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Mathematical Creativity through STEM-Integrated Project-Based Learning: An Experimental Study

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ABSTRACT

Recent discussions in mathematics education increasingly highlight the integration of STEM perspectives and project-based pedagogies as pathways for cultivating higher-order competencies. Despite this growing interest, empirical evidence specifically addressing their role in fostering mathematical creative thinking at the lower secondary level remains limited. This study investigates whether a STEM-integrated Project-Based Learning (STEM-PjBL) model meaningfully supports students' creative thinking in mathematics. A quasi-experimental design with pretest and posttest control groups was implemented involving eighth-grade students from a public junior high school. Two intact classes were assigned to experimental and comparison conditions. Students in the experimental class engaged in mathematics learning through STEM-integrated projects, while those in the comparison class experienced conventional instructional practices. Mathematical creative thinking was assessed using an open-ended written task aligned with established creativity indicators. Statistical analysis, including regression modeling and one-tailed hypothesis testing, indicated that the STEM-PjBL approach produced a statistically significant improvement in students' creative mathematical performance, explaining 14.2% of the variance observed. Students exposed to STEM-PjBL also demonstrated consistently higher creative thinking scores compared to their peers in conventional settings. These findings provide empirical support for positioning STEM-integrated project-based instruction as a viable pedagogical strategy for nurturing mathematical creativity in secondary education contexts.

Kata kunci:
berpikir kreatif matematis
pembelajaran berbasis proyek
STEM

Kajian kontemporer dalam pendidikan matematika semakin menekankan integrasi perspektif STEM dan pedagogi berbasis proyek sebagai pendekatan untuk mengembangkan kompetensi berpikir tingkat tinggi. Meskipun perhatian terhadap pendekatan ini terus meningkat, bukti empiris yang secara khusus mengkaji perannya dalam menumbuhkan kemampuan berpikir kreatif matematis pada jenjang sekolah menengah pertama masih terbatas. Penelitian ini mengkaji apakah model Project-Based Learning terintegrasi STEM (STEM-PjBL) secara signifikan dapat mendukung pengembangan kemampuan berpikir kreatif siswa dalam matematika. Penelitian ini menggunakan desain kuasi-eksperimen dengan kelompok kontrol pretest–posttest yang melibatkan siswa kelas VIII dari sebuah sekolah menengah pertama negeri. Dua kelas yang sudah terbentuk ditetapkan sebagai kelompok eksperimen dan kelompok pembanding. Siswa pada kelompok eksperimen mengikuti pembelajaran matematika melalui proyek-proyek terintegrasi STEM, sedangkan kelompok pembanding memperoleh pembelajaran konvensional. Kemampuan berpikir kreatif matematis diukur melalui tugas tertulis terbuka yang disusun berdasarkan indikator kreativitas yang telah teruji. Analisis statistik yang mencakup pemodelan regresi dan uji hipotesis satu arah menunjukkan bahwa pendekatan STEM-PjBL menghasilkan peningkatan yang signifikan secara statistik *terhadap kemampuan berpikir kreatif matematis siswa, dengan kontribusi sebesar 14,2% terhadap variasi skor yang diamati. Selain itu, siswa yang mengikuti pembelajaran STEM-PjBL secara konsisten memperoleh skor berpikir kreatif yang lebih tinggi dibandingkan siswa pada pembelajaran konvensional. Temuan ini memberikan dukungan empiris bahwa integrasi STEM dalam pembelajaran berbasis proyek merupakan strategi pedagogis yang potensial untuk mengembangkan kreativitas matematis pada konteks pendidikan menengah.*

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INTRODUCTION

Mathematics education in the twenty-first century plays a crucial role in equipping students with the competencies required to respond to rapid global developments. This century is frequently characterized by the expansion of knowledge, the rise of knowledge-based economies, advances in information technology, globalization, and the Fourth Industrial Revolution (Redhana, 2019). Consequently, educational institutions are expected to develop human resources who possess essential twenty-first-century skills, particularly the 4C competencies: creative thinking, critical thinking and problem-solving, communication, and collaboration (Almarzooq et al., 2020; Pramasdyahsari et al., 2021). As a core subject, mathematics holds substantial potential to cultivate these competencies simultaneously (Saputri et al., 2019).

Ideally, mathematics learning should extend beyond conceptual mastery to foster students' systematic, logical, and creative thinking abilities, as well as discipline and effective collaboration within increasingly complex and competitive contexts (Marliani, 2015). Among these competencies, mathematical creative thinking is particularly important. Ulfa et al., (2019), describe mathematical creative thinking as the ability to generate diverse and flexible solutions to open-ended mathematical problems that remain mathematically valid. This ability is essential for enabling students to adapt to technological innovation and address multifaceted challenges in the twenty-first century.

Despite its importance, the development of students' mathematical creative thinking remains suboptimal in many classroom settings. Empirical evidence suggests that students' creative thinking abilities are still relatively low, largely due to instructional practices that continue to rely on teacher-centered approaches (Syamsidah et al., 2020). Such practices often position students as passive recipients of information, emphasizing formula memorization over contextual understanding and meaningful application. As a result, opportunities for idea exploration and creative problem-solving are limited, directly constraining the development of mathematical creative thinking. In contrast, contemporary society increasingly demands individuals who can think creatively and logically to produce original, useful, and contextually relevant solutions to real-life problems (Ghosh, 2024; Istikomah et al., 2025; Pangestu, 2024; Putu et al., 2025).

To address the gap between ideal educational goals and classroom realities, student-centered instructional approachs that explicitly promote creative thinking are required. One promising approach is Project-Based Learning (PjBL). PjBL is a learner-centered instructional approach that engages students in actively and independently solving problems through the completion of meaningful projects (Zannah, 2020). Previous studies have demonstrated the effectiveness of PjBL in enhancing students' creative thinking skills (Amalia et al., 2019). Additionally, the STEM (Science, Technology, Engineering, and Mathematics) approach has been shown to support creativity development through contextual and real-world problem-solving experiences (Pramasdyahsari, Zuhri, et al., 2025; Winarni et al., 2016).

Creative thinking in education is commonly conceptualized as the ability to generate ideas that are both novel and appropriate within a given context. Torrance (1974) identifies key dimensions of creative thinking, including fluency (the ability to produce many ideas), flexibility (the ability to generate diverse ideas), originality (the ability to produce unique ideas), and elaboration (the ability to develop and refine ideas). These dimensions provide a useful framework for assessing how instructional approaches can foster students' creativity. From a constructivist perspective, creative thinking develops through active engagement, exploration, and interaction with meaningful problems, where learners construct knowledge rather than passively receive it.

STEM-integrated learning facilitates the development of critical, creative, systematic, and logical thinking, aligning with the competencies required for twenty-first-century human resources (Anggraini & Huzaifah, 2017; Pramasdyahsari, 2023; Pramasdyahsari et al., 2023). Integrating PjBL with a STEM approach is therefore expected to provide more meaningful learning experiences by promoting active exploration and interdisciplinary engagement (Pramasdyahsari, 2023; Pramasdyahsari et al., 2023). Through STEM-PjBL, students participate in authentic, challenging, and contextually grounded projects that integrate multiple disciplines within a coherent learning framework. Consequently, learning emphasizes not only conceptual understanding but also the practical and relevant application of mathematical knowledge in everyday contexts (Pramasdyahsari, Zuhri, et al., 2025).

Accumulating empirical evidence has suggested the pedagogical value of STEM-integrated Project-Based Learning (STEM-PjBL). Previous studies, such as Sukmawijaya and Juhanda (2019), reported improvements in students' creative performance under STEM-PjBL conditions, particularly when compared with conventional instruction in science classrooms. Likewise, Noviyana (2017) identified positive gains in creative thinking through project-based learning, although the study did not explicitly situate the intervention within a STEM framework. Despite these promising findings, the pedagogical mechanisms through which STEM-PjBL fosters creativity, particularly in mathematics require further elaboration. From a theoretical perspective, STEM integration encourages divergent thinking by engaging students in interdisciplinary problem-solving contexts that allow multiple solution pathways and representations, rather than relying on a single procedural approach (Honey et al., 2014).

In addition, the incorporation of engineering design processes such as problem identification, prototyping, testing, and iterative refinement plays a crucial role in stimulating originality, as students are required to generate, evaluate, and improve ideas within given constraints (Dym et al., 2005). Furthermore, the project-based structure promotes flexibility in mathematical reasoning through extended inquiry, collaboration, and engagement with authentic problems, enabling students to shift between strategies and connect mathematical concepts to real-world applications (Bell, 2010). These dimensions, divergent thinking, originality, and flexibility are widely recognized as core components of creativity (Torrance, 1974) and have been specifically linked to mathematical creativity in terms of fluency, flexibility, and originality in problem solving (Silver, 1997).

Taken together, STEM integration, engineering design practices, and project-based learning structures form an interconnected pedagogical pathway that supports the development of mathematical creative thinking. However, empirical studies that explicitly examine this relationship within formal mathematics education contexts remain limited. Addressing this gap, the present study investigates the implementation of a STEM-PjBL model and its influence on students' mathematical creative performance.

METHOD

This study adopted an experimental research framework (Creswell, 2014) to explore the instructional impact of STEM-integrated project-based learning on students' mathematical creative thinking. The research was conducted at SMP Negeri 8 Pati and involved eighth-grade students enrolled in the academic year of the study. From the existing cohort, two intact classes were designated as comparison groups. Class VIII E functioned as the treatment group, experiencing mathematics instruction structured around STEM-PjBL principles, whereas Class VIII D participated in conventional teacher-centered learning activities. The study implemented a pre-intervention and post-intervention assessment structure to examine changes in students' creative mathematical performance over time. Students completed a mathematical creative thinking assessment (Figure 1) prior to the instructional treatment and again following the completion of the learning sequence. The instrument consisted of open-ended tasks designed to elicit indicators of fluency, flexibility, and originality within mathematical problem-solving contexts. The research instrument comprised essay-type questions based on Cartesian coordinate content, designed to comprehensively assess students' mathematical creative thinking ability.

Data analysis was conducted to determine the effect of the STEM-PjBL approach on students' mathematical creative thinking ability. The analyses included simple linear regression to examine the direction and magnitude of the effect, correlation analysis and the coefficient of determination to assess the strength of the relationship and the contribution of the instructional approach, and a one-tailed *t*-test to test the research hypotheses by comparing the experimental and control groups.

1. Sekelompok anak mengadakan kegiatan *outbond*. Dalam *outbond* tersebut ada 6 jenis permainan yang terletak di pos yang berbeda. Jika digambarkan dalam bidang koordinat, Pos 1 terletak di titik (-4,3), pos 2 terletak di titik (0,6), pos 3 terletak di titik (-2,-5), pos 4 terletak di titik (3,2), pos 5 terletak di titik (5,-5) dan pos 6 terletak di titik (7,-2). Lamanya waktu bermain dalam setiap pos ialah 5 menit. Panitia *outbond* hanya menyediakan waktu selama 45 menit untuk menyelesaikan seluruh permainan. Susunlah strategi untuk kelompokmu supaya mendapatkan jalur yang terdekat agar dapat menyelesaikan seluruh permainan tepat waktu. *Start* dan *finish outbond* berada di titik kumpul yaitu di (-5,-3).

Figure 1. Sample of Mathematical Creative Thinking Test

RESULTS AND DISCUSSION

Research Results

The analysis focused on students' post-intervention performance in mathematical creative thinking, following the completion of the instructional treatment. Both the experimental group (Class VIII E) and the comparison group (Class VIII D) completed the same posttest instrument aligned with established creativity indicators. To examine the instructional effect, the data were modeled using simple linear regression, followed by a one-tailed independent samples t-test to determine directional differences between groups. Statistical computations were performed using IBM SPSS Statistics. The results of the simple linear regression analysis showed a regression coefficient of 11.187 with a constant value of 56.375, resulting in the following regression equation:

1. Linear Regression Analysis

   The simple linear regression analysis was conducted using IBM SPSS Statistics 26, with the following results:

   a. Regression Equation

   The simple linear regression analysis of the STEM-PjBL approach on students' creative thinking ability is presented in Table 1, which shows a regression coefficient of 11.187 and a constant of 56.375. Accordingly, the regression equation is $\hat{Y}$ = 56,375 + 11,187X. This result indicates that when the STEM-PjBL approach (X) is set to zero, the predicted value of students' creative thinking ability (Y) is 56.375. The regression coefficient of 11.187 suggests that each one-unit increase in the implementation of the STEM-PjBL approach is associated with an increase of 11.187 units in students' creative thinking ability. The positive value of the regression coefficient (b) indicates a positive relationship between the learning approach and students' creative thinking ability.

Table 1. *Output* Coefficients

Coefficients[a]

Approach		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	56,375	5,511		10,229	,000
	Approach Pembelajaran (X)	11,187	3,486	,377	3,210	,002

b. Significance Test of the Regression Coefficient

The independence test, or significance test, was conducted to determine whether the relationship between the independent variable (X), namely the STEM-PjBL approach, and the dependent variable (Y), namely creative thinking ability, is statistically significant. The decision criteria in the independence test are based on the comparison between the calculated F-value ($F_{calculated}$) *and the critical F-value (*F_{table})

Table 2. *Output* Anova

ANOVA[a]

Approach		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2002,562	1	2002,562	10,302	,002[b]
	Residual	12051,875	62	194,385		
	Total	14054,438	63			

The regression significance was evaluated by comparing the obtained F statistic with the critical threshold value. The analysis yielded an F value of 10.302, exceeding the critical value of 4.00 at $\alpha = 0.05$, with 1 numerator and 62 denominator degrees of freedom. Since the calculated statistic surpassed the critical benchmark, the null hypothesis was rejected. This result indicates that the STEM-PjBL instructional approach demonstrates a statistically significant association with students' mathematical creative thinking performance.

c. Regression Linearity Test

To verify whether the relationship between the instructional treatment and creative thinking outcomes followed a linear pattern, a regression linearity test was performed. The decision rule was based on the significance probability value. A significance level greater than 0.05 would indicate the absence of a linear relationship, whereas a value below 0.05 would confirm linearity between the variables. The analysis produced a significance value of 0.002, which falls well below the 0.05 threshold. This confirms that the relationship between the STEM-PjBL intervention and students' mathematical creative thinking scores can be appropriately interpreted within a linear regression framework.

d. Correlation Coefficient Calculation

The determination of the correlation coefficient aims to identify the strength of the relationship between the STEM-PjBL approach and creative thinking ability. The testing criteria are as follows:

Table 3. *Output* Approach Summary

Approach Summary				
Approach	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	,377[a]	,142	,129	13,942

a. Predictors: (Constant), Approach Pembelajaran (X)

The correlation coefficient r_{xy} was obtained from Table 3 (Approach Summary), with r_{xy} = 0.377. The critical r-value $r_{table}$for df = 64 at a significance level of 0.05 is 0.242. Therefore, $r_{calculated}$> r_{table}, and in this case H_0 is rejected, indicating a positive relationship between the STEM-PjBL approach and students' creative thinking ability.

e. Coefficient of Determination

The coefficient of determination is used to determine the proportion of variance in creative thinking ability explained by the STEM-PjBL approach. The coefficient of determination (KD) is calculated as rxy2; thus, KD = 0.3772. Based on the results in Table 3 (Approach Summary), the R Square value is 0.142. This indicates that the STEM-PjBL approach accounts for 14.2% of the variance in students' creative thinking ability, while the remaining 85.8% is influenced by other factors.

2. Right-Tailed *t*-Test

Table 4. *Output One-tailed t-test (right-tailed)*

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Kemampuan	Equal variances assumed	1,045	,311	-3,210	62	,002	-11,187	3,486	-18,155	-4,220

Based on the results of the independent samples t-test, the experimental class taught using the PjBL–STEM approach achieved a higher mean score (78.75) than the control class taught using the conventional learning approach (67.56). The calculated *t*-value $(t_{calculated})$ was 3.210. For df = 62 and a significance level of 0.05, the critical *t*-value (t_{table}) was 1.669. Since $(t_{calculated})$ > (t_{table}), H_0 is rejected. These results indicate that the mean creative thinking ability score of students taught using the PjBL–STEM approach is higher than that of students taught using the conventional learning approach.

Discussion

The findings of this study indicate that the STEM-based Project-Based Learning (STEM-PjBL) approach has a statistically significant positive effect on students' mathematical creative thinking. The regression analysis revealed a moderate positive relationship ($\beta = 0.377$, $p = 0.002$), indicating that students who engaged in STEM-PjBL tended to demonstrate higher levels of creative thinking compared to those in conventional learning environments. Although the coefficient of determination ($R^2 = 0.142$) shows that 14.2% of the variance in creative thinking can be explained by the instructional approach, this effect size remains meaningful within educational research contexts, where learning outcomes are influenced by multiple interacting factors (Hattie, 2009). The significant linearity ($p = 0.002$) and regression model ($F = 10.302$, $p = 0.002$) further confirm that this relationship reflects a consistent and meaningful pattern rather than a chance occurrence.

These findings are consistent with previous studies (Aini et al., 2025; Ananda & Johari, 2024; Rahman et al., 2025; Winarni et al., 2016), particularly those by Pramasdyahsari, Rubowo, et al. (2025), Pramasdyahsari, Zuhri, et al. (2025), and Pramasdyahsari and Setyawati (2025), which demonstrate that contextual and STEM-integrated project-based learning enhances students' creative thinking through increased motivation and engagement in real-world problem solving. The positive regression coefficient ($B = 11.187$) in this study further suggests that greater implementation of STEM-PjBL is associated with substantial gains in creative performance, supporting the view that creativity can be fostered through structured pedagogical design.

Importantly, beyond statistical significance, the effectiveness of STEM-PjBL can be explained through its underlying pedagogical characteristics. The integration of real-world, open-ended problems requires students to generate multiple solution strategies, thereby promoting fluency and flexibility in mathematical thinking. At the same time, the incorporation of engineering design processes such as planning, testing, and revising solutions encourages elaboration, as students refine and expand their initial ideas through iterative cycles. Furthermore, the interdisciplinary nature of STEM learning fosters originality, as students draw upon concepts from multiple domains to construct novel and meaningful solutions (Honey et al., 2014). These findings suggest that STEM-PjBL is particularly effective because it aligns closely with the core dimensions of creativity proposed by Torrance (1974), namely fluency, flexibility, originality, and elaboration.

From a constructivist perspective (Piaget, 1970; Vygotsky, 1978), the learning processes embedded in STEM-PjBL such as inquiry, collaboration, and reflection enable students to actively construct knowledge and develop higher-order thinking skills. In this study, the most noticeable improvements were observed in students' ability to propose multiple solution strategies and adapt their approaches when encountering challenges, indicating strong development in flexibility and fluency. This suggests that the open-ended and student-centered nature of project-based tasks plays a crucial role in fostering adaptive and creative mathematical reasoning.

The results of the independent samples t-test ($t = 3.210$, $p < 0.05$) further strengthen this interpretation, showing that students in the experimental group achieved significantly higher creative thinking scores (78.75) than those in the control group (67.56), indicating that STEM-PjBL not only correlates with but also leads to improved learning outcomes. However, rather than merely indicating numerical differences, this result reflects meaningful changes in how students approach mathematical problems shifting from procedural execution toward exploratory and generative thinking. Nevertheless, the moderate correlation coefficient ($r = 0.377$) suggests that creativity is a multifaceted construct influenced by both internal and external factors (Hurlock, 1999; Beghetto & Kaufman, 2014), meaning that STEM-PjBL should be understood as a significant contributing factor rather than the sole determinant. Factors such as prior knowledge, learning motivation, classroom environment, and teacher facilitation may also interact with the effectiveness of the instructional approach.

From a pedagogical standpoint, these findings have important implications for mathematics teaching practice. First, teachers are encouraged to design learning experiences that incorporate open-ended, context-rich problems to stimulate diverse solution pathways. Second, embedding iterative project cycles within instruction can support deeper conceptual understanding and sustained engagement. Third, integrating elements of STEM particularly engineering design can help bridge abstract mathematical concepts with real-world applications, making learning more meaningful and conducive to creative thinking development. Overall, these results highlight that STEM-PjBL creates a learning environment that is not only statistically effective but also pedagogically and theoretically grounded in fostering students' creative thinking in mathematics.

CONCLUSION

Summary

Based on the research objectives outlined in the background, the findings indicate that the implementation of STEM-PjBL has a positive effect on students' mathematical creative thinking ability. The results of the analysis show that students who engaged in STEM-PjBL demonstrated higher levels of creative thinking than those who experienced conventional instruction. These findings suggest that integrating project-based learning with a STEM approach provides meaningful learning experiences, promotes active student engagement, and supports the contextual and applied use of mathematical concepts, aligning with the demands of 21st-century learning.

Recommendation

Based on the research findings, teachers are encouraged to implement the STEM-PjBL approach as an instructional approach to enhance students' mathematical creative thinking through contextual, project-oriented activities. Schools are expected to support the effective implementation of this approach by providing adequate facilities and professional development for teachers. Future research is recommended to explore the application of STEM-PjBL across different mathematical topics, educational levels, and additional relevant variables.

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