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The Influence of the PjBL Model with the STEAM Approach on the Creative Thinking Ability and Mathematical Learning Motivation

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ABSTRACT

Learning mathematics in the 21st century requires students to develop creative thinking skills and strong learning motivation. However, these aspects remain relatively low because mathematics instruction is often procedural and lacks contextual learning experiences. Therefore, innovative learning approaches that integrate both cognitive and affective dimensions are needed. This study aimed to examine the effect of the Project-Based Learning (PjBL) model integrated with the STEAM approach on students' creative thinking ability and mathematics learning motivation. This study employed a quantitative approach with a quasi-experimental pretest-posttest control group design. The participants consisted of 54 eighth-grade students selected through cluster random sampling, with 27 students assigned to the experimental class and 27 students to the control class. The research instruments included a mathematical creative thinking test and a mathematics learning motivation questionnaire. Data were analyzed using Multivariate Analysis of Covariance (MANCOVA) and Pearson Product-Moment correlation at a significance level of 0.05. The findings revealed that the STEAM-based PjBL model significantly affected students' creative thinking ability and learning motivation simultaneously ($p < 0.05$). The multivariate test also demonstrated a very large practical effect, as indicated by the partial eta squared value ($\eta p^2 = 0.966$). Furthermore, the correlation analysis showed a very strong positive relationship between creative thinking ability and learning motivation ($r = 0.885$; $p < 0.05$). These findings indicate that STEAM-integrated project-based learning creates contextual, interactive, and meaningful learning experiences that support both cognitive and affective development. Therefore, the STEAM-based PjBL model can be considered an effective and innovative alternative for fostering 21st-century skills in mathematics learning.

Keywords: Project-Based Learning; STEAM; Creative Thinking; Learning Motivation; Math Learning.

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1. INTRODUCTION

Mathematics learning in the 21st century is not only directed toward conceptual mastery but also toward the development of higher-order thinking skills and positive learning attitudes. Among these competencies, creative thinking has become one of the most essential cognitive skills because it enables students to generate original ideas, think flexibly, and construct multiple problem-solving strategies (Nurhikmayati & Darhim, 2024). In mathematics education, creative thinking supports students in solving problems beyond procedural approaches and encourages deeper conceptual understanding (Ferdiansyah et al., 2025). Previous studies also indicate that students with strong mathematical creativity tend to demonstrate better reasoning, flexibility, and effectiveness in solving mathematical problems (Asare et al., 2025; Hansen, 2022; Wang et al., 2025). Furthermore, mathematical creative thinking is considered an important component of 21st-century competencies because it promotes innovation, adaptability, and reflective problem-solving skills (Henriksen et al., 2018; Li et al., 2026).

From an affective perspective, learning motivation also plays a crucial role in mathematics learning. Based on Self-Determination Theory (SDT), students' intrinsic motivation develops when they actively participate in learning, experience autonomy, and perceive learning as meaningful to their daily lives (Rehman et al., 2024). Ryan and Deci (2020) further explain that supportive learning environments significantly improve students' engagement and academic achievement. In addition, several studies have confirmed that learning motivation positively affects students' persistence, participation, and conceptual understanding in mathematics learning (Fayanto et al., 2025; Oanh & Dang, 2025; Putri et al., 2021). Students with higher motivation are more likely to engage actively in exploration, collaborative activities, and higher-order thinking processes. Therefore, mathematics learning should integrate both cognitive and affective dimensions to create meaningful and sustainable learning experiences.

However, students' mathematical creative thinking abilities are still relatively low, particularly in geometry topics involving flat-sided spatial constructions that require visualization and conceptual reasoning skills. Learning activities in mathematics classrooms are still frequently dominated by procedural instruction and teacher-centered approaches, limiting students' opportunities to explore ideas creatively (Lithner, 2017; Zhao & Abdullah, 2025). Several studies reveal that the lack of contextual learning experiences and real-world problem integration contributes significantly to students' low creativity and engagement (Chen et al., 2022; Papilaya & Salhuteru, 2024). In geometry learning specifically, students often experience difficulties in connecting abstract mathematical concepts with practical applications, resulting in limited conceptual understanding and reduced creative exploration (Kuo, 2025; Li et al., 2026).

In addition to cognitive challenges, students' motivation to learn mathematics also remains problematic. Low motivation negatively affects students' participation, persistence, and conceptual comprehension during mathematics learning (Oanh & Dang, 2025). Putri et al. (2021) also reported a significant relationship between learning motivation and mathematics achievement. Similar findings by Rehman et al. (2024) and Wahyudi et al. (2022) Indicate that students with low motivation tend to show less engagement in collaborative and inquiry-based learning activities. These conditions highlight the urgent need for innovative learning approaches that simultaneously strengthen students' cognitive abilities and affective engagement in mathematics classrooms.

One learning model considered relevant to address these issues is Project-Based Learning (PjBL). Rooted in constructivist theory, PjBL emphasizes active knowledge construction through authentic and contextual learning experiences (Ndiung & Menggo, 2024). Through project activities, students are encouraged to investigate problems, collaborate with peers, and create meaningful products that represent their understanding. Previous studies have shown that PjBL effectively improves students' creative thinking skills because it provides opportunities for idea exploration, problem-solving, and innovation (Amriah et al., 2025; Chen et al., 2022). Moreover, PjBL has been found to increase students' motivation and engagement because learning activities become more meaningful and student-centered (Rehman et al., 2024; Wahyudi et al., 2022; Weng et al., 2022).

The effectiveness of PjBL can be further strengthened through integration with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach. STEAM integrates interdisciplinary learning experiences that encourage students to connect concepts from multiple disciplines in solving real-world problems (Kuo, 2025). The inclusion of arts elements in STEAM also facilitates creativity, visualization, and innovative expression, especially in geometry learning contexts requiring spatial representation. Empirical studies have demonstrated that STEAM-integrated project-based learning significantly enhances students' creativity, critical thinking, collaboration, and learning motivation (Chang et al., 2023; Indahwati et al., 2023; Oanh & Dang, 2025). Other studies also confirm that STEAM-based learning improves students' mathematical creativity and supports deeper conceptual understanding through interdisciplinary exploration (Henriksen et al., 2018; Sucilestari et al., 2025).

Various studies have reported positive impacts of integrating PjBL and STEAM on either creative thinking skills or learning motivation. However, several research gaps remain. First, most previous studies focused only on a single dependent variable, either cognitive outcomes or affective outcomes, without simultaneously examining both aspects through multivariate analysis. Second, studies investigating the integration of PjBL and STEAM in junior high school mathematics learning are still limited, particularly on flat-sided geometry materials that require visualization and contextual representation. Third, limited studies have specifically employed MANCOVA analysis to examine the simultaneous influence of STEAM-based PjBL on creative thinking ability and mathematics learning motivation while controlling students' initial abilities. Therefore, this study aims to examine the effect of the STEAM-based Project-Based Learning model on students' creative thinking ability and mathematics learning motivation in learning flat-sided spatial geometry at the junior high school level.

2. METHODS

2.1 Research Design

This study employed a quantitative approach with a quasi-experimental method using a pretest-posttest control group design. The design involved two groups: an experimental class receiving the STEAM-based Project-Based Learning (PjBL) treatment and a control class receiving conventional learning. This design was selected because it allows researchers to compare students' conditions before and after treatment and evaluate the effectiveness of the learning intervention more accurately (Bergman et al., 2015; Gopalan et al., 2020). The study was conducted from February to March 2026 at SMP Darul Falah Kemang Indah, Ogan Komering Ilir Regency, South Sumatra, Indonesia, as shown in Figure 1.

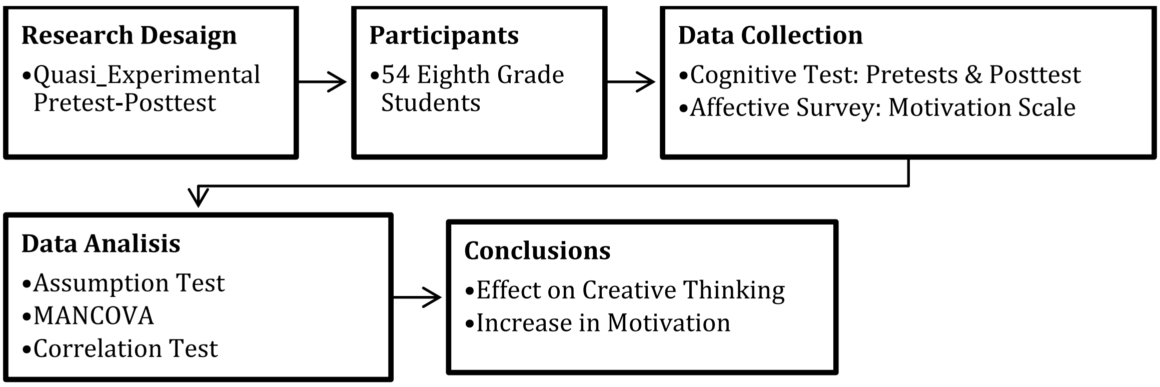

Figure 1. Research Procedure

Figure 1 illustrates the research procedure employed in this study. The investigation used a quasi-experimental design with a pretest-posttest control group approach involving 54 eighth-grade students divided into experimental and control classes. Data collection was conducted using two instruments: a cognitive test in the form of pretests and posttests to measure students' mathematical creative thinking ability, and an affective instrument consisting of a learning motivation questionnaire. The collected data were then analyzed through assumption tests, including normality and homogeneity tests, followed by MANCOVA and Pearson correlation analysis to examine the simultaneous effect of the STEAM-based Project-Based Learning (PjBL) model on students' creative thinking ability and learning motivation. The results of the analysis were used to draw conclusions regarding the effectiveness of the STEAM-based PjBL model in improving both cognitive and affective learning outcomes.

2.2 Participants

The population of this study consisted of all eighth-grade students at SMP Darul Falah Kemang Indah in the 2025/2026 academic year. The sample was selected using cluster random sampling because the participants were naturally organized into intact classroom groups. Two classes were randomly assigned as the experimental and control groups. The experimental class consisted of 27 students taught using the STEAM-based PjBL model, while the control class consisted of 27 students taught using conventional instruction, resulting in a total sample of 54 students. The use of cluster random sampling was considered appropriate in this quasi-experimental study because it maintained the natural classroom setting without reorganizing students individually, thereby preserving classroom validity and minimizing instructional disruption (Ballance, 2024; Taheri et al., 2025). Although the study involved a relatively limited sample from one school, the sample size was considered adequate for multivariate statistical analysis, particularly MANCOVA, which was used to examine the simultaneous effects of the intervention on cognitive and affective variables. The study primarily emphasizes internal validity within a specific educational context; therefore, broader generalization should be interpreted cautiously.

2.3 Data Collection

Research instruments in mathematics education generally consist of cognitive and affective components. Cognitive instruments are often administered through pretest and posttest formats to measure students' mathematical creative thinking, which is commonly assessed using indicators such as fluency, flexibility, originality, and elaboration (Suherman & Vidákovich, 2025; Zhao & Abdullah, 2025). Meanwhile, the affective instrument consisted of a mathematics learning motivation questionnaire measured using the Likert scale, which included aspects of interest, attention, perseverance, and confidence (Rehman et al., 2024).

This study used two research instruments consisting of a cognitive instrument and an affective instrument. The cognitive instrument was a mathematical creative thinking test administered through a pretest and a posttest to measure students' creative thinking ability in learning flat-sided spatial geometry. The creative thinking test consisted of 5 essay items. The test was developed based on four indicators of creative thinking: fluency, flexibility, originality, and elaboration. Meanwhile, the affective instrument was a mathematics learning motivation questionnaire using a Likert scale that measured students' interest, attention, confidence, and persistence during mathematics learning. The learning motivation questionnaire consisted of 20 Likert-scale statements.

The pretest and posttest scores were used to identify students' improvement in creative thinking ability, while the questionnaire results were used to analyze students' learning motivation after the implementation of the STEAM-based Project-Based Learning model. The interpretation of students' scores referred to three categories: high, medium, and low, based on the score distribution obtained during data analysis.

2.4 Data Analysis

Data analysis was conducted using SPSS version 27. Preliminary analyses included normality and homogeneity tests. The Shapiro-Wilk test was used to determine whether the data were normally distributed, while Levene's test was employed to examine the homogeneity of variance. Data were considered normally distributed and homogeneous when the significance value exceeded 0.05 (Ghasemi & Zahediasl, 2012; Kim, 2017). After fulfilling the statistical assumptions, hypothesis testing was conducted using Multivariate Analysis of Covariance (MANCOVA) to examine the simultaneous effect of the STEAM-based PjBL model on students' creative thinking ability and learning motivation while controlling for pretest scores as covariates. Effect size interpretation was based on partial eta squared (ηp^2), categorized as small (0.01), medium (0.06), and large (0.14). Furthermore, the Pearson Product-Moment correlation test was used to analyze the relationship between creative thinking ability and learning motivation. All statistical analyses used a significance level of 0.05.

3. RESULT AND DISCUSSION

The goal of this investigation is to determine whether using the PjBL model in conjunction with a STEAM approach may enhance students' motivation and capacity for creative thought. The study is based on the PjBL syntax that emphasizes authentic project-based learning, in which students are actively engaged both independently and collaboratively. The model includes six main stages: discussing key questions, project planning, creating an activity calendar, keeping an eye on the execution process, assessing project outcomes, and evaluating and reflecting on learning. For 4 sessions, students participate in project-based learning that integrates elements of mathematics, science, technology, and engineering through the topic of building spaces with flat sides, namely prisms and pyramids. The learning process demonstrates the active involvement of students from start to finish, from formulating fundamental questions, planning projects, developing schedules, integrating work progress, and evaluating results. In this activity, students work collaboratively using Student Worksheets (LKPD) and utilize learning media such as videos and presentations to support conceptual understanding.

In each session, students are guided to research mathematical concepts through the observation of contextual phenomena, which are then combined with the use of technology. The results of this exploration are then applied to problem-solving and group discussions, encouraging deeper cognitive engagement and strengthening students' conceptual understanding.

Figure 2. Miniature Building Manufacturing.

At the third and fourth meetings, students began to develop a project in the form of a miniature building that visually and concretely represents a geometric building with flat sides. This activity requires students to apply mathematical concepts such as surface area, volume, and proportions in real products. The process of design, evaluation, and presentation of projects is carried out systematically, allowing pupils to artistically express their opinions while improving their mathematical communication skills. The stages of PjBL implementation, such as project planning, group assignments, and guided discussions, have been proven to establish a setting for learning that supports the exploration of ideas and innovation. Furthermore, the collaborative activities carried out by students also contribute to the development of social skills and teamwork.

The investigation findings demonstrated that using the STEAM-based PjBL paradigm improved pupils' capacity for mathematical creativity. This improvement is evident both in the understanding of abstract concepts and in their capacity to use those concepts in real-life situations. Student engagement throughout the project cycle, from design to final presentation, reflects the comprehensive integration of STEAM components into the learning process. Thus, students are not only focused on procedural problem-solving, but are also required to come up with creative solutions, design products, and communicate ideas reflectively. This demonstrates how well the STEAM-based PjBL method develops conceptual knowledge and problem-solving abilities, as well as encouraging students' creativity also innovation in mathematics learning.

The descriptive analysis showed an improvement in students’ creative thinking ability and learning motivation after the implementation of the STEAM-based PjBL model. In the experimental class, the average posttest scores were higher than the pretest scores for both variables, indicating positive learning progress after the intervention. Compared to the control class, students in the experimental group demonstrated greater improvement in generating creative mathematical ideas, problem-solving flexibility, and active engagement during learning activities. Furthermore, the percentage increase in students’ scores in the experimental class was higher than that of the control class, suggesting that the STEAM-based PjBL model contributed more effectively to the development of creative thinking skills and learning motivation. These findings indicate that project-based and contextual learning experiences can encourage students to participate more actively and meaningfully in mathematics learning, as shown in Table 1.

Table 1. Mean Scores of Pretest and Posttest

Variable	Classes	Average
Creative Thinking Pretest	Control	60,37
	Eksperimen	61,37
Creative Thinking Posttest	Control	65,22
	Eksperimen	74,37
Learning Motivation Pretest	Control	65,52
	Eksperimen	66,63
Posttest of Learning Motivation	Control	69,11
	Eksperimen	79,11

3.1 Normality Test

The Shapiro-Wilk test was chosen to do the normality evaluation due to its appropriateness for datasets with relatively small sample sizes. Data are regarded as normally distributed when the significance value exceeds 0.05. The test covered factors of learning motivation and creative thinking abilities in both the experimental and control groups, and it was applied to both pretest and posttest results. SPSS version 27 was used for all statistical analyses. Table 2 displays the normalcy test results.

Table 2. Normality Test Results

Variable	Groups	Shapiro-Wilk		
		Statistic	df	Sig.
Creative Thinking Pretest	Control	0.949	27	0.208
	Eksperimen	0.949	27	0.208
Learning Motivation Pretest	Control	0.937	27	0.100
	Eksperimen	0.896	27	0.211
Posttest of Learning Motivation	Control	0.942	27	0.139
	Eksperimen	0.896	27	0.101
Creative Thinking Posttest	Control	0.938	27	0.110
	Eksperimen	0.949	27	0.208

The findings of the normality test showed that all data on the variables of creative thinking ability and learning motivation, both in the experimental class and the control class, were distributed normally. The Shapiro-Wilk test significance value greater than 0.05 for every data group indicates this. Thus, the data fulfills one of the important assumptions in parametric statistical analysis. Theoretically, normality tests aim to ensure that the data distribution is close to the normal distribution so that further analyses, such as MANCOVA, can be validly performed. Ghasemi dan Zahediasl (2012) stating that data can be regarded as regularly distributed if the Shapiro-Wilk test yields significance values larger than 0.05 and is suitable for use in parametric analysis.

3.2 Homogeneity Test

Levene's test was used to evaluate for variance homogeneity after the normality evaluation. If the significance value based on the mean was more than 0.05, the data were deemed homogeneous. The experimental and control groups' pretest and posttest results for self-efficacy and divergent thinking abilities were compared using this test. Table 3 displays the homogeneity test findings.

Table 3. Homogeneity Test Results

Variable	Item	Levene Statistic	df1	df2	Sig.
Creative Thinking Pretest	Based on Mean	0.000	1	52	1.000
Learning Motivation Pretest	Based on Mean	0.368	1	52	0.547
Posttest of Learning Motivation	Based on Mean	0.247	1	52	0.621
Creative Thinking Posttest	Based on Mean	0.323	1	52	0.572

The findings of the homogeneity test showed that the data variance in the control and experimental groups was homogeneous, as indicated by all significance values of the Levene test greater than 0.05. This indicates that the variance the two groups is not significantly different. With the fulfillment of this homogeneity assumption, the analysis can be continued to the next stage, namely hypothesis testing using MANCOVA to determine the impact of the STEAM method and the PjBL model on pupils' capacity for creative thought, also learning motivation simultaneously.

3.3 MANCOVA Multivariate Test

After the assumption of normality and homogeneity was met, the analysis was continued using the MANCOVA test to determine the influence of the PjBL learning model with the STEAM approach on creative thinking skills as well as simultaneous learning motivation, as shown in Table 4.

Table 4. MANCOVA Multivariate Test Results

Effect	Item	Value	F	Hypothesis df	Error df	Sig.	Particle eta Squared
Intercept	Pillai's Trace	0.488	23.309b	2.000	49.000	0.000	0,225
	Wilks' Lambda	0.512	23.309b	2.000	49.000	0.000	0,225
	Hotelling's Trace	0.951	23.309b	2.000	49.000	0.000	0,225
	Roy's Largest Root	0.951	23.309b	2.000	49.000	0.000	0,225
Creative Thinking Pretest	Pillai's Trace	0.984	1496.222b	2.000	49.000	0.000	0,701
	Wilks' Lambda	0.016	1496.222b	2.000	49.000	0.000	0,701
	Hotelling's Trace	61.070	1496.222b	2.000	49.000	0.000	0,701
	Roy's Largest Root	61.070	1496.222b	2.000	49.000	0.000	0,701
Pretest learning motivation	Pillai's Trace	0.695	55.805b	2.000	49.000	0.000	0,63
	Wilks' Lambda	0.305	55.805b	2.000	49.000	0.000	0,63
	Hotelling's Trace	2.278	55.805b	2.000	49.000	0.000	0,63
	Roy's Largest Root	2.278	55.805b	2.000	49.000	0.000	0,63
Classes	Pillai's Trace	0.997	7168.472b	2.000	49.000	0.000	0,966
	Wilks' Lambda	0.003	7168.472b	2.000	49.000	0.000	0,966
	Hotelling's Trace	292.591	7168.472b	2.000	49.000	0.000	0,966
	Roy's Largest Root	292.591	7168.472b	2.000	49.000	0.000	0,966

This is evidenced by the Pillai's Trace value of 0.997, with an F value of 7168.472 and a significance level of < 0.001. Furthermore, consistent results are also shown by other indicators such as Wilks' Lambda (0.003), Hotelling's Trace (292.591), and Roy's Largest Root (292.591), all of which have significance values below 0.001. Thus, it can be concluded that there is a notable distinction between the experimental and control classes in terms of students' creative thinking ability and simultaneous learning motivation. Furthermore, the influence of covariates also showed significant results. The cognitive pretest variable (precognitive) had a Pillai's Trace value of 0.984 with an F value of 1496.222 (Sig < 0.001), while the affective pretest (preaffective) had a

Pillai's Trace value of 0.695 with an F value of 55.805 (Sig < 0.001). This suggests that students' initial abilities, both cognitive and affective, significantly contribute to posttest results. The multivariate analysis also showed a very large effect size (Partial Eta Squared = 0.966), indicating that the STEAM-based PjBL model had a substantial contribution to improving students' creative thinking ability and learning motivation. In other words, the difference in learning outcomes is not only influenced by the treatment but also by students' initial conditions.

Overall, the MANCOVA results show that the implementation of the PjBL model with the STEAM approach significantly improves students' creative thinking skills and learning motivation, even after controlling for initial abilities. These findings are in line with constructivist theory, which states that "experiential and project-based learning can improve student engagement cognitively and affectively." (Ndiung & Menggo, 2024). Furthermore, incorporating the STEAM methodology also strengthens learning through contextual and creative activities, thereby improving learning outcomes more comprehensively (Sucilestari et al., 2025). However, the learning model is not the sole factor influencing changes in learning outcomes; other factors, such as the role of the teacher, classroom interaction, and student characteristics, also play a role. Therefore, these results need to be understood as part of a complex learning system.

3.4 Correlation Test

The following are the correlation test results, as shown in Table 5.

Table 5. Correlation Test Results

Variable	Item	Creative Thinking Posttest	Posttest of Learning Motivation
Creative Thinking Posttest	Pearson Correlation	1	.885**
	Sig. (1-tailed)		.000
	N	54	54
Posttest of Learning Motivation	Pearson Correlation	.885**	1
	Sig. (1-tailed)	.000	
	N	54	54

**. Correlation is significant at the 0.01 level (1-tailed).

The findings of the Pearson correlation test showed a significant connection between creative thinking ability and student learning motivation. According to the correlation table, the value of the correlation coefficient obtained was r = 0.885, with a significance value of < 0.001 at the level of 0.01. This shows a positive significant connection between the two variables. The correlation coefficient value of 0.885 is categorized as very strong, meaning that the higher the student's motivation to learn, the higher the creative thinking ability. In contrast, students with low learning motivation tend to have lower creative thinking abilities. This strong relationship shows the close interconnectedness between the affective and cognitive aspects of the mathematics learning process.

These results are in line with the theory of learning motivation, which states that motivation is a major driving factor that influences students' involvement in higher thinking processes (Rehman et al., 2024). Explain that students with high learning motivation tend to be more active in exploring ideas, trying different strategies, and being persistent in solving problems. This tendency is closely associated with the development of creative thinking skills. Oanh dan Dang

(2025) which states that STEAM-based learning can simultaneously increase students' motivation and creative thinking skills. Integrating project activities into learning allows students to engage emotionally and intellectually, thus strengthening the relationship between the two variables.

Thus, the findings of this investigation confirm that learning motivation plays an important role in developing students' creative thinking skills. Therefore, in the mathematics learning process, teachers not only need to pay attention to the cognitive aspect but also design learning that can increase students' motivation to achieve optimal learning outcomes (Liao, 2016). Although the results show a significant impact, there are some limitations to consider. First, this investigation was only conducted in one school with a relatively small sample size, so the generalization of the results was limited. Second, external factors such as teacher competence, learning environment, and student characteristics also have the potential to affect research results. Therefore, further research is recommended to involve a broader sample and examine other variables such as self-efficacy, collaboration skills, and problem-solving abilities to get a more comprehensive picture (Henriksen et al., 2018).

This strong correlation indicates that cognitive and affective aspects in mathematics learning are interconnected and mutually reinforcing. Students with higher learning motivation tend to participate more actively in exploration, discussion, and project completion, which subsequently supports the development of creative thinking skills. Conversely, students who are actively involved in creative problem-solving activities may experience greater satisfaction and confidence, thereby strengthening their motivation to learn mathematics. This reciprocal relationship demonstrates that meaningful, student-centered learning environments are essential for developing both higher-order thinking skills and positive learning attitudes.

The findings of this study provide practical implications for mathematics teachers, particularly in designing learning environments that integrate contextual projects and interdisciplinary approaches. The STEAM-based PjBL model can be used as an alternative strategy to foster students' 21st-century skills by promoting creativity, collaboration, active engagement, and meaningful learning experiences in mathematics classrooms, particularly for geometry learning involving visualization and contextual projects.

4. CONCLUSION

The findings of this study indicate that the implementation of the STEAM-based Project-Based Learning (PjBL) model significantly improved students' creative thinking ability and mathematics learning motivation. Descriptive analysis showed that students in the experimental class experienced higher improvements than those in the control class. The average creative thinking score in the experimental class increased from 61.37 to 74.37 (21.18%), while the control class showed an increase of only 8.03%. Similarly, students' learning motivation in the experimental class increased from 66.63 to 79.11 (18.73%), compared to 5.48% in the control class. Furthermore, the MANCOVA results demonstrated a significant multivariate effect of the intervention, supported by a very large effect size (partial eta squared $\eta p^2 = 0.966$). In addition, the correlation analysis revealed a very strong positive association between creative thinking ability and learning motivation ($r = 0.885$; $p < 0.05$), indicating that both variables are closely associated within the mathematics learning process. These findings suggest that STEAM-integrated PjBL creates meaningful, contextual, and interactive learning experiences that support both cognitive and affective student development in mathematics learning.

This study implies that the STEAM-based PjBL model can be implemented as an innovative learning strategy, particularly in mathematics topics requiring visualization, contextual understanding, and creative problem-solving. Future studies are recommended to apply this learning model to other mathematics materials, such as algebra, statistics, and mathematical modeling, to examine its broader effectiveness across different learning contexts. In addition, further research should integrate additional variables such as self-efficacy, Higher Order Thinking Skills (HOTS), collaboration skills, and problem-solving abilities to obtain a more comprehensive understanding of students' cognitive and affective development. Future investigations are also encouraged to involve larger and more diverse samples and to employ mixed-method or longitudinal approaches to strengthen the generalizability and practical contribution of STEAM-based PjBL implementation in mathematics education.

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