

Enhancing Mathematical Creative Thinking Ability through TPACK-Based Project Based Learning in Defense Oriented Higher Education

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Abstract. The rapid advancement of digital technology and the increasing demand for twenty-first-century competencies require higher education institutions to adopt instructional approaches that foster higher-order thinking skills, particularly mathematical creative thinking ability. This demand is especially critical in defense-oriented higher education, where students are expected to integrate mathematical concepts, modeling, and technology to support strategic decision-making. This study aims to examine the improvement of students' mathematical creative thinking ability through the implementation of Project Based Learning (PjBL) grounded in the Technological Pedagogical Content Knowledge (TPACK) framework in ellipse learning. This study employed a quantitative approach using a pre-experimental one-group pretest-posttest design. The participants consisted of 25 undergraduate students enrolled in the Mathematics Study Program at a defense-oriented higher education institution. Data were collected through an essay-based mathematical creative thinking test administered before and after the implementation of TPACK-based PjBL. Data analysis was conducted using SPSS version 27, including descriptive statistics, paired-samples t-test, Wilcoxon signed-rank test, and normalized gain (N-Gain) analysis. The results indicate a significant improvement in students' mathematical creative thinking ability after the intervention. The mean score increased from 59.24 in the pretest to 85.32 in the posttest, with a statistically significant difference ($p < 0.05$). The average N-Gain score of 0.747 falls into the high category, indicating that TPACK-based PjBL is pedagogically effective in enhancing students' mathematical creative thinking ability. These findings suggest that TPACK-based Project Based Learning is an effective and relevant instructional approach for improving mathematical creative thinking ability in analytic geometry courses within defense oriented higher education.

Keywords: *Analytic Geometry; Defense Oriented Higher Education; Mathematical Creative Thinking Ability; Project Based Learning; TPACK*

Abbreviations: Project Based Learning (PjBL) adalah model pembelajaran yang menekankan keterlibatan mahasiswa dalam penyelesaian proyek autentik berbasis masalah. Technological Pedagogical Content Knowledge (TPACK) merupakan kerangka integratif yang menggabungkan pengetahuan konten, pedagogi, dan teknologi dalam perancangan pembelajaran. Normalized Gain (N-Gain) digunakan untuk mengukur tingkat peningkatan kemampuan belajar mahasiswa antara pretest dan posttest. Semua singkatan digunakan secara konsisten di seluruh naskah.

INTRODUCTION

The development of digital technology and the demands of 21st-century competencies have brought significant implications for the implementation of mathematics education in higher education. Universities are no longer focused solely on the mastery of mathematical concepts and procedures; instead, they are also required to foster higher-order thinking skills, such as creative thinking, critical thinking, and complex problemsolving that are relevant to real-world contexts [1], [2]. These challenges become increasingly crucial in defense-oriented higher education, which requires graduates to be capable of integrating mathematical knowledge, modeling, and technology to support strategic decision-making.

Mathematical creative thinking skills constitute an essential component of higher-order thinking skills. These skills encompass fluency in generating ideas, flexibility in selecting problem solving strategies, originality of solutions, and the ability to elaborate ideas in solving mathematical problems [4]. Research indicates that the development of mathematical creative thinking skills cannot be optimally achieved through conventional lecturer centered instruction; rather, it requires learning approaches that position students as active subjects in the knowledge construction process [3].

One learning model considered effective in developing mathematical creative thinking skills is Project Based Learning (PjBL). The PjBL model emphasizes students' engagement in solving authentic problems through structured, collaborative projects oriented toward tangible products. Several empirical studies in mathematics education have shown that the implementation of PjBL significantly enhances creativity,

conceptual understanding, and mathematical problem solving skills compared to traditional learning approaches [5], [6], [12]. Moreover, findings from systematic reviews indicate that PjBL contributes positively to the development of higher-order thinking skills in mathematics learning across various educational levels [7]

Along with the advancement of educational technology, the integration of technology into PjBL has become an indispensable aspect of contemporary learning. The Technological Pedagogical Content Knowledge (TPACK) framework provides a strong conceptual foundation for the holistic integration of technological, pedagogical, and content knowledge in the learning process [8]. In the context of mathematics education, TPACK enables lecturers to design learning activities that are not only pedagogically and conceptually appropriate but also effective in utilizing technology to support students' understanding and creativity [9], [10]

Recent studies indicate that integrating PjBL with the TPACK framework has the potential to enhance students' learning engagement and higher-order thinking skills. [11] found that TPACK-integrated project based learning instruments significantly improved students' higher-order thinking skills. Similar findings were reported by [6], [12] who demonstrated that the implementation of TPAC based PjBL positively affected students' engagement and higher-order thinking skills in mathematics learning.

The topic of ellipses in analytic geometry is one of the mathematical subjects with high applicative relevance, particularly in the context of trajectory modeling, radar systems, navigation, and orbital analysis related to the defense sector [13]. However, research shows that students often experience difficulties in understanding analytic geometry concepts, including ellipses, due to their abstract nature and the high demands on visualization and mathematical modeling skills [14]. This condition results in low levels of student engagement and creativity in solving contextual problems related to the topic.

Students in the Mathematics Study Program at defense-oriented higher education institutions possess unique academic characteristics, as they are prepared to address mathematical problems directly related to national defense systems. Therefore, a learning approach that can balance the integration of contextual projects, technology, and conceptual understanding is required. Although numerous studies have examined the effectiveness of PjBL and TPACK separately, empirical research that specifically investigates the effect of TPACK-based PjBL on students' mathematical creative thinking skills in the topic of ellipses within the context of defense-oriented higher education remains very limited.

Based on the above discussion, this study aims to analyze the effect of implementing Project Based Learning based on Technological Pedagogical Content Knowledge on the mathematical creative thinking skills of Mathematics Study Program students in learning the topic of ellipses. The findings of this study are expected to provide empirical contributions to the development of mathematics learning in defense-oriented higher education and to enrich the literature on the integration of PjBL and TPACK in enhancing students' mathematical creative thinking skills.

METHODS

Study area

This study was conducted in the Mathematics Study Program, Faculty of Military Mathematics and Natural Sciences, Indonesia Defence University. The research subjects were cohort 4 students enrolled in the Analytic Geometry course, particularly in the topic of ellipses. A total of 25 students participated in the study, all of whom attended the learning activities within a single intact class.

The selection of the research site was based on the characteristics of defense-oriented higher education, which emphasize the integration of mastery of mathematical concepts, modeling skills, and the use of technology in the context of strategic decision-making. All learning activities, data collection, and measurements of students' mathematical creative thinking skills were carried out within the same academic semester to ensure consistency of treatment and the reliability of the research data.

Procedures

Research Design

This study employed a quantitative method with a pre-experimental one-group pretest–posttest design. This design was used to analyze changes in students' mathematical creative thinking skills before and after the implementation of Technological Pedagogical Content Knowledge (TPACK) based Project Based Learning (PjBL). Pre-experimental designs are commonly used to evaluate the impact of an instructional treatment under controlled learning conditions within a single group of participants [15].

The selection of the one-group pretest–posttest design was based on the intact class condition, in which the topic of ellipses was taught in only one class; therefore, the establishment of a control group was not feasible [16]. The schematic representation of the research design is presented in Table 1.

Table 1. One-Group Pretest–Posttest Research Design

Pretest	Treatment	Posttest
O_1	X	O_2

Note:

O_1 = Pretest of students' mathematical creative thinking skills

X = TPACK-based Project Based Learning

O_2 = Posttest of students' mathematical creative thinking skills

Source: [16]

This design was employed to identify changes and improvements in students' mathematical creative thinking skills as a result of the implementation of TPACK-based Project Based Learning on the topic of ellipses.

Learning Implementation

The implementation of the study began with the administration of a pretest to measure students' initial mathematical creative thinking skills on the topic of ellipses. Subsequently, the learning process was conducted using a TPACK based Project Based Learning model, which integrates mathematical content knowledge, project based pedagogical strategies, and the use of digital technology in a cohesive manner [8].

The learning activities were carried out over two meetings, each allocated 3 credit hours, equivalent to 135 minutes of Analytic Geometry instruction per meeting. The first meeting focused on the introduction of contextual problems, exploration of ellipse concepts, and the design of defense-related application projects. The second meeting emphasized the development of mathematical models of ellipses, the utilization of visualization or simulation technologies, and the presentation and reflection of project outcomes.

Students worked collaboratively in small groups to explore ideas, develop problem solving strategies, and utilize mathematical visualization or simulation software. The lecturer acted as a facilitator by guiding discussions, providing feedback, and directing reflection on the mathematical solutions developed. After the completion of the entire learning sequence, students were administered a posttest with a level of difficulty equivalent to that of the pretest.

Research Instruments

The research instrument consisted of an essay test designed to assess students' mathematical creative thinking skills based on four main indicators: fluency, flexibility, originality, and elaboration. The instrument was tailored to the characteristics of the ellipse topic and the applicative problem contexts related to the defense sector. Content validity was established through expert judgment conducted by lecturers specializing in mathematics content and mathematics education [4].

In addition to the written test, project assessment was conducted using a performance assessment rubric completed by the lecturer to evaluate the implementation of TPACK based Project Based Learning as well as the alignment between project activities and the indicators of mathematical creative thinking skills. The indicators used in the project assessment are presented in Table 2.

Table 2. Indicators for Assessing Mathematical Creative Thinking Skills in Projects

No.	Indicator	Assessed Aspect	Description
1	Fluency	Number of ideas and solutions	Ability to generate more than one mathematical idea or approach in ellipse modeling
2	Flexibility	Variety of strategies	Ability to use diverse strategies, representations, or solution methods
3	Originality	Uniqueness of solutions	Degree of novelty of the ideas or ellipse models developed in the project
4	Elaboration	Depth of explanation	Ability to develop solutions in a detailed, logical, and systematic manner

Note: Indicators of mathematical creative thinking skills refer to [4].

Data Analysis

The research data, consisting of students' pretest and posttest scores on mathematical creative thinking skills, were analyzed quantitatively using SPSS version 27 to determine the effectiveness of implementing Technological Pedagogical Content Knowledge (TPACK) based Project Based Learning. The analysis procedure began with a data normality test using the Shapiro-Wilk test to determine the appropriate inferential statistical technique. If the data were normally distributed, differences between pretest and posttest scores were analyzed using a paired samples t-test. If the data did not meet the normality assumption, the Wilcoxon signed-rank test was employed as a non-parametric alternative [18].

In addition to the difference tests, improvements in students' mathematical creative thinking skills were analyzed using the Normalized Gain (N-Gain) index. N-Gain analysis was used to determine the effectiveness of the learning process by comparing the difference between posttest and pretest scores

normalized against the maximum possible score (Meltzer, 2002). The N-Gain value was calculated using the following formula:

The obtained N-Gain values were then classified into three categories: high, medium, and low. The classification criteria followed those proposed by Meltzer (2002) and [15]. The distribution of N-Gain values for students' mathematical creative thinking skills is presented in Table 3.

Table 3. Distribution of N-Gain Values of Students' Mathematical Creative Thinking Skills

No.	N-Gain Category	N-Gain Value Range
1	High	$g \geq 0.70$
2	Medium	$0.30 \leq g < 0.70$
3	Low	$g < 0.30$

Note: N-Gain classification criteria refer to [16] and [17].

RESULTS AND DISCUSSION

Result-1 Descriptive Statistics of Pretest and Posttest Scores on Mathematical Creative Thinking Skills

The analysis of the research results began with the presentation of descriptive statistics of students' mathematical creative thinking skills before and after the implementation of the Technological Pedagogical Content Knowledge (TPACK) based Project Based Learning (PjBL) model on the topic of ellipses. The pretest and posttest data were obtained from 25 students of the Mathematics Study Program, Faculty of Military Mathematics and Natural Sciences, Indonesia Defence University. The descriptive statistics of pretest and posttest scores on mathematical creative thinking skills are presented in Table 4.

Table 4. Descriptive Statistics of Pretest and Posttest Scores on Mathematical Creative Thinking Skills

Statistics	Pretest	Posttest
Number of Students	25	25
Minimum Score	40	65
Maximum Score	90	100
Mean	59.24	85.32
Standard Deviation	15.30	10.17

Note: Descriptive statistics of pretest and posttest scores. Data were processed using SPSS version 27

Based on Table 4, the mean pretest score of students' mathematical creative thinking skills was 59.24, while the mean posttest score increased to 85.32. The increase of 26.08 points indicates that the implementation of TPACK based PjBL had a positive impact on students' ability to generate mathematical ideas, apply flexible problem-solving strategies, and develop ellipse related solutions in a more in-depth and contextual manner.

Prior to hypothesis testing, the data were examined for the required statistical assumptions. Normality was tested using the Shapiro–Wilk test, while homogeneity was assessed using Levene's Test. The results of the Shapiro–Wilk normality test indicated that both pretest and posttest data were normally distributed (Sig. > 0.05), as shown in Table 5.

Table 6. Shapiro–Wilk Normality Test Results

	Shapiro-Wilk				
		Statistic	Statistic	df	Sig.
Ellipse Pretest		.167	.915	25	.050
Ellipse Posttest		.180	.927	25	.065
Posttest–Pretest Difference		.175	.941	25	.155

a. Lilliefors Significance Correction.

Note: Data were processed using SPSS version 27

The results of the Shapiro–Wilk normality test showed that the significance (Sig.) value for the pretest of mathematical creative thinking skills on the topic of ellipses was 0.050, for the posttest was 0.065, and for the posttest–pretest difference was 0.155. All significance values were greater than or equal to 0.05 (Sig. $\geq$ 0.05), indicating that the pretest, posttest, and their difference scores were normally distributed. Therefore, the data met the normality assumption and were suitable for analysis using parametric statistical methods, specifically the paired samples t-test, to examine the effect of TPACK-based Project Based Learning on students' mathematical creative thinking skills in ellipse learning within a defense-oriented context.

The main hypothesis was tested using a paired samples t-test. The results of the analysis are presented in Table 7.

Table 7. Results of the Paired Samples t-Test

		Mean	Std. Deviation	t	df	Sig. (2-tailed)
Pair 1	Pretest Ellipses – Posttest Ellipses	-26.08000	9.55214	-13.651	24	.000

Note: Significance level $\alpha = 0.05$. Data were processed using SPSS version 27.

The results of the paired samples t-test comparing pretest and posttest scores of students' mathematical creative thinking skills on the topic of ellipses indicated a mean difference of -26.08 with a standard deviation of 9.55. The test results showed a t value of -13.651 with 24 degrees of freedom ($df = 24$) and a significance value (Sig. 2-tailed) of 0.000. Since the significance value was less than 0.05 ($p < 0.05$), the null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted. This finding indicates that the TPACK-based Project Based Learning model had a statistically significant effect on students' mathematical creative thinking skills in learning ellipses within a defense-oriented context.

As further confirmation, to examine differences in students' mathematical creative thinking skills before and after the implementation of TPACK-based Project Based Learning in ellipse learning within a defense context, an analysis using the related-samples Wilcoxon signed-rank test was also conducted. This non-parametric test was employed to assess differences between two related samples. The results of this analysis are presented in Table 8.

Table 8. Wilcoxon Signed-Rank Test Statistics for Pretest and Posttest of Mathematical Creative Thinking Skills

Test Statistic	Posttest Ellipses – Pretest Ellipses
Z	-4.392
Asymp. Sig. (2-tailed)	0.000
a. Wilcoxon Signed Ranks Test	
b. Based on negative ranks.	

Note: $\alpha = 0.05$; $p < 0.05$ indicates a statistically significant difference between pretest and posttest scores.

Based on the results presented in Table 8, the Wilcoxon signed-rank test yielded with a two-tailed significance value of 0.000. Since the significance value is less than the significance level of $\alpha = 0.05$, it can be concluded that there is a statistically significant difference between the pretest and posttest scores of students' mathematical creative thinking skills. Accordingly, the null hypothesis (H_0) is rejected, while the alternative hypothesis (H_1) is accepted. These results indicate that the implementation of TPACK-based Project Based Learning has a significant effect on students' mathematical creative thinking skills in learning the topic of ellipses.

Result 2. Learning Effectiveness Based on N-Gain

To determine the level of learning effectiveness, an N-Gain analysis was conducted on the pretest and posttest scores of students' mathematical creative thinking skills. The results of the N-Gain calculation are presented in Table 9.

Table 9. Results of the N-Gain Analysis of Mathematical Creative Thinking Skills

	N	Minimum	Maximum	Mean	Std. Deviation
N_Gain_Score	25	.50	1.00	.7468	.16282
N_Gain_Score_Persentase	25	50.00	100.00	74.6818	16.28187
Valid N (listwise)	25				

Note: N-Gain criteria refer to [16]

Based on the analysis conducted using SPSS version 27, the mean N-Gain value was 0.7468, which falls into the high category. This finding indicates that TPACK based Project Based Learning is effective in enhancing students' mathematical creative thinking skills in learning the topic of ellipses.

Discussion

The results of this study indicate a significant improvement in students' mathematical creative thinking skills following the implementation of TPACK-based Project Based Learning (PjBL). The increase in the mean score from 59.24 to 85.32 suggests that students not only acquired procedural knowledge of ellipses but were also able to develop mathematical solutions that were more flexible, original, and contextually grounded. This finding is consistent with the [1] report, which emphasizes the importance of project based and technology enhanced learning in fostering higher-order thinking skills in 21st-century higher education. The integration of contextual projects within a defense-related framework enabled students at Universitas Pertahanan to connect ellipse concepts with real-world applications such as trajectory modeling, radar systems, and orbital analysis, thereby making learning more meaningful and authentic.

The consistency of the statistical results obtained from both the paired samples t-test and the Wilcoxon signed-rank test further strengthens the validity of the findings. All students demonstrated an increase in posttest scores, indicating that the TPACK-based PjBL model had an equitable impact and was not limited to students with specific initial ability levels. This result supports previous studies by [5] as well as [6], [12],

which reported that Project Based Learning significantly enhances creative thinking skills in mathematics education. Moreover, the N-Gain value classified in the high category indicates that the learning intervention was not only statistically significant but also pedagogically effective. This finding aligns with studies by [7] and [11] which highlight that integrating PjBL within the TPACK framework enhances students' higher-order thinking skills through the use of technology as a tool for visualization, exploration, and conceptual understanding.

In the context of defense oriented higher education, these findings reinforce the argument that mathematics instruction should be designed to be contextual, project based, and technologically integrated. Students are not only expected to master mathematical concepts but also to apply them in complex and strategic situations. Therefore, TPACK-based Project Based Learning represents a relevant and effective instructional approach for developing mathematical creative thinking skills among students at Universitas Pertahanan, particularly in learning abstract yet highly applicable topics such as ellipses.

CONCLUSION

Based on the data analysis conducted using SPSS version 27, it can be concluded that the implementation of the Technological Pedagogical Content Knowledge (TPACK) based Project Based Learning (PjBL) model has a significant effect on improving the mathematical creative thinking skills of students in the Mathematics Study Program, Faculty of Military Mathematics and Natural Sciences, Universitas Pertahanan Republik Indonesia, on the topic of ellipses. Descriptive statistical results indicate an increase in the mean score of students' mathematical creative thinking skills from 59.24 in the pretest to 85.32 in the posttest. The paired samples t-test revealed a statistically significant difference between pretest and posttest scores ($p < 0.05$), which was further confirmed by the Wilcoxon signed-rank test with a significance value of 0.000. These findings confirm that the observed improvement in mathematical creative thinking skills was a direct effect of the TPACK-based PjBL implementation rather than random variation in the data.

The effectiveness of the learning intervention is further supported by the mean N-Gain value of 0.747, which falls into the high category. This result indicates that the structured integration of project-based learning and technology use effectively facilitates the development of key dimensions of mathematical creative thinking, including fluency, flexibility, originality, and elaboration, in solving contextual and applied problems related to ellipses. Therefore, TPACK based Project Based Learning is proven to be an effective and relevant instructional approach for enhancing students' mathematical creative thinking skills in analytic geometry courses within defense-oriented higher education.

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