjBL-based STEM instruction? These questions were addressed using a qualitative descriptive design supported by quantitative pre-test and post-test learning outcome data to obtain a comprehensive, in-depth account of the learning phenomenon (Creswell, 2014; Miles et al., 2014). Specifically, this study aims to describe the stages of PjBL-STEM implementation and analyze the developmental dynamics of creativity, problem-solving skills, and conceptual mastery of geological disaster mitigation among lower-grade primary students. By fulfilling these objectives, this article contributes empirical insights toward advancing contextual, inclusive, and meaningful STEM pedagogical innovations in primary education.

Method

This study employed a qualitative descriptive approach supported by quantitative student learning outcome data. The qualitative descriptive design was utilized to examine in depth the implementation process of Project-Based Learning (PjBL)-oriented STEM instruction, alongside the development of students' creativity and problem-solving skills throughout the learning activities. Quantitative data served as complementary evidence to corroborate qualitative findings through a comparison of students' pre-test and post-test scores. Rather than testing statistical hypotheses (Creswell, 2014; Sugiyono, 2019), this study sought to portray the instructional phenomenon of STEM education applied to lower-grade primary school learners within a geological disaster mitigation context. The research was conducted during the odd semester of the 2024/2025 academic year at SDN Sadagori 1. The participants comprised 23 students from Class III B, aged 8–9 years. At this developmental stage, learners are situated in

the concrete operational phase, making instruction emphasizing hands-on activity, exploration, and contextual problem-solving highly appropriate (Piaget, 1972; Slavin, 2018). Class III B was purposively selected based on students' readiness to engage in project-based learning and the alignment of geological disaster mitigation topics with basic competencies in the primary school curriculum. Data collection was carried out using tests, observations, and performance assessments. Written tests were administered to measure improvements in students' conceptual understanding before and after the project-based STEM intervention. Classroom observations were conducted using a structured creativity observation sheet encompassing indicators of generating novel ideas, modifying prototype designs, and identifying alternative solutions to encountered obstacles. Performance assessments were executed using an analytical rubric evaluating students' competencies during project work, including STEM project execution skills, group collaboration, and the final water-filtration prototype artifact. The collected data were analyzed both qualitatively and quantitatively. Qualitative observational data were analyzed descriptively by documenting student behaviors indicative of creativity and problem-solving throughout the instructional sequence. Quantitative data from pre-tests and post-tests were analyzed by comparing individual and class-wide scores prior to and following instruction. Data trustworthiness was ensured through methodological triangulation, integrating evidence from test scores, structured observations, and performance assessments to yield a holistic and accurate depiction of gains in learning outcomes, creativity, and problem-solving skills. As noted by Miles et al. (2014), data triangulation constitutes an effective strategy in educational research for strengthening the credibility and dependability of findings. Furthermore, all research instruments were constructed based on pedagogical indicators aligned with primary school learners' developmental characteristics to ensure objective measurement of classroom conditions (Sugiyono, 2013).

Results and Discussion

Results

The research findings were derived from analyzing the pre-test and post-test data of Class III B students at SDN Sadagori 1 following the implementation of Project-Based Learning (PjBL)-oriented STEM instruction on geological disaster mitigation. This analysis was conducted to evaluate improvements in students' academic achievement as well as the progression of their creativity and problem-solving skills after engaging in project-based learning (Fraenkel et al., 2012). Pre-test results indicated that a substantial proportion of students initially possessed low baseline comprehension of environmental concepts and geological disaster mitigation, demonstrating that prior to the PjBL-STEM intervention, conceptual mastery remained suboptimal (Sugiyono, 2013).

Following participation in the project-based STEM instruction, students' post-test scores exhibited marked improvement. Overall, the class mean score increased substantially from 74.35 ($SD = 20.19$) on the pre-test to 95.65 ($SD = 7.28$) on the post-test, representing an average gain of 21.30 points. This upward trend was evident across the cohort, with the majority of students achieving higher post-test scores relative to their pre-test baselines. Notable gains were also observed at the individual level; specifically, two students coded as S-04 and S-05, who initially scored 40 on the pre-test, demonstrated remarkable progress on the post-test, achieving scores of 100 and 90, respectively. These findings indicate that project-based STEM instruction

is highly effective in assisting initially low-performing learners to grasp scientific concepts through active, hands-on engagement (Larmer et al., 2015).

As illustrated in Figure 1, nearly all students (16 out of 23 students) experienced score gains from pre-test to post-test, while 6 students maintained high baseline scores (including five students who scored 100 on both tests). Post-test performance clustered predominantly within the high-achievement range, with 16 students attaining the maximum score of 100. Moreover, the substantial score differentials among students with low initial baselines underscore the pedagogical efficacy of the STEM-PjBL intervention.

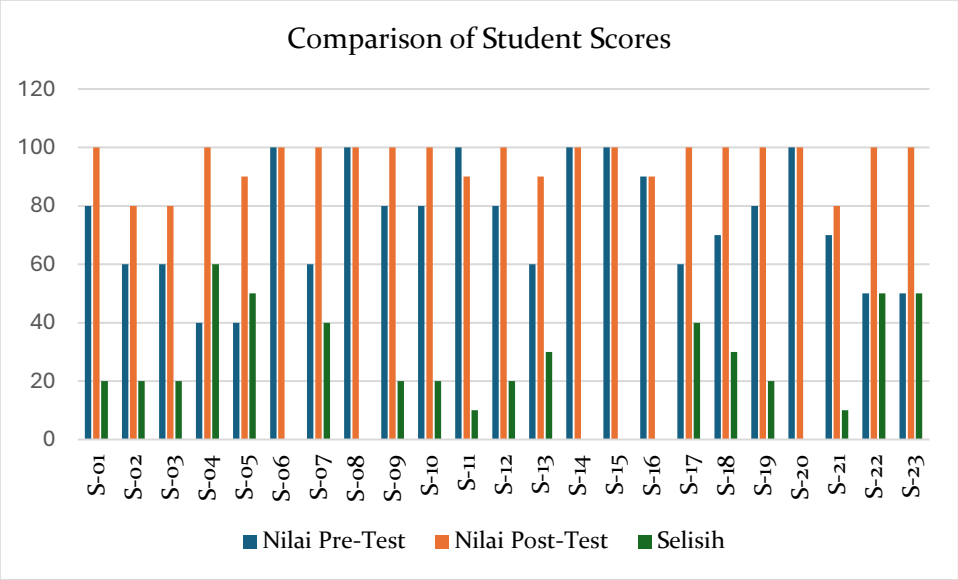

Figure 1. *Comparison of Pre-Test and Post-Test Scores of Class III B Students at SDN Sadagori 1 (N = 23)*

Table 1. Comparison of Pre-Test and Post-Test Scores

Student Code	Pre-Test Score	Post-Test Score	Score Gain (Δ)	Student Code	Pre-Test Score	Post-Test Score	Score Gain (Δ)
S-01	80	100	+20	S-13	60	90	+30
S-02	60	80	+20	S-14	100	100	0
S-03	60	80	+20	S-15	100	100	0
S-04	40	100	+60	S-16	90	90	0
S-05	40	90	+50	S-17	60	100	+40
S-06	100	100	0	S-18	70	100	+30
S-07	60	100	+40	S-19	80	100	+20
S-08	100	100	0	S-20	100	100	0
S-09	80	100	+20	S-21	70	80	+10
S-10	80	100	+20	S-22	50	100	+50
S-11	100	90	-10	S-23	50	100	+50
S-12	80	100	+20	Mean	74.35	95.65	+21.30

The improvement in student learning outcomes following PjBL-based STEM implementation demonstrates that contextual, experiential learning enables learners to

internalize concepts more effectively. This finding aligns with Kelley and Knowles (2016), who assert that STEM education allows learners to construct knowledge by integrating disciplinary concepts with authentic experiences. Similarly, Rohman et al. (2022) emphasize that project-based learning enhances academic achievement because students actively engage in problem-solving rather than passively receiving information. Beyond cognitive gains reflected in test scores, process observations during project execution revealed tangible creative thinking and problem-solving dynamics as students tested their simple water-filtration prototypes.

During the first trial, the majority of groups arranged filter materials randomly, such as placing gravel at the bottom layer and cotton at the top, resulting in turbid water passing through with fine silt particles and retaining a brownish hue. Confronting this initial failure, students engaged in group discussions to diagnose the cause of particle leakage and modified their layer configurations based on pore size and the specific function of each medium. During the design revision stage, students systematically reordered the filtration layers from top to bottom: gravel at the top to trap coarse debris, fine sand beneath to retain silt sediment, activated charcoal to adsorb odors and contaminants, and cotton at the bottom layer as a final fine filter prior to water discharge. The revised prototypes proved effective in producing noticeably clearer filtered water, demonstrating students' capacity to execute engineering iterations both independently and collaboratively.

More specifically, the iterative design cycle in the simple water-filtration project cultivated two core dimensions of creative thinking among third-grade learners: *fluency* and *flexibility*. Thinking fluency was evidenced when students generated diverse alternative ideas regarding combinations and sequences of local materials after observing the persistent turbidity of the initial filtrate. Conversely, thinking flexibility was honed when students willingly abandoned their initial configurations and restructured their layering strategies according to pore size and material filtration properties (Syukri et al., 2018; Thibaut et al., 2018). Nevertheless, classroom implementation also revealed several technical constraints warranting pedagogical attention, particularly concerning the limited fine motor coordination of 8- to 9-year-old students when cutting plastic bottles, compacting cotton layers evenly, and gauging sand thickness to prevent structural collapse under water pressure. Additionally, repeated testing cycles and the cleaning of used filtration media consumed more instructional time than initially scheduled, necessitating rigorous time management and intensive teacher scaffolding within each group (Margot & Kettler, 2019; Tucker et al., 2024).

Discussion

The improvement in student learning outcomes observed in this study can be attributed to the defining characteristics of STEM education, which integrates multiple disciplines and anchors them in authentic real-world problems. Project-based learning compels students to participate actively throughout the inquiry cycle, from problem identification to solution design and empirical testing. This aligns with Kelley and Knowles (2016), who posit that STEM education enables students to build deep understanding through experiential learning and the synthesis of science, technology, engineering, and mathematics concepts. These findings are further corroborated by Becker and Park (2011), who concluded that integrative, project-based STEM approaches exert a positive impact on students' conceptual comprehension and academic performance. Beyond cognitive learning gains, STEM instruction substantially contributed to

nurturing student creativity. Throughout the water-filtration design activity, learners were afforded opportunities to propose ideas, refine prototypes, and test alternative configurations whenever initial trials proved unsuccessful. This corroborates Thibaut et al. (2018), who contend that learning environments providing space for experimentation and learning from failure foster both creativity and positive dispositions toward learning.

Students' problem-solving skills also progressed systematically across the stages of project-based STEM instruction. Learners were trained to identify a tangible real-world problem, post-disaster water turbidity caused by geological hazards, and engineer a practical solution through a simple filtration device. This structured inquiry process fostered logical and systematic reasoning in resolving technical challenges (Kartini et al., 2021; Syukri et al., 2018). These observations resonate with Hmelo-Silver (2004), who established that anchoring instruction in authentic contexts simultaneously elevates learner motivation and strengthens problem-solving proficiency. The efficacy of PjBL-oriented STEM education in boosting achievement was further reinforced by project tasks demanding sustained active learner agency. Through constructing a functional water filter, students moved beyond passive knowledge reception to direct engagement in planning, executing, and evaluating solutions to real-world challenges. Such experiential learning has been shown to deepen conceptual retention and long-term recall (Kelley & Knowles, 2016; Rohman et al., 2022). In addition to hands-on engineering tasks, STEM-PjBL fostered peer collaboration throughout the instructional process. Working in small groups, students deliberated, exchanged ideas, and cooperated to troubleshoot and refine their prototypes. This collaborative dynamic not only consolidated conceptual understanding but also honed interpersonal communication and teamwork, indispensable components of 21st-century competencies (Guzey et al., 2016; Han et al., 2014).

Furthermore, situating STEM learning within authentic environmental challenges heightened students' intrinsic motivation. When confronted with a relatable scenario directly impacting community well-being, such as securing clean water following a geological disaster, students exhibited heightened enthusiasm and sustained engagement. This dual cognitive and emotional involvement encouraged learners to ask probing questions, experiment iteratively, and seek viable solutions, thereby optimizing the overall learning process (English, 2016). These findings carry significant pedagogical implications for primary education. The PjBL-oriented STEM approach offers a viable instructional alternative capable of concurrently advancing academic achievement, creativity, and problem-solving skills. Through thoughtful context selection and structured lesson planning, this approach can be deployed effectively even in schools with limited infrastructure and laboratory facilities (Margot & Kettler, 2019). Ultimately, implementing PjBL-based STEM education proves instrumental not only in elevating cognitive test performance but also in cultivating creative and analytical problem-solvers, transforming young learners from passive recipients of facts into active agents constructing meaningful, real-world knowledge.

Conclusion

Based on the empirical findings and discussion, it can be concluded that implementing Project-Based Learning (PjBL)-oriented STEM education effectively enhances the learning outcomes, creativity, and problem-solving skills of third-grade primary school students. These gains are evidenced by substantial improvements between pre-test and post-test scores,

reflecting deeper conceptual mastery following the project-based intervention. PjBL-based STEM provides meaningful experiential learning by actively engaging students in identifying authentic problems, engineering prototype solutions, and empirically testing their designs. This integrated, contextualized learning process encourages young learners to think creatively, systematically, and collaboratively when addressing real-world challenges, particularly within the domain of geological disaster mitigation. Accordingly, PjBL-oriented STEM instruction serves as an effective pedagogical alternative for lower-grade primary classrooms, fostering essential 21st-century skills, most notably creativity and problem-solving, and ensuring that primary education remains deeply relevant to real-life societal and environmental challenges.

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Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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