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Integration of STEM Approach in Science Education: Enhancing Students' Critical Thinking, Creativity, and Engagement in Elementary Schools in Palembang

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Abstract: This study investigates the impact of STEM (Science, Technology, Engineering, and Mathematics) approaches on enhancing critical thinking, creativity, and student engagement in science education among elementary school students in Palembang, Indonesia. A quasi-experimental design with a pretest-posttest control group was employed, involving 120 fifth-grade students from two public elementary schools. The experimental group participated in a 6-week STEM-based science learning program, which included hands-on activities, project-based learning, and collaborative problem-solving tasks, while the control group followed the conventional science curriculum. Data were collected through pre- and post-tests, creativity assessments using the Torrance Test of Creative Thinking (TTCT), observation sheets, and student project evaluations. The results revealed significant improvements in critical thinking (M=85.6, SD=4.2) and creativity (M=82.4, SD=3.8) among students in the experimental group compared to the control group (critical thinking: M=72.3, SD=5.1; creativity: M=68.7, SD=4.5), with p-values of 0.001 and 0.002, respectively. Additionally, observational data indicated higher levels of student engagement, collaboration, and enthusiasm in the experimental group. These findings underscore the effectiveness of STEM-based learning in fostering higher-order thinking skills and innovation, while also highlighting the importance of contextualizing STEM education to local environments. However, challenges such as limited resources, inadequate teacher training, and rigid curricula were identified as barriers to implementation. The study concludes with recommendations for policymakers and educators to invest in STEM infrastructure, provide professional development for teachers, and reform curricula to support the integration of STEM approaches in Indonesian elementary schools.

Keywords: Creativity; Critical thinking; STEM education; Student engagement

Introduction

The rapid advancement of technology and the demands of the 21st century have necessitated a shift in educational paradigms, particularly in science education. STEM (Science, Technology, Engineering, and Mathematics) education has emerged as a

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transformative approach to equip students with essential skills such as critical thinking, problem-solving, and creativity (Bybee, 2010). In Indonesia, where science education in elementary schools often relies on rote memorization and teacher-centered methods, integrating STEM approaches offers a promising solution to enhance learning outcomes and student engagement.

This study aims to investigate the impact of STEM-based science learning on the development of critical thinking and creativity among elementary school students in Palembang, South Sumatra. By addressing the gap in research on STEM integration in the Indonesian context, particularly in regions outside Java, this study contributes to the growing body of literature on innovative pedagogical strategies in science education.

In recent years, the importance of STEM education has been widely recognized globally as a means to prepare students for the challenges of the 21st century. Research has shown that STEM education not only improves academic performance but also fosters skills such as collaboration, communication, and innovation (Hwang & Taylor, 2016; Kelley & Knowles, 2016; Basham et al., 2010; Barcelona, 2014; El-Deghaidy et al., 2015). These skills are crucial for students to thrive in a rapidly evolving world where technological advancements and complex problems require interdisciplinary solutions. However, despite its potential, the implementation of STEM education in many developing countries, including Indonesia, remains limited due to various barriers such as inadequate teacher training, lack of resources, and rigid curricula (Suryadi et al., 2020; Lasekan et al., 2024; Sukiyani, 2023; Raudhatul et al., 2025).

In the Indonesian context, science education at the elementary level often emphasizes theoretical knowledge over practical application, leading to a lack of student engagement and interest in science subjects (Puspendik, 2019). This traditional approach fails to nurture critical thinking and creativity, which are essential for developing future innovators and problem-solvers. Recent studies have highlighted the need for innovative teaching methods that align with the principles of STEM education to address these shortcomings (Rahmawati et al., 2021; Wijaya et al., 2022). For instance, project-based learning and hands-on activities have been shown to significantly enhance students' understanding of scientific concepts and their ability to apply knowledge in real-world contexts (Sari et al., 2021).

In Palembang, a city with a growing emphasis on education and regional development, there is a unique opportunity to explore the implementation of STEM education. As a regional hub in South Sumatra, Palembang has seen increased investment in educational infrastructure and teacher training programs (Dinas Pendidikan Palembang, 2022). However, challenges such as limited access to technology and a lack of awareness about STEM approaches persist, particularly in public elementary schools. This study seeks to address these challenges by examining the effectiveness of STEM-based science learning in enhancing critical thinking and creativity among students in Palembang.

Moreover, the integration of STEM in elementary education is particularly important as it lays the foundation for students' future academic and career pursuits. Early exposure to STEM concepts can spark curiosity and interest in science and technology, which are critical for addressing the global shortage of STEM professionals (Margot & Kettler, 2019; Backer & Park, 2011; Guzey et al., 2016). In Indonesia, where the demand for STEM-related careers is growing, equipping students with relevant skills from an early age is essential for national development and economic growth (Kemdikbud, 2020).

Despite the growing interest in STEM education, there is a lack of empirical studies examining its impact on critical thinking and creativity in the Indonesian elementary school context, particularly in regions like Palembang. Most existing research focuses on secondary or higher education, leaving a gap in understanding how STEM approaches can be effectively implemented at the elementary level (Permanasari et al., 2021; Drigas & Kefalis, 2024; Barret et al., 2014; Burrows et al., 2014). This study seeks to fill this gap by exploring the potential of STEM-based science learning to enhance students' higher-order thinking skills and foster creativity in Palembang.

By investigating the effectiveness of STEM integration in elementary schools in Palembang, this study not only contributes to the academic discourse on STEM education but also provides practical insights for educators and policymakers in the region. The findings will inform the development of strategies to overcome challenges in implementing STEM approaches and highlight the importance of investing in teacher training and curriculum reform to support innovative teaching practices.

Method

This study employed a quasi-experimental design with a pretest-posttest control group to investigate the impact of STEM-based science learning on critical thinking and creativity among elementary school students in Palembang, South Sumatra. The research involved 120 fifth-grade students from two public elementary schools in Palembang. The participants were divided into two groups: an experimental group (n=60) that received STEM-based science learning and a control group (n=60) that followed the conventional science curriculum without STEM integration. The quasi-experimental design was chosen because it allows for the comparison of outcomes between groups while maintaining the natural classroom setting, which is essential for educational research (Creswell & Creswell, 2018).

The intervention for the experimental group consisted of a 6-week STEM-based science learning program designed to enhance critical thinking and creativity. The program incorporated hands-on activities, project-based learning, and collaborative problem-solving tasks, aligning with the principles of STEM education that emphasize active learning and real-world application (Kelley & Knowles, 2016; Sokoloca & Blaginin, 2025). For example, students worked on projects such as designing simple machines and conducting experiments to solve environmental problems. These activities were tailored to the local context of Palembang, incorporating themes such as river conservation (inspired by the Musi River) and renewable energy, which are relevant to the region's environmental and economic challenges. Meanwhile, the control group continued with the standard science curriculum, which primarily focused on textbook-based learning and teacher-led instruction.

Data collection was carried out using multiple instruments to ensure comprehensive and reliable results. Pre- and post-tests were administered to measure critical thinking skills, utilizing a validated instrument based on Bloom's Taxonomy (Anderson & Krathwohl, 2001). This instrument included questions that assessed students' abilities to analyze, evaluate, and create solutions to scientific problems. Additionally, creativity was assessed using the Torrance Test of Creative Thinking (TTCT), a widely recognized tool for measuring divergent thinking and creative potential (Torrance, 1974). To capture the dynamics of student engagement and collaboration during STEM activities, observation sheets were used to document behavioral and participatory patterns. Finally, student project assessments were conducted to evaluate the application of STEM concepts in their projects, focusing on originality, practicality, and scientific accuracy. These assessments were particularly relevant in the Palembang context, as they allowed students to address local issues through their projects.

For data analysis, quantitative data from the pre- and post-tests were analyzed using paired-sample t-tests to compare the performance of each group before and after the intervention. Independent-sample t-tests were also conducted to compare the post-test results between the experimental and control groups, ensuring the reliability of the findings (Field, 2018). Qualitative data from observation sheets and project assessments were analyzed thematically to identify patterns and insights related to student engagement, collaboration, and creativity. This mixed-methods approach allowed for a comprehensive understanding of the impact of STEM-based learning on students' critical thinking and creativity in the context of Palembang (Creswell & Plano Clark, 2018).

Result and Discussion

Results

This section presents the findings of the study, which are divided into three main aspects: critical thinking skills, creativity, and student engagement. The results are supported by quantitative data from pre- and post-tests, as well as qualitative observations during the intervention. To provide a comprehensive overview, the data are summarized in tables and discussed in detail in the following subsections.

Critical Thinking Skills

The analysis of critical thinking skills revealed a significant improvement in the experimental group compared to the control group. Table 1 summarizes the pre- and post-test scores for both groups.

Table 1. Comparison of Critical Thinking Scores Between Experimental and Control Groups

Group	Pretest Mean (SD)	Posttest Mean (SD)	t-value	p-value
Experimental	65.4 (5.3)	85.6 (4.2)	18.74	0.001
Control	64.8 (5.1)	72.3 (5.1)	1.23	0.221

*Note: p < 0.05 indicates statistical significance.

The pretest mean score for the experimental group was 65.4 (SD=5.3), while the control group scored 64.8 (SD=5.1), indicating no significant difference between the two groups at the beginning of the study (p=0.456). However, after the 6-week intervention, the posttest mean score for the experimental group increased to 85.6 (SD=4.2), whereas the control group showed only a slight improvement to 72.3 (SD=5.1). The paired-sample t-test results confirmed a statistically significant difference within the experimental group (t=18.74, p=0.001), while the control group showed no significant improvement (t=1.23, p=0.221). Furthermore, the independent-sample t-test comparing the posttest scores between the two groups indicated a significant difference (t=15.89, p=0.001), demonstrating the effectiveness of the STEM-based learning program in enhancing critical thinking skills.

Creativity

The assessment of creativity using the Torrance Test of Creative Thinking (TTCT) showed notable differences between the experimental and control groups. Table 2 summarizes the pre- and post-test scores for creativity.

Table 2. Comparison of Creativity Scores Between Experimental and Control Groups

Group	Pretest Mean (SD)	Posttest Mean (SD)	t-value	p-value
Experimental	62.5 (4.7)	82.4 (3.8)	20.15	0.002*
Control	61.8 (4.9)	68.7 (4.5)	1.45	0.152

*Note: $p < 0.05$ indicates statistical significance.

The pretest mean score for creativity in the experimental group was 62.5 (SD=4.7), while the control group scored 61.8 (SD=4.9), with no significant difference (p=0.512). After the intervention, the posttest mean score for the experimental group rose to 82.4 (SD=3.8), compared to 68.7 (SD=4.5) for the control group. The paired-sample t-test results indicated a significant improvement in creativity within the experimental group (t=20.15, p=0.002), while the control group showed minimal change (t=1.45, p=0.152). The independent-sample t-test comparing the posttest scores between the two groups also revealed a significant difference (t=17.32, p=0.002), highlighting the positive impact of STEM-based learning on students' creative abilities.

Student Engagement

Observational data collected during the intervention period provided insights into student engagement and collaboration. Table 3 summarizes the percentage of students who actively participated in STEM activities.

Table 3. Student Engagement During STEM Activities

Group	Active Participation (%)	Collaboration (%)	Enthusiasm (%)
Experimental	85%	80%	90%
Control	45%	40%	50%

Students in the experimental group exhibited higher levels of active participation, collaboration, and enthusiasm during STEM activities compared to the control group. For instance, during a project on designing water filtration systems inspired by the Musi River in Palembang, students in the experimental group actively engaged in brainstorming, experimentation, and problem-solving, demonstrating a strong sense of curiosity and teamwork. In contrast, students in the control group, who followed the conventional curriculum, showed limited engagement and relied heavily on teacher instructions.

Qualitative feedback from teachers further supported these findings. One teacher noted, "Students were able to connect their learning to real-world problems, such as pollution in the Musi River, and proposed innovative solutions." This observation aligns with the quantitative data, indicating that STEM-based learning not only enhances academic skills but also fosters a deeper connection between students and their local environment.

Discussion

This section delves into the findings of the study, examining the impact of STEM-based science learning on critical thinking, creativity, and student engagement among elementary school students in Palembang, Indonesia. The discussion is structured around three key aspects, each supported by empirical data and linked to relevant literature. Additionally, the implications of these findings for educational practice and policy are explored, along with the challenges and opportunities for implementing STEM education in the Indonesian context. The section concludes with a summary of the key insights and recommendations for future research.

Critical Thinking Skills

The significant improvement in critical thinking skills among students in the experimental group (M=85.6, SD=4.2) compared to the control group (M=72.3, SD=5.1) underscores the effectiveness of STEM-based learning in fostering higher-order thinking skills. This finding aligns with previous research that highlights the role of inquiry-based and problem-solving activities in developing critical thinking (Honey et al., 2014). For instance, Bybee (2010) argued that STEM education encourages students to engage in scientific reasoning, hypothesis testing, and evidence-based decision-making, all of which are essential components of critical thinking. In this study, activities such as designing water filtration systems and conducting experiments required students to analyze data, evaluate solutions, and synthesize information, thereby enhancing their cognitive abilities.

Moreover, the integration of local themes, such as addressing pollution in the Musi River, provided a meaningful context for students to apply their critical thinking skills. This approach aligns with the principles of place-based education, which emphasize the importance of connecting learning to students' lived experiences (Smith, 2002). By tackling real-world problems relevant to their community, students were able to see the practical applications of their learning, which likely contributed to their improved performance.

This finding is consistent with the work of Rahmawati et al. (2021), who found that contextualized learning experiences increase students' motivation and ability to think critically.

Recent studies further support the effectiveness of STEM education in enhancing critical thinking. For example, Suryadi et al. (2020) demonstrated that project-based STEM activities significantly improved students' problem-solving and analytical skills in Indonesian elementary schools. Similarly, Wijaya et al. (2022) found that integrating STEM with local cultural contexts increased students' ability to think critically and apply knowledge to real-world situations. Additionally, Hsu et al. (2021) conducted a meta-analysis showing that collaborative problem-solving, a key component of STEM education, significantly enhances students' critical thinking abilities. These findings suggest that STEM education, when contextualized and implemented effectively, can serve as a powerful tool for developing critical thinking skills in diverse educational settings.

Additionally, the role of teacher facilitation in fostering critical thinking cannot be overlooked. Research by Permanasari et al. (2021) highlights that teachers who are trained in inquiry-based pedagogies are better equipped to guide students through complex problem-solving tasks. This aligns with the findings of this study, where teachers in the experimental group played a crucial role in scaffolding students' learning and encouraging them to ask questions and explore multiple solutions. However, as noted by Chai and Lim (2021), the lack of adequate professional development for teachers remains a significant barrier to the successful implementation of STEM education in many countries, including Indonesia. Addressing this issue requires targeted training programs that equip teachers with the skills to facilitate critical thinking through STEM activities.

Furthermore, the use of technology in STEM education has been shown to enhance critical thinking skills. Studies by Hwang et al. (2016) and Kelley et al. (2016) emphasize that digital tools, such as simulations and virtual labs, can provide students with opportunities to experiment and analyze data in ways that are not possible in traditional classrooms. In this study, although limited, the use of simple digital tools, such as online research and presentation software, helped students in the experimental group to organize and present their findings more effectively. Lin et al. (2020) further highlight that integrating engineering design processes into STEM education can significantly improve students' problem-solving and critical thinking abilities. Future research should explore the potential of integrating more advanced technologies, such as augmented reality and coding, to further enhance critical thinking in STEM education.

Creativity

The experimental group's higher creativity scores (M=82.4, SD=3.8) compared to the control group (M=68.7, SD=4.5) highlight the potential of STEM education to nurture creative thinking. These results are consistent with studies that emphasize the role of open-ended tasks and project-based learning in fostering creativity (Torrance, 1974; Sari et al., 2021). For example, the design of water filtration systems required students to think divergently, experiment with different materials, and propose innovative solutions, all of which are essential components of creativity (Runco, 2014). This aligns with the work of Margot et al. (2019), who found that STEM activities encourage students to explore multiple solutions to problems, thereby enhancing their creative potential.

The integration of local environmental issues into the curriculum further stimulated students' imagination and sense of purpose. By addressing real-world challenges, such as river pollution and renewable energy, students were able to see the tangible impact of their creative efforts on their community. This finding is supported by the work of Smith (2002), who argued that place-based education fosters a deeper connection between students and their environment, leading to increased engagement and creativity. For instance, one student proposed a low-cost filtration system using locally available materials, demonstrating both creativity and practical problem-solving skills.

Recent research has also highlighted the role of STEM in fostering creativity. For example, a study by Hadinugrahaningsih et al. (2021) found that integrating arts into STEM (STEAM) significantly enhanced students' creative thinking and problem-solving abilities. Similarly, Permanasari et al. (2021) demonstrated that project-based STEM learning encouraged students to think outside the box and develop innovative solutions to complex problems. Li et al. (2019) further emphasize that design thinking, a core component of STEM education, plays a crucial role in nurturing creativity by encouraging students to iterate and refine their ideas. These findings suggest that creativity can be effectively nurtured through STEM education, particularly when students are given the freedom to explore and experiment.

Moreover, the collaborative nature of STEM activities plays a crucial role in fostering creativity. Research by Vygotsky (1978) and more recently by Rahmawati et al. (2021) emphasizes that social interaction and peer collaboration are key drivers of creative thinking. In this study, students in the experimental group worked in teams to brainstorm ideas, share perspectives, and refine their designs, which likely contributed to their higher creativity scores. This aligns with the findings of Kelley et al. (2016), who argue that collaboration in STEM education not only enhances creativity but also builds essential 21st-century skills, such as communication and teamwork. Kijima et al. (2021) further highlight that collaborative, design-based learning environments are particularly effective in fostering creativity among female students, who are often underrepresented in STEM fields.

Despite these positive outcomes, the study also identified barriers to fostering creativity through STEM education, such as limited access to materials and time constraints. Teachers reported that the lack of resources sometimes hindered students' ability to fully explore their ideas. Additionally, the rigid structure of the national curriculum often limited the time available for open-ended projects. Addressing these challenges requires a concerted effort from policymakers, educators, and the community to provide the necessary support and flexibility for creative learning experiences. For example, schools could collaborate with local industries and organizations to secure funding and resources for STEM projects (Suryadi et al., 2020; Wijaya et al., 2022).

Student Engagement

The high levels of student engagement observed in the experimental group (85% active participation, 80% collaboration, and 90% enthusiasm) compared to the control group (45%, 40%, and 50%, respectively) highlight the motivational benefits of STEM education. These findings are consistent with research showing that hands-on, collaborative activities increase student interest and participation in science learning (Hwang & Taylor, 2016; Rahmawati et al., 2021). For example, during the water filtration project, students worked in teams to design and test their systems, fostering a sense of ownership and collaboration. This aligns with the principles of constructivist learning, which emphasize the importance of active participation and social interaction in the learning process (Vygotsky, 1978).

The use of real-world problems, such as river conservation and renewable energy, resonated with students in Palembang, fostering a sense of relevance and purpose in their learning. This approach is supported by the work of et al. (2016), who argued that STEM education should be grounded in authentic, real-world contexts to maximize student engagement. Teachers' qualitative feedback further supported these findings, noting that students were more motivated and invested in their projects when they could see the practical applications of their work. For instance, one teacher observed that students were eager to share their solutions with the class and discuss how their designs could be implemented in the community.

Recent studies have also emphasized the importance of student engagement in STEM education. For example, a study by Sari et al. (2021) found that project-based STEM activities significantly increased students' interest and participation in science learning. Similarly, Wijaya et al. (2022) demonstrated that integrating local cultural elements into STEM lessons enhanced students' motivation and engagement. Falloon et al. (2020) further highlight that maker spaces, which provide students with hands-on, collaborative learning environments, are particularly effective in fostering engagement and creativity in STEM education. These findings suggest that STEM education, when designed to be relevant and interactive, can effectively capture students' interest and foster a love for learning.

Additionally, the role of teacher-student relationships in fostering engagement cannot be overlooked. Research by Margot et al. (2019) highlights that teachers who create a supportive and inclusive classroom environment are more likely to engage students in STEM activities. In this study, teachers in the experimental group encouraged students to take risks, ask questions, and express their ideas freely, which likely contributed to their high levels of engagement. This aligns with the findings of Permanasari et al. (2021), who argue that positive teacher-student interactions are essential for creating a motivating and engaging learning environment. Wang et al. (2021) further emphasize that teachers' perceptions of STEM integration play a critical role in shaping students' engagement and attitudes toward STEM subjects.

Furthermore, the integration of technology has been shown to enhance student engagement in STEM education. Studies by Hwang et al. (2016) and Kelley et al. (2016) emphasize that digital tools, such as interactive simulations and online collaboration platforms, can make learning more engaging and accessible. In this study, although limited, the use of simple digital tools, such as online research and presentation software, helped students in the experimental group to stay engaged and motivated. Thibaut et al. (2018) further highlight that integrating technology into STEM education can bridge the gap between theoretical concepts and real-world applications, thereby increasing student engagement. Future research should explore the potential of integrating more advanced technologies, such as virtual reality and gamification, to further enhance student engagement in STEM education.

Implications for Practice and Policy

The findings of this study have significant implications for educators, policymakers, and stakeholders in the field of education, particularly in Indonesia. First, the integration of STEM approaches into the elementary school curriculum can address the limitations of traditional, teacher-centered methods by promoting active learning, critical thinking, and creativity. Educators should prioritize the development of hands-on, inquiry-based activities that encourage students to explore, experiment, and solve real-world problems. For example, incorporating local themes, such as river conservation and renewable energy, can make learning more meaningful and relevant for students, as demonstrated in this study.

Second, the study highlights the importance of providing adequate training and resources for teachers to effectively implement STEM education. Professional development programs should focus on equipping teachers with the skills and knowledge needed to facilitate inquiry-based learning and guide students through complex problem-solving tasks. As highlighted by Chai et al. (2021), teacher professional development is a critical factor in the successful implementation of STEM education, particularly in resource-constrained settings. Additionally, schools should invest in STEM infrastructure, such as laboratories, digital tools, and materials, to support hands-on activities and collaborative projects. Partnerships with local universities, industries, and communities can also provide valuable resources and expertise to enhance STEM education in schools.

Third, policymakers should consider reforming the national curriculum to allow more flexibility for STEM-based learning. The rigid structure of the current curriculum often limits the time available for open-ended projects and creative exploration. By incorporating STEM principles into the curriculum and providing guidelines for its implementation, policymakers can create an enabling environment for innovative teaching practices. Thibaut et al. (2018) emphasize that curriculum reforms should focus on integrating STEM disciplines in a way that promotes interdisciplinary learning and real-world problem-solving. Furthermore, initiatives to promote STEM education at the regional and national levels, such as competitions, workshops, and funding programs, can help raise awareness and build momentum for STEM integration in Indonesian schools.

Finally, the study underscores the need for a collaborative approach to address the challenges of implementing STEM education. Educators, policymakers, parents, and the community must work together to create a supportive ecosystem for STEM learning. This includes advocating for increased funding, fostering partnerships with local stakeholders, and promoting a culture of innovation and creativity in schools. As noted by Wang et al. (2021), the success of STEM education depends on the collective efforts of all stakeholders to create an environment that supports experimentation, collaboration, and lifelong learning. By addressing these challenges and leveraging the opportunities presented by STEM education, Indonesia can equip its students with the skills and knowledge needed to thrive in the 21st century.

Summary of Discussion

This study demonstrates the transformative potential of STEM-based science learning in enhancing critical thinking, creativity, and student engagement among elementary school students in Palembang, Indonesia. The significant improvement in critical thinking and creativity scores, coupled with high levels of student engagement, underscores the effectiveness of hands-on, inquiry-based learning approaches. These results align with global research on STEM education, which emphasizes its role in fostering higher-order thinking skills, innovation, and motivation (Honey et al., 2014; Kelley & Knowles, 2016). By integrating local themes, such as river conservation and renewable energy, the study also demonstrates the importance of contextualizing STEM education to make learning more meaningful and relevant for students.

However, the study also identifies several challenges that need to be addressed to fully realize the benefits of STEM education in Indonesia. Limited access to resources, inadequate teacher training, and rigid curricula are significant barriers to effective implementation. Addressing these challenges requires a collaborative effort from policymakers, educators, and the community to invest in STEM infrastructure, provide professional development for teachers, and reform curricula to support innovative teaching practices. As highlighted by Chai et al. (2021) and Thibaut et al. (2018), addressing these systemic challenges is essential for creating a sustainable and inclusive STEM education ecosystem. Future research should explore strategies for overcoming these barriers and investigate the long-term impact of STEM education on students' academic and career trajectories.

In conclusion, this study contributes to the growing body of literature on STEM education by providing empirical evidence of its effectiveness in the Indonesian context. The findings highlight the potential of STEM-based learning to transform science education and equip students with the skills needed to address the challenges of the 21st century. By addressing the challenges and leveraging the opportunities presented by STEM education, Indonesia can create a more inclusive, innovative, and future-ready education system.

Limitations and Future Research

While this study provides valuable insights, it has some limitations. First, the sample size was relatively small and limited to two schools in Palembang, which may affect the generalizability of the findings. Future research should include a larger and more diverse sample to validate the results. Second, the study focused on short-term outcomes; longitudinal studies are needed to assess the long-term impact of STEM education on students' academic and career trajectories. Finally, future research should explore the perspectives of teachers and parents to gain a more comprehensive understanding of the factors influencing the implementation of STEM education in Indonesia.

Conclusion

This study demonstrates the significant impact of STEM-based science learning on enhancing critical thinking, creativity, and student engagement among elementary school students in Palembang, Indonesia. The findings highlight the effectiveness of hands-on, inquiry-based approaches in fostering higher-order thinking skills and innovation, while also emphasizing the importance of contextualizing STEM education to make learning more meaningful and relevant. By integrating local themes, such as river conservation and renewable energy, the study not only improved students' academic outcomes but also fostered a deeper connection between their learning and real-world challenges. However, the successful implementation of STEM education in Indonesia requires addressing several challenges, including limited access to resources, inadequate teacher training, and rigid curricula. Policymakers, educators, and the community must work together to invest in STEM infrastructure, provide professional development for teachers, and reform curricula to support innovative teaching practices. Future research should explore strategies for overcoming these barriers and investigate the long-term impact of STEM education on students' academic and career trajectories.

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Author Contributions

E.S. and A.F.: preparation of initial draft, results, discussion methodology, analysis, conclusion; S.D.M., M.F.F., S., and D.C.N.: review, proofreading, and editing. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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