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The Effectiveness of STEAM-Based Learning on Vocational Students' Creative Thinking Skills and Self-Efficacy in Linear Equations

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ABSTRACT

The development of 21st-century competencies requires mathematics learning that fosters not only conceptual understanding but also creative thinking skills and self-efficacy. However, these competencies are often underdeveloped in vocational high schools due to teacher-centered learning approaches. This study examines the effectiveness of STEAM-based Project-Based Learning (PjBL) on students' creative thinking skills and self-efficacy in learning systems of linear equations in two variables. A quasi-experimental pretest–posttest control group design was employed involving 60 tenth-grade students from the Visual Communication Design (DKV) program. The experimental group received STEAM-based PjBL, while the control group received conventional PjBL. Creative thinking skills were measured using essay tests (fluency, flexibility, originality, elaboration) and self-efficacy via a Likert-scale questionnaire, both validated through expert judgment with Cronbach's alpha of 0.76 and 0.87. Data were analyzed using Pearson correlation and MANCOVA. The experimental group outperformed the control group in creative thinking (M = 86.50, SD = 3.72 vs. M = 75.27, SD = 3.25; N-Gain = 0.65 vs. 0.36, medium category) and self-efficacy (M = 88.00, SD = 2.56 vs. M = 76.93, SD = 2.96; N-Gain = 0.33 vs. 0.19, moderate vs. low category). MANCOVA confirmed a significant simultaneous effect (Wilks' Lambda = 0.010, $p < 0.05$, $\eta^2 = 0.990$), and a very strong correlation between both variables ($r = 0.978$, $p < 0.01$). These findings confirm that STEAM+PjBL provides meaningful, contextual, and interdisciplinary learning experiences that simultaneously enhance creativity and self-confidence, and is recommended as an innovative instructional strategy in vocational mathematics education.

Keywords: STEAM-Based Learning; Project-Based Learning; Creative Thinking; Self-Efficacy; Vocational Education.

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1. INTRODUCTION

The development of digital technology and the demands of 21st century competencies are driving fundamental changes in the orientation of mathematics learning. Mastery of concepts and procedures alone is no longer adequate, mathematics learning is now required to be able to cultivate high-level thinking skills, especially creative thinking skills and self-efficacy. Creative thinking in mathematics is a cognitive ability that allows students to produce a variety of alternative solutions flexibly and originally, which can be measured through four indicators: fluency, flexibility, originality, and elaboration (Suherman & Vidákovich, 2022). On the affective side, self-efficacy, which is an individual's belief in his or her ability to complete a task under certain conditions, directly affects students' motivation, perseverance, and learning strategies,

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with three main dimensions: magnitude, strength, and generality (Al-Abyadh & Azeem, 2022; Zakariya, 2022). Students who have high self-efficacy are shown to be more active, more resistant to difficulties, and obtain better learning outcomes in mathematics learning.

Although both competencies have been recognized as important, the reality in the classroom shows that mathematics learning in Vocational High Schools (SMK) is still not optimal in integrating cross-disciplinary approaches that can encourage students' creativity and self-efficacy at the same time. Applied learning is generally still limited to a single approach without cross-disciplinary involvement, thus leaving little room for the exploration of ideas and strengthening students' self-confidence (Rahmatin et al., 2025). This limitation is reflected in students' tendency to apply procedural rather than creative approaches when solving mathematical problems, leaving little room for divergent thinking and the development of mathematical self-confidence (Amanova et al., 2025; Putri et al., 2023). This condition has a direct impact on the low involvement of students and their level of self-efficacy in facing mathematical challenges.

One of the materials that is often a point of difficulty is the Two-Variable Linear Equation System (SPLDV). Students generally experience obstacles in understanding concepts, determining the right variables, changing equations to standard forms, and interpreting results contextually (Hulu, 2023). Misconceptions related to the definition of SPLDV and weak conceptual understanding also exacerbate the difficulties in choosing and implementing the correct settlement method (Fatio et al., 2020). This condition was directly observed at SMK Negeri 1 Purwokerto, Banyumas Regency, Central Java, where one of the authors serves as a mathematics teacher. Based on classroom observations and grade documentation, a considerable number of Class X DKV students scored below the Minimum Completeness Criteria (KKM = 75) in SPLDV material prior to remediation. Students also demonstrated passive learning behavior, showing limited initiative and quickly giving up when faced with non-routine or challenging mathematical problems. Furthermore, students' mathematical self-efficacy was observed to be low, as evidenced by their reluctance to attempt difficult tasks and their tendency to rely heavily on teacher guidance rather than independent problem-solving. This condition is consistent with findings from previous studies showing that students generally struggle with conceptual understanding in SPLDV material (Fatio et al., 2020; Hulu, 2023), and that limited exposure to student-centered approaches contributes to low mathematical self-efficacy among vocational students (Masdarini, 2024; Samsudin et al., 2020).

One of the learning approaches that is considered to be able to answer these challenges is STEAM (Science, Technology, Engineering, Art, and Mathematics)-based learning. STEAM integrates five disciplines in one learning experience that is authentic, contextual, and oriented towards real problem-solving, thus providing a wider space for students to think divergently and creatively (Li et al., 2022). Within the framework of STEAM, art (Art) plays an important role as a bridge between logical-mathematical reasoning and creative expression, encouraging students to not only find the right solutions, but also present them innovatively and aesthetically. Various studies have proven that the implementation of STEAM in schools has a positive impact on students' learning achievement, high-level thinking skills, and affective variables (Amanova et al., 2025). In particular, Putri et al. (2023) found that STEAM-based learning significantly improved students' creative thinking skills compared to conventional learning. In a vocational context, STEAM integration is very relevant because it allows students to connect mathematical concepts including SPLDV with real applications in their areas of expertise, including Visual Communication Design (DKV), so that learning becomes more meaningful and motivating (Ariyanto et al., 2025).

In addition to having an impact on creative thinking skills, STEAM-based learning has also been proven to contribute to increasing students' self-efficacy. The characteristics of STEAM that emphasize collaboration, open exploration, and active involvement in real projects create learning conditions conducive to the growth of students' self-confidence in their mathematical abilities. Jia et al. (2021) report that a curriculum that integrates STEAM with a maker education approach significantly improves students' academic self-efficacy and cross-disciplinary knowledge mastery. Similar findings were put forward by Zakariya (2022) who affirmed that innovative learning interventions that encourage active engagement and repeated successful experiences are key factors in building strong mathematical self-efficacy. Additional evidence from Samsudin et al. (2020) and Masdarini (2024) further confirms that project-based learning approaches significantly improve self-efficacy among vocational high school students through hands-on, contextual learning experiences. Although empirical evidence on the benefits of STEAM on creative thinking and self-efficacy is getting stronger, research that specifically examines the simultaneous effect of STEAM-based learning on these two variables on vocational school students, especially in the context of SPLDV material and Visual Communication Design (DKV) skill programs, is still very limited. This research gap is the basis and urgency for the implementation of this study.

The low ability to think creatively and self-efficacy of vocational school students, which is exacerbated by the lack of optimal integration of cross-disciplinary approaches in mathematics learning and conceptual difficulties in SPLDV materials, confirms that learning innovations are needed that are able to answer both challenges simultaneously. STEAM-based learning integrated in the Project-Based Learning (STEAM+PjBL) model offers a relevant and contextual framework to address this need. Although previous studies have examined the effect of STEAM on creative thinking (Putri et al., 2023) or self-efficacy (Jia et al., 2021; Zakariya, 2022) separately, no study has simultaneously investigated both variables using MANCOVA in the context of SPLDV material within a vocational high school DKV program. Therefore, this study aims to test the effectiveness of STEAM+PjBL learning on the creative thinking ability and self-efficacy of Class X DKV SMK Negeri 1 Purwokerto students on SPLDV material, with the hope of making a theoretical and practical contribution to mathematics learning innovations in vocational schools that are relevant to the demands of the 21st century.

2. METHODS

This study uses a quantitative approach with a quasi-experimental design of the non-equivalent control group design, where the experimental and control groups were determined based on naturally formed classes in schools without individual randomization (Creswell & Creswell, 2023). The experimental group was Class X DKV 1 (n = 30 students) who received STEAM-based Project-Based Learning (STEAM+PjBL), while the control group was Class X DKV 2 (n = 30 students) who received conventional Project-Based Learning without STEAM integration (PjBL), with a total sample of N = 60 students from SMK Negeri 1 Purwokerto, Banyumas Regency, Central Java in the 2025/2026 school year. Both groups were given a pretest before treatment and a posttest after the treatment was completed.

In the experimental group, STEAM+PjBL learning was conducted over two weeks with five lesson periods per week (5 × 45 minutes), comprising three formal classroom sessions and an independent out-of-class project work period with teacher guidance. The implementation followed the six stages of Project-Based Learning (Thomas, 2000). In the first classroom session, stages 1 to 3 were facilitated: (1) Start with the Essential Question, where students were

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presented with a real-world problem related to SPLDV in the context of visual communication design, such as determining the optimal cost of designing promotional materials; (2) Design a Plan, where students planned their project approach by mapping the integration of five STEAM components; and (3) Create a Schedule, where groups organized their workflow and task distribution for the out-of-class project work. Between the first and second classroom sessions, students worked independently outside the classroom to develop their projects. Stage (4) Monitor the Progress was facilitated through the second classroom session, in which the teacher reviewed each group's development, provided feedback, and guided revisions. In the third and final classroom session, stages (5) Assess the Outcome and (6) Evaluate the Experience were conducted, where students presented their completed projects and engaged in reflective discussion on their learning process. The five STEAM components were integrated as follows: Science through modeling real-world situations into systems of linear equations; Technology through the use of digital tools such as Canva and PowerPoint for data visualization and design; Engineering through the design of a systematic problem-solving framework for SPLDV; Art through visual representation and creative design of solutions relevant to the DKV context; and Mathematics through the application of precise SPLDV algebraic solution procedures (Jia et al., 2021; Wilson et al., 2021). Students worked collaboratively in small groups and produced creative visual works in the form of flowcharts and infographics as their final learning products. In the control group, learning was carried out using the PjBL model without the integration of STEAM components, where students worked on SPLDV-related mathematics projects without cross-disciplinary involvement. The overall research procedure is illustrated in Figure 1.

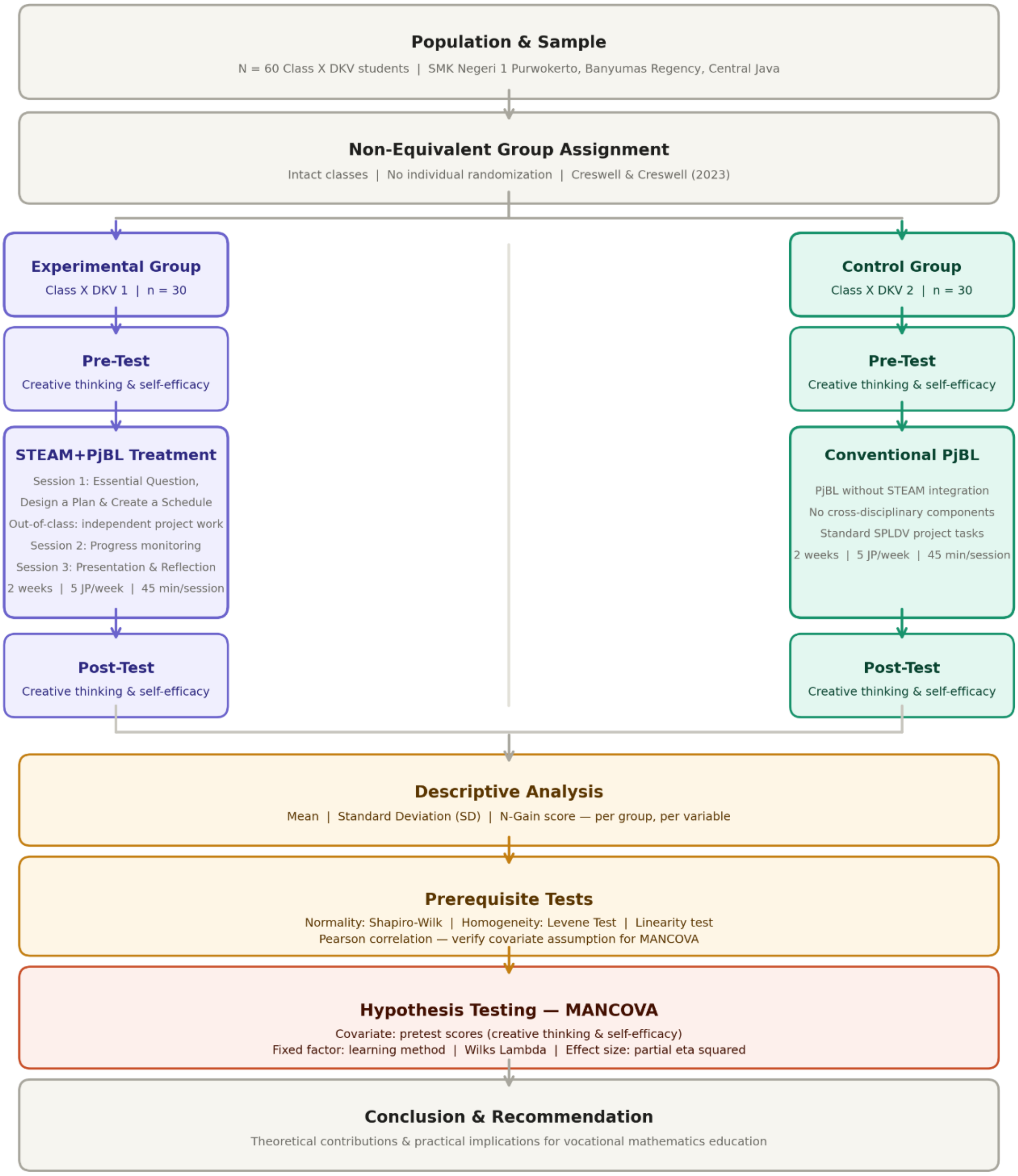

Figure 1. Research Procedure

Two instruments were used to measure the dependent variables in this study. First, the creative thinking ability test consists of 2 description questions, where each item is designed to contain all four indicators of mathematical creative thinking simultaneously: fluency, flexibility, originality, and elaboration (Suherman & Vidákovich, 2022). Although the test consists of only two items, this approach follows an integrated assessment design in which each item is constructed to simultaneously elicit all four creative thinking indicators within a single problem-solving task, rather than measuring each indicator with a separate item (Suherman & Vidákovich, 2022). The design of each item was reviewed and validated through expert judgment by two validators consisting of a mathematics education lecturer and an experienced mathematics teacher to ensure content validity and adequate construct representativeness across all four indicators. Second, the self-efficacy questionnaire consists of 28 statement items with a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), developed based on three dimensions

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of self-efficacy: magnitude, strength, and generality (Julaihi et al., 2022). Both instruments were validated by 2 expert validators consisting of lecturers and mathematics teachers, then tested for reliability using Cronbach's alpha with a coefficient of 0.76 for the creative thinking test and 0.87 for the self-efficacy questionnaire, both of which are included in the category of adequate reliability (George & Mallery, 2003).

Data were analyzed descriptively and inferentially using IBM SPSS Statistics version 25. Descriptive analysis included the calculation of mean, standard deviation, and N-Gain to measure the relative increase of each group. Before hypothesis testing, a series of prerequisite tests were carried out including the Shapiro-Wilk normality test ($\alpha = 0.05$), the Levene's Test homogeneity test, and the Pearson correlation test between the pretest and posttest of each variable to verify that the covariate is significantly correlated with the dependent variable as the main assumption of MANCOVA (Tabachnick & Fidell, 2019). Hypothesis testing was conducted using Multivariate Analysis of Covariance (MANCOVA) with pretest scores of creative thinking ability and self-efficacy as covariates and learning method (STEAM+PjBL vs. PjBL) as a fixed factor, using Wilks' Lambda criteria to test the simultaneous effect of STEAM+PjBL learning on the two dependent variables after controlling for initial ability differences between groups (Tabachnick & Fidell, 2019). The magnitude of the treatment effect was estimated using partial eta squared (η^2).

3. RESULT AND DISCUSSION

3.1 Result

The findings of this study are presented based on data analysis, which includes descriptive statistics, prerequisite tests, Pearson correlation test, and hypothesis testing using MANCOVA. The analysis aimed to examine the effect of STEAM-based Project-Based Learning (PjBL) on students' creative thinking skills and self-efficacy while controlling for their initial abilities.

a. Descriptive Statistics

Prior to inferential analysis, descriptive statistics were calculated to provide a comprehensive overview of student learning outcomes in both groups before and after the treatment. The N-Gain score was calculated using the normalized gain formula proposed by Hake (1999), with categories interpreted as follows: high ($g \geq 0.70$), medium ($0.30 \leq g < 0.70$), and low ($g < 0.30$), as shown in Table 1.

Table 1. Descriptive Statistics of Creative Thinking Skills and Self-Efficacy

Variable	Group	n	Mean Pretest (SD)	Mean Posttest (SD)	N-Gain	Category
Creative Thinking Skills	Experimental (STEAM+PjBL)	30	61.73 (3.24)	86.50 (3.72)	0.65	Medium
	Control (PjBL)	30	61.43 (3.08)	75.27 (3.25)	0.36	Medium
Self-Efficacy	Experimental (STEAM+PjBL)	30	62.47 (2.53)	88.00 (2.56)	0.33	Medium
	Control (PjBL)	30	61.83 (2.38)	76.93 (2.96)	0.19	Low

Note. N-Gain categories based on Hake (1999): High ($g \geq 0.70$), Medium ($0.30 \leq g < 0.70$), Low ($g < 0.30$). SD = Standard Deviation.

As shown in Table 1, both groups had comparable pretest scores prior to treatment, indicating similar initial abilities. After the treatment, the experimental group demonstrated a notably higher mean posttest score in creative thinking skills (M = 86.50, SD = 3.72) compared to the control group (M = 75.27, SD = 3.25), with N-Gain values of 0.65 and 0.36 respectively, both categorized as medium. In terms of self-efficacy, the experimental group also showed greater improvement (M = 88.00, SD = 2.56) than the control group (M = 76.93, SD = 2.96), with N-Gain values of 0.33 (medium) and 0.19 (low) respectively. These descriptive findings suggest that STEAM+PjBL learning contributed to greater improvement in both variables compared to conventional PjBL.

b. Prerequisite Test

The normality test using the Shapiro–Wilk test indicated that all data were normally distributed. This was evidenced by the significance values for creative thinking skills: the pretest scores were 0.083 (experimental) and 0.165 (control), while the posttest scores were 0.285 (experimental) and 0.472 (control). For self-efficacy, the pretest significance values were 0.074 (experimental) and 0.200 (control), while the posttest values were 0.213 (experimental) and 0.176 (control). Since all significance values were greater than 0.05 ($p > 0.05$), the data were considered normally distributed.

The homogeneity test using Levene's Test showed that the variances of the two groups were homogeneous. This was indicated by the significance values for creative thinking skills, with 0.744 for the pretest and 0.270 for the posttest, and for self-efficacy, with 0.620 for the pretest and 0.382 for the posttest. All significance values were greater than 0.05 ($p > 0.05$), indicating that the assumption of homogeneity was satisfied. The linearity test indicated that the relationship between creative thinking skills and self-efficacy was linear. This was shown by the significance value of deviation from linearity of 0.180 ($p > 0.05$), indicating no significant deviation from linearity, and the significance value for linearity of 0.000 ($p < 0.05$), indicating a significant linear relationship between the two variables

c. Pearson Correlation Test

The results of the Pearson correlation analysis indicated a very strong positive relationship between students' creative thinking skills and self-efficacy, as shown in Table 2.

Table 2. Pearson Correlation Test

		Post_Kog	**Post_Self**
Post_Kog	Pearson Correlation	1	.978**
	Sig. (2-tailed)		.000
	N	60	60
Post_Self	Pearson Correlation	.978**	1
	Sig. (2-tailed)	.000	
	N	60	60
**. Correlation is significant at the 0.01 level (2-tailed).			

Based on Table 2 the correlation coefficient is 0.978 with a significance value of 0.000 ($p < 0.01$), indicating a very strong and statistically significant relationship between creative thinking skills and self-efficacy. This suggests that students with higher levels of creative thinking tend to exhibit higher self-efficacy.

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d. Hypothesis Testing (MANCOVA)
The results of hypothesis testing using MANCOVA to examine the simultaneous effect of STEAM-based learning on students’ creative thinking skills and self-efficacy are presented in Table 3.

Table 3. Mancova Result

Effect		Value	F	Sig.	Partial Eta Squared
Class	Pillai's Trace	.990	2824.247[b]	.000	.990
	Wilks' Lambda	.010	2824.247[b]	.000	.990
	Hotelling's Trace	102.700	2824.247[b]	.000	.990
	Roy's Largest Root	102.700	2824.247[b]	.000	.990

Based on Table 3, the Wilks’ Lambda value is 0.010, with F = 2824.247 and a significance value of 0.000 ($p < 0.05$). This indicates that STEAM-based learning has a statistically significant effect on students’ creative thinking skills and self-efficacy simultaneously after controlling for their initial abilities. Furthermore, the Partial Eta Squared value of 0.990 indicates that the effect size of the treatment is very large.

3.2 Discussion

The results of this study confirm that STEAM-based Project-Based Learning (STEAM+PjBL) has a statistically significant simultaneous effect on students' creative thinking skills and self-efficacy (Wilks' Lambda = 0.010, F = 2824.247, $p < 0.05$, $\eta^2 = 0.990$). Descriptively, the experimental group demonstrated substantially higher improvement in creative thinking skills, with a mean posttest score of 86.50 (SD = 3.72) compared to 75.27 (SD = 3.25) in the control group, and N-Gain values of 0.65 and 0.36 respectively (both medium category). A similar pattern was observed for self-efficacy, where the experimental group achieved a mean posttest score of 88.00 (SD = 2.56) with an N-Gain of 0.33 (medium), compared to 76.93 (SD = 2.96) with an N-Gain of 0.19 (low) in the control group. These descriptive findings indicate that STEAM+PjBL contributed to greater and more meaningful improvement in both variables compared to conventional PjBL, supporting the effectiveness of cross-disciplinary, project-based approaches in vocational mathematics learning.

The effectiveness of STEAM+PjBL can be explained through its integrative and contextual characteristics. STEAM combines five disciplines: Science, Technology, Engineering, Art, and Mathematics within an authentic, problem-based learning framework that encourages students to think divergently and creatively (Li et al., 2022). Creative thinking indicators of fluency, flexibility, originality, and elaboration develop naturally through open-ended project activities that require students to generate and evaluate multiple solution strategies. This is consistent with research demonstrating that STEAM learning contributes to significant improvements in creative thinking through multidisciplinary exploration (Gracia et al., 2024; Putri et al., 2023). In the specific context of this study, the integration of STEAM within the DKV program was particularly effective because project tasks such as designing flowcharts and infographics to represent SPLDV solutions, directly connected mathematical reasoning with students' vocational competencies in visual communication design. This contextual relevance made abstract algebraic concepts more accessible and meaningful, which in turn facilitated deeper cognitive engagement and higher creative output (Amanova et al., 2025; Ariyanto et al., 2025).

The very strong positive correlation between creative thinking skills and self-efficacy ($r = 0.978$, $p < 0.01$) represents one of the most significant empirical findings of this study. This finding suggests that in the context of STEAM+PjBL learning, cognitive and affective development are deeply intertwined and mutually reinforcing. A closer examination of this relationship in the DKV context reveals an important mechanism: when students produced visual project outputs flowcharts and infographics that drew on their existing design expertise, they simultaneously engaged in mathematical problem-solving and experienced a tangible sense of achievement. This alignment between project tasks and vocational identity created powerful mastery experiences, which according to Bandura's social cognitive theory serve as the primary source of self-efficacy. Students who successfully translated SPLDV concepts into creative visual products not only demonstrated higher creative thinking across all four indicators, but also reported greater confidence in their mathematical abilities. This bidirectional dynamic where creative success reinforces self-efficacy, and higher self-efficacy in turn enables greater creative risk-taking explains the exceptionally strong correlation observed and highlights the unique advantage of STEAM-integrated learning in vocational education settings (Jia et al., 2021; Xu et al., 2022; Zakariya, 2022). However, this correlation should be interpreted cautiously because both variables were measured within the same instructional context and timeframe, which may increase shared variance between the constructs.

The improvement in self-efficacy observed in the experimental group can be further explained through the collaborative and supportive nature of STEAM+PjBL. The mastery experience gained through project completion is the primary driver of self-efficacy formation, while group interaction provides vicarious learning and social support that further strengthen students' confidence (Masdarini, 2024; Samsudin et al., 2020). In the control group, where learning followed conventional PjBL without STEAM integration, students lacked the cross-disciplinary stimulus and the vocational relevance that characterize STEAM tasks, resulting in lower self-efficacy gains. This comparison underscores that the quality and contextual authenticity of learning experiences not merely the use of project-based approaches are critical determinants of affective outcomes in vocational mathematics learning (Greco et al., 2022; Yasir et al., 2021).

The use of MANCOVA provides robust methodological support for causal inference by controlling for initial ability differences through pretest scores as covariates. The significant covariate effect confirms that prior ability is an important predictor of learning outcomes, and that the observed between-group differences genuinely reflect the treatment effect rather than pre-existing differences (Wysocki et al., 2022; Tabachnick & Fidell, 2019). However, the extremely high effect size ($\eta^2 = 0.990$) warrants critical scrutiny. Values approaching 1.00 are exceptionally rare in educational research and may partly reflect methodological characteristics of this study: the small, homogeneous sample ($n = 30$ per group) from a single school and program likely reduced within-group variance; the highly specific and contextually aligned intervention may have created particularly favorable conditions; and the statistical control of pretest differences through MANCOVA may have amplified between-group contrasts. These factors suggest that while the treatment effect is genuine and substantial, the magnitude of the effect size should be interpreted cautiously. Therefore, the effect size should not be interpreted as indicating near-perfect instructional effectiveness, but rather as evidence of a substantial treatment effect within a highly controlled and relatively homogeneous educational context. Future studies with larger and more diverse samples across different vocational programs and school settings are needed to establish more generalizable effect estimates and to examine whether similar effect sizes can be replicated in broader educational contexts (Breznau et al., 2022; Lakens, 2013).

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The findings of this study carry important pedagogical implications for mathematics instruction in vocational high schools. First, teachers should design project tasks that explicitly connect mathematical concepts with students' vocational competencies as demonstrated in this study through the integration of SPLDV with DKV design projects. Second, the six-stage PjBL model Thomas (2000) provides a structured yet flexible framework that can be adapted to other mathematics topics and vocational programs beyond DKV. Third, authentic assessments such as project rubrics evaluating both cognitive and affective outcomes are essential for comprehensively capturing the multidimensional benefits of STEAM+PjBL. Fourth, school administrators should support cross-disciplinary collaboration between mathematics and vocational subject teachers to facilitate the development of contextually meaningful learning experiences. Future research is encouraged to explore the long-term impact of STEAM+PjBL across different mathematics topics, extended timeframes, and diverse vocational programs, as well as to investigate additional variables such as teacher competency, student motivation, and learning style that may moderate its effectiveness (Ekayana et al., 2025; Oanh & Dang, 2025).

4. CONCLUSION

This study demonstrates that STEAM-based Project-Based Learning (STEAM+PjBL) is significantly more effective than conventional PjBL in simultaneously improving students' creative thinking skills and self-efficacy among Class X DKV students at SMK Negeri 1 Purwokerto. The experimental group outperformed the control group in both variables, with creative thinking posttest scores of 86.50 vs. 75.27 and N-Gain values of 0.65 (medium) vs. 0.36 (medium), and self-efficacy posttest scores of 88.00 vs. 76.93 with N-Gain values of 0.33 (medium) vs. 0.19 (low). These differences were statistically confirmed by MANCOVA (Wilks' Lambda = 0.010, $p < 0.05$, $\eta^2 = 0.990$), and a very strong positive correlation was found between both variables ($r = 0.978$, $p < 0.01$). Together, these findings confirm that integrating STEAM within a PjBL framework creates a contextually meaningful and cross-disciplinary learning environment that fosters simultaneous development of cognitive and affective competencies in vocational mathematics education.

For practical implementation, mathematics teachers in vocational high schools are encouraged to adopt STEAM+PjBL by designing project tasks that explicitly link mathematical concepts with students' vocational competencies. In DKV programs, this can be realized by asking students to design cost-optimization flowcharts and promotional infographics using SPLDV; in Multimedia programs, by applying statistics to real data visualization projects; and in Civil Engineering programs, by exploring geometry through structural or architectural design tasks. The six-stage PjBL framework Essential Question, Design a Plan, Create a Schedule, Monitor the Progress, Assess the Outcome, and Evaluate the Experience provides a structured and replicable model that teachers can adapt across mathematics topics and vocational programs. School administrators are also encouraged to facilitate cross-disciplinary collaboration between mathematics and vocational subject teachers to ensure that project tasks are contextually authentic and professionally relevant.

This study has several limitations that should be acknowledged. The sample was relatively small and homogeneous ($n = 60$) from a single school and program, which may limit the generalizability of the findings. The exceptionally high effect size ($\eta^2 = 0.990$) should therefore be interpreted with caution. Future research is recommended to: (1) replicate this study with larger and more diverse samples across different vocational programs and school contexts; (2) examine the long-term effects of STEAM+PjBL on creative thinking and self-efficacy over extended instructional periods; and (3) investigate moderating variables such as teacher competency in

STEAM integration, students' prior vocational knowledge, and classroom learning climate to deepen understanding of the conditions under which STEAM+PjBL is most effective.

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