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The Effectiveness of a STEAM-Integrated Project-Based Learning Model for Teaching Motorcycle CVT Diagnostics in Vocational Schools

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ABSTRACT

This study examines the effectiveness of integrating Project-Based Learning (PBL) with a STEAM approach to enhance students' conceptual understanding and diagnostic skills in continuous variable transmission (CVT) systems within vocational education. A quasi-experimental design was employed involving 34 Grade XII students from the Motorcycle Engineering program at SMK Negeri 4 Rambah, Indonesia. Participants were divided into an experimental group receiving PBL-STEAM instruction and a control group receiving traditional teaching. Data were collected through posttests and analyzed using N-gain, independent samples t-tests, and effect size (Cohen's d). The experimental group achieved a higher mean posttest score in conceptual understanding (84.24) compared to the control group (74.00). The N-gain for the experimental group was 0.68 (high), while the control group showed 0.28 (low). Diagnostic skills also improved significantly, with mean scores of 90.00 (experimental) and 76.00 (control). Statistical analysis revealed significant differences between groups ($p < 0.05$). Effect sizes were large ($d = 1.77$ for conceptual understanding; $d = 2.68$ for diagnostic skills). The findings indicate that the PBL-STEAM approach substantially improves both conceptual mastery and diagnostic skills. This model aligns well with vocational education objectives and supports the development of competencies relevant to industry demands.

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1. INTRODUCTION

Vocational education plays a crucial role in preparing young people to meet workplace demands. In response to rapid industrial development, vocational high schools (SMKs) are expected to produce graduates who not only demonstrate technical competence but also exhibit critical and creative thinking, as well as effective problem-solving abilities (Hergisa, 2025). Traditional instructional approaches that emphasize technical skills alone are no longer sufficient to address the increasing complexity of industry requirements. Consequently, vocational education must adopt more interactive, practice-oriented pedagogies that integrate real-world applications and interdisciplinary knowledge, ensuring that learning experiences remain relevant to contemporary workforce needs (Muharam et al., 2025).

One study program that requires a great deal of discipline-specific skills is otomotif, especially when learning the Continuously Variable Transmission (CVT) system for motor vehicles. The CVT system is increasingly used in modern motor vehicles, and understanding it is very important for SMK students studying Motorcycle Engineering. In addition to understanding the CVT system's operating principles, students must develop diagnostic skills to analyze and resolve potential problems. However, in many available teaching practices, the CVT system is often addressed through theoretical and routine approaches that emphasize conceptual understanding rather than practical and analytical ones (Suhartadi et al., 2024).

Project-Based Learning (PjBL), which is rooted in constructivist theory, encourages students to build knowledge through active engagement and hands-on experience, which enhances conceptual understanding and diagnostic skills (Asnur, Weriza, & Putri, 2025). The STEAM approach, combined with PjBL, or STEAM-PBL, puts learning in a real-world context, making abstract concepts more relevant and easy to understand, as seen in ecological or energy transformation projects (Rahmawati, 2021). Situated learning theory supports this idea by emphasizing that learning occurs in real, relevant contexts, helping students connect theory to practical application in technical work. In addition, by engaging students in real-world problem-solving, PjBL-STEAM not only deepens their understanding of concepts but also develops their diagnostic skills, such as fault identification and solution testing, which are crucial in vocational education. In addition, diagnostic skills in vocational education include fault identification, causation analysis, testing, and technical decision-making, which are developed through a Project-Based Learning (PjBL) approach integrated with STEAM to provide practical experience in solving technical problems in the real world, such as in CVT systems (Vijayalakshmi, Patil, & Karikatti, 2022).

PjBL (Project-Based Learning) is a constructivist learning model that emphasizes students' active involvement through real-world projects, which develop critical skills such as collaboration, problem-solving, and self-reliance (Mota, Cabral, Amara, Braga, & Lopes, 2024). The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach, combined with PjBL, is known as STEAM-PBL and has been proven to increase students' learning capacity and motivation (Sigit, 2022). The implementation of STEAM-PBL has also been reported to provide high satisfaction and significant competency acquisition in various domains, including personal, professional, academic, and sociall (García-llamas, Taboada, Sanz-chumillas, Lopes, & Alvarez, 2025). However, although the benefits of STEAM-PBL are proven to be wide-ranging, there is still a lack of understanding of the types of school leadership that support the effective implementation of this model, as well as a lack of comprehensive diagnostic skills training in vocational education, particularly in the context of teaching continuous variable transmission (CVT) systems.

One of the main challenges in CVT system education is developing diagnostic skills and conceptual understanding. Conventional teaching that focuses on theory and routine tasks inhibits students' active engagement with the material, making it difficult to develop the 4C (Critical thinking, Communication, Collaboration, and Creativity) skills that are so important in the workplace. In addition, learning models that lack attention to real-world context and involvement in relevant projects risk resulting in students being less skilled in handling complex and multifaceted technical situations (Pratiwi et al., 2024). This study aims to fill this gap by exploring how the PjBL-STEAM model can improve diagnostic skills and concept understanding in CVT education in vocational schools.

A more innovative, project-based approach must be implemented to address this issue. One effective solution is to implement the Project-Based Learning (PjBL) model with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach. PjBL gives students the opportunity to learn through projects that integrate theoretical concepts with real-world applications. Conversely, STEAM education enhances learning by integrating various academic disciplines, allowing students to develop analytical, creative, and more complex problem-solving skills. This approach is highly relevant to vocational education, where students are taught not only theory but also practical skills applicable to the workplace. (Surti, Sudira, Mutohhari, & Suyitno, 2022).

Integrating PjBL with STEAM in the CVT learning system can provide students with more engaging learning experiences. By involving students in projects grounded in the real world, they can apply the knowledge they have learned in more practical contexts and develop critical diagnostic skills in the automotive. In addition, STEAM education integrates science, technology, engineering, the arts, and mathematics, helping students see connections across academic disciplines and deepen their holistic understanding of the CVT system. This will not only increase students' technical proficiency but also their ability to collaborate and innovate (Indahwati, Rachmadiarti, & Hariyono, 2023).

Previous investigations have shown that implementing project-based learning (PBL) and STEAM integration in vocational education can improve educational outcomes, encourage student engagement, and enhance problem-solving skills. Research findings indicate that students who use project-based methods show higher levels of activity and motivation in knowledge acquisition. Additionally, these students can develop advanced skills in analytical thinking and innovation compared to traditional, passive learning paradigms (Megayanti, 2020).

However, despite a large number of studies illustrating the successful implementation of Project-Based Learning combined with STEAM (PJBL-STEAM) across various disciplines, there remains a lack of research that rigorously investigates the effectiveness of this pedagogical model in the automotive education field, particularly regarding the learning of the Continuous Variable Transmission (CVT) system. As a result, the study aims to investigate this gap, which integrating the PJBL-STEAM model can enhance students' understanding of theoretical concepts and diagnostic competencies in the context of CVT system education. Furthermore, this investigation is expected to make a significant contribution to advancing more innovative vocational education that aligns with industry needs, as well as to improving the caliber of vocational high school graduates equipped to thrive in the digital era.

This study aims to test the effectiveness of the PjBL-STEAM learning model in improving understanding of CVT (Continuously Variable Transmission) diagnostic concepts and skills compared with conventional teaching. Based on previous research, PjBL-STEAM is expected to provide a more immersive, real-world learning experience that strengthens students' understanding of technical concepts and improves their practical skills in diagnosing and repairing CVT systems. Therefore, this study proposes two hypotheses: H1: PjBL-STEAM improves concept understanding better than conventional teaching, and H2: PjBL-STEAM improves CVT diagnostic skills more effectively than conventional teaching.

2. METHODS

This research employed a quantitative quasi-experimental design using a Non-Equivalent Control Group Design due to the impracticality of random participant assignment. Two groups were involved: an experimental group and a control group. The experimental group engaged in Project-Based Learning (PjBL) integrated with the STEAM approach, whereas the control group received conventional instruction. The effectiveness of the instructional model was examined by comparing pretest and posttest results between the two groups.

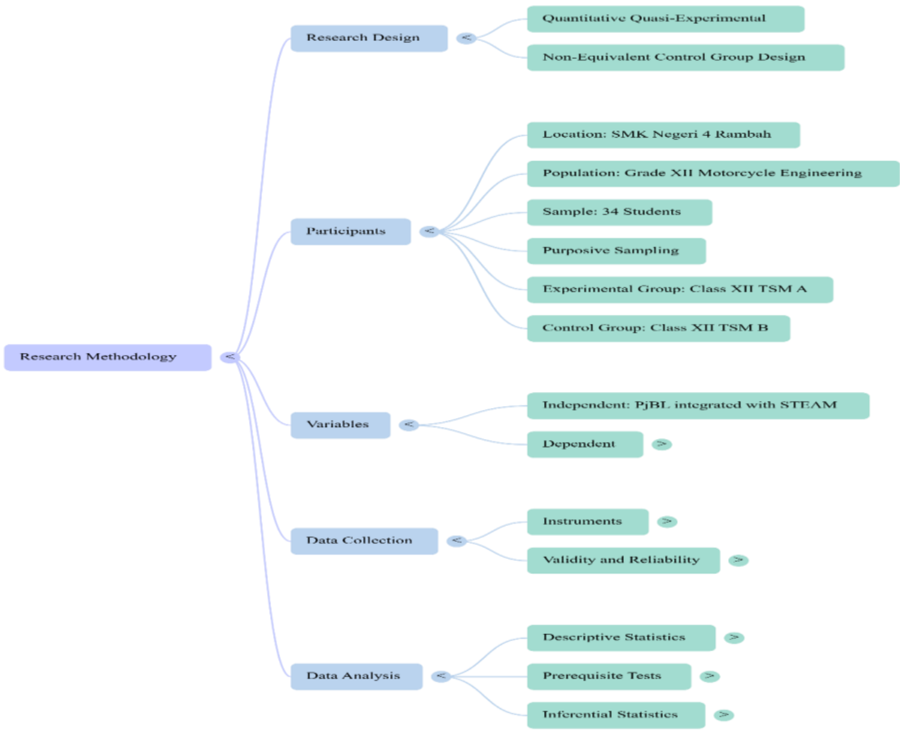

Figure 1. Framework for PjBL and STEAM Integrated Research Methodology

The research was conducted at SMK Negeri 4 Rambah Rokan Hulu Regency, Riau Province, Indonesia, during the even semester of the 2025/2026 academic year. The population consisted of all Grade XII students in the Motorcycle Engineering program (N = 34). Using purposive sampling, two intact classes with equivalent initial abilities were selected. Class XII TSM A (n = 17) served as the experimental group, and Class XII TSM B (n = 17) served as the control group.

In this study, the intervention used the PjBL-STEAM model, which consisted of three stages: planning, in which students studied CVT problems; implementation, where students diagnosed and designed solutions using diagnostic tools and related technologies; and evaluation, where they tested and analyzed the results. The STEAM elements used include Science (mechanical principles), Technology (diagnostic tools), Engineering (technical solutions), the Arts (creative approaches), and Mathematics (technical calculations). The teacher acts as a facilitator, assisting students during a two-week project, with 6 hours per week. The tools used include multimeters and analysis software.

As a control condition, conventional teaching uses lectures and worksheets that assess conceptual understanding without hands-on practice. Conventional teaching time is 4 hours per week, with a focus on theory without real project involvement or in-depth technical analysis.

ANCOVA (Analysis of Covariance) is applied to control for initial differences between the experimental group and the control group. In this analysis, the pretest is used as a covariate to control for differences in initial scores, while the posttest becomes the dependent variable (DV) and group (experimental vs. control) as the independent variable (IV). This approach allows for a more fair comparison between the two groups because the differences in pretest scores have been adjusted. Additionally, gain scores (the difference between pretest and posttest) are also analyzed to ensure that the observed differences in the final results reflect the impact of the intervention, rather than baseline differences between groups. Therefore, the use of ANCOVA and gain score analysis avoids potential bias that could arise if only a posttest t-test were used, which does not account for initial differences between groups.

The independent variable was PjBL integrated with STEAM, and the dependent variables were students' mastery of CVT system concepts and their diagnostic skills related to the CVT system.

Data were collected using tests, observations, performance assessments, and documentation. Cognitive learning outcomes were measured using 30 multiple-choice pretest and posttest items, covering CVT components, operating principles, centrifugal force, pulley ratios, roller and spring functions, and engine performance relationships. The test was designed with a blueprint that included easy (10 items), moderate (15 items), and difficult (5 items) questions to assess students' theoretical understanding and application skills. Students' diagnostic skills were evaluated through workshop-based performance assessments using a rubric that focused on fault identification, cause analysis, inspection procedures, and repair recommendations accuracy. Observations were conducted using Likert-scale observation sheets to monitor student engagement and the implementation of PjBL-STEAM, with a scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Documentation was also used to support evidence of students' progress and learning outcomes.

Instrument validity was assessed using Pearson's correlation, and reliability was evaluated using Cronbach's Alpha, with $\alpha \geq 0.50$ indicating acceptable reliability. Only instruments deemed valid and reliable were considered for analysis.

Data analysis involved both descriptive and inferential statistics. Descriptive analysis included mean and standard deviation scores. Prior to hypothesis testing, normality was examined using the Shapiro–Wilk test, and homogeneity of variance was tested using Levene's Test. Learning improvement was analyzed using Normalized Gain (N- Gain). Hypothesis testing employed paired-samples t-tests to examine pretest–posttest differences within each group and independent-samples t-tests to compare posttest results between the experimental and control groups. The PjBL–STEAM model was considered effective if it produced statistically significant differences ($p < 0.05$) and moderate to high N- Gain values.es

3. FINDINGS AND DISCUSSION

This study analyzed students' learning outcomes, including concept mastery and CVT diagnostic skills, using pretest and posttest scores from the control and experimental groups, each consisting of 17 students.

3.1 Findings

The experimental group initially had a lower mean pretest score than the control group. However, after the intervention, the experimental group showed a substantially higher mean posttest score (84.24) than the control group (74.00). This result indicates that Project-Based Learning integrated with STEAM (PjBL–STEAM) led to stronger improvement in students' conceptual understanding of the CVT system.

Table 1. Descriptive Statistics of Concept Mastery

	N	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error
Pre-Test Eksperimen	17	40	65	51.18	1.781	7.342	53.904	.077	.550
Post-Test Eksperimen	17	75	95	84.24	1.410	5.815	33.816	.054	.550
Pre-Test Kontrol	17	55	72	64.12	1.280	5.278	27.860	.060	.550
Post-Test Kontrol	17	65	84	74.00	1.388	5.723	32.750	.073	.550
Valid N	17								

Both groups showed comparable diagnostic skills at the pretest. Nevertheless, the experimental group achieved a markedly higher posttest mean score (90.00) than the control group (76.00). This finding indicates that PjBL–STEAM effectively enhances both conceptual knowledge and technical diagnostic competence, which are essential in vocational automotive education.

Table 2. Descriptive Statistics of Diagnostic Skills

	N	Minimum	Maximum	Mean		Std. Deviation	Variance	Skewness	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic	Statistic	Std. Error
Pre-Test Eksperimen	17	55	75	65.29	1.543	6.362	40.471	-.138	.550
Post-Test Eksperimen	17	82	98	90.00	1.128	4.650	21.625	.072	.550
Pre-Test Control	17	57	74	66.12	1.280	5.278	27.860	-.060	.550
Post-Test Control	17	67	86	76.00	1.388	5.723	32.750	.073	.550
Valid N	17								

Before hypothesis testing, assumption tests were conducted. Therefore, the data met the requirements for parametric statistical analysis using an independent samples t-test.

Table 3. N-Gain of Concept Mastery

Group	N-Gain	Category
Control	0.28	Low
Experimental	0.68	Medium - High

The table presents differences in learning improvement between the control and experimental groups, as measured by N-Gain scores. The control group achieved an N-Gain of 0.28, placing it in the low–moderate category and indicating limited improvement through conventional instruction. In contrast, the experimental group, which implemented Project-Based Learning (PjBL) integrated with the STEAM approach, achieved an N-Gain of 0.68, categorized as high. These results suggest that the PjBL–STEAM model is more effective at enhancing students' learning outcomes than conventional teaching methods.

Table 4. N-Gain of Diagnostic Skills

Group	N-Gain	Category
Control	0.29	Low
Experimental	0.71	High

The experimental group achieved high N-Gain scores for both variables, indicating that PjBL–STEAM significantly improved learning effectiveness compared with conventional instruction.

Table 5. Independent t-Test Results for Concept Mastery

Statistic	Value
t-value	5.17
df	32
p-value	< 0.001
Decision	H_0 Rejected

The results of the statistical test show a t-value of 5.17 with 32 degrees of freedom, indicating a strong difference between the groups. The p-value of 0.000 ($p < 0.05$) confirms that the difference is statistically significant. Therefore, the null hypothesis (H_0) is rejected, indicating that the implementation of the PjBL–STEAM model has a significant effect on students' learning outcomes compared with conventional instruction.

Table 6. Independent t-Test Results for Diagnostic Skills

Statistic	**Value**
t-value	7.83
df	32
p-value	<0.001
Decision	H_0 Rejected

The findings reveal significant disparities in concept mastery and diagnostic abilities between the experimental and control groups ($p < 0.05$).

Table 7. Effect Size (Cohen's d)

Variable	**Cohen's d**	**Interpretation**
Concept Mastery	1.77	Very Large
Diagnostic Skills	2.68	Very Large

The substantial effect sizes suggest a significant influence of the PjBL–STEAM model on student learning outcomes.

3.1 Discussion

The findings indicate that students instructed through the Project-Based Learning (PjBL) model, combined with the STEAM framework, achieved markedly higher mastery of the CVT system than their peers receiving traditional instruction. The experimental group's posttest mean was 84.24, compared with 74.00 in the control group. In addition, the experimental group's normalized gain (N-Gain) was 0.68 (high category), whereas the control group achieved only 0.28 (low–moderate category). These findings align with recent empirical evidence indicating that PjBL significantly improves learning outcomes in vocational contexts. (Rahim et al., 2024).

These findings suggest that PjBL–STEAM is more effective at fostering deep conceptual understanding than rote memorization. Through authentic project activities, students analyzed the functional relationships among CVT components, such as pulleys, rollers, and belt mechanisms. By manipulating these components in real-world scenarios, students connected theoretical knowledge to practical application. This process helped them gain insights into the underlying mechanical principles, such as how pulley ratios influence performance and how centrifugal force affects system function. These activities helped students construct knowledge in a contextual and meaningful way. This result is consistent with previous studies that assert project-based learning (PjBL) promotes meaningful learning by actively engaging students in real-world problem-solving. (Zhang, 2023). Additionally, research on PjBL integrated with STEM/STEAM models indicates that interdisciplinary project learning enhances higher-order thinking and conceptual understanding, especially in technical and vocational education settings (Paramita & Fitria, 2025).

Furthermore, integrating science and mathematics within the STEAM framework helped students interpret mechanical phenomena using data-driven reasoning. This was reflected in how students were encouraged to apply mathematical calculations to predict mechanical outcomes and to use scientific principles to explain observed phenomena. This approach aligns with findings in the STEAM–PjBL literature, which emphasize the role of disciplinary integration in strengthening cognitive processes. By embedding both science and mathematics in the project, students were able to make data-driven decisions that contributed to a deeper understanding of the CVT system's functionality. (Supianti, Yaniawati, Bonyah, Hasbiah, & Rozalini, 2025).

A substantial improvement was also observed in students' diagnostic skills. The experimental group achieved a posttest mean of 90.00, which was considerably higher than the control group's 76.00. The N-Gain for diagnostic skills in the experimental group was 0.71 (high category), whereas the control group reached only 0.29. This finding demonstrates that PjBL–STEAM effectively develops students' analytical reasoning, cause-and-effect analysis, and technical decision-making abilities. Project tasks that required students to diagnose CVT malfunctions, test mechanical variables, and evaluate system performance not only challenged students to apply technical knowledge but also encouraged the development of higher-order thinking skills such as problem-solving and critical evaluation. This result aligns with the arguments of Hmelo-Silver (2004) and Jonassen (2011), who emphasized that problem- and project-based learning environments are particularly effective in enhancing diagnostic reasoning and complex problem-solving skills.

The independent-samples t-test indicated significant differences in concept mastery and diagnostic skills between groups ($p < 0.05$). These findings confirm that the observed learning gains in the experimental group were not due to chance but rather a direct consequence of implementing the PjBL–STEAM model. Statistically, this strengthens the study's internal validity and supports the proposed research hypothesis. However, although the results are statistically significant, potential threats to validity should be addressed. For example, using only one school as the research site and the relatively small sample size (n=34) may limit the generalizability of these findings (Author, Year). Further research involving larger and more diverse samples could provide additional insight into the broader applicability of the PjBL–STEAM model.

Beyond statistical significance, the effect size analysis provides strong evidence of the intervention's practical impact. Cohen's d values were 1.77 for concept mastery and 2.68 for diagnostic skills, both classified as very large effects. According to Cohen (1988), such effect sizes indicate that an instructional model yields substantial educational benefits in real classroom settings. The large effect sizes suggest that PjBL–STEAM not only improves students' test scores but also leads to substantial gains in cognitive processes and technical abilities, which are highly relevant to vocational education.

These results demonstrate that PjBL–STEAM not only improves test scores but also yields meaningful learning outcomes that are highly relevant to vocational education objectives. Systematic literature reviews of STEM and STEAM pedagogies indicate that integrated project-based approaches consistently enhance 21st-century competencies, such as critical thinking and problem-solving, across educational levels, including vocational settings (Ayu et al., 2024). By integrating scientific, technological, engineering, artistic, and mathematical knowledge, PjBL–STEAM fosters a more holistic approach to learning that prepares students for real-world challenges.

Overall, the findings confirm that the PjBL–STEAM model is highly suitable for vocational education, particularly in automotive engineering programs. By integrating interdisciplinary knowledge with authentic project tasks, PjBL–STEAM bridges the gap between theoretical instruction and industry-oriented practice. This approach aligns with the core mission of vocational education, which emphasizes employability, problem-solving competence, and workplace readiness. As research on PjBL and STEAM in vocational contexts (Author, Year) suggests, hands-on, project-based tasks enhance students' practical skills, making them better equipped to meet workforce demands.

Therefore, implementing PjBL integrated with STEAM is strongly recommended for teaching the CVT system in vocational high schools, as it effectively enhances both conceptual understanding and diagnostic competence required in the automotive industry. Future research could explore the ideal project duration, group size, and assessment strategies to further optimize the implementation of PjBL–STEAM in vocational education. In addition, safety considerations and the use of appropriate workshop equipment should be addressed to ensure that students engage in learning experiences that are both effective and safe.

4. CONCLUSION

This study shows that Project-Based Learning (PjBL) combined with the STEAM framework is more effective than traditional teaching methods in learning the Continuously Variable Transmission (CVT) system at vocational high schools. The experimental group demonstrated a significant increase in conceptual understanding and diagnostic skills, with higher posttest scores and an N-Gain of 0.68 (high category), while the control group only achieved an N-Gain of 0.28 (low-moderate category). An independent t-test indicated a significant difference ($p < 0.05$). The very large effect sizes (Cohen's $d = 1.77$ for conceptual understanding and 2.68 for diagnostic skills) suggest that the PjBL–STEAM model not only produces statistically significant results but also has a substantial practical impact on students' learning performance. These findings confirm that integrating project-based learning with interdisciplinary STEAM elements enhances meaningful learning, analytical skills, and diagnostic competence, which are essential in automotive vocational education. Based on these results, it is recommended to adopt PjBL–STEAM in teaching CVT topics at vocational schools, provide teacher training in rubric-based assessment to improve objectivity, and ensure adequate workshop resources to support project-based learning. For future research, it is suggested to replicate the study in multiple schools to test the generalizability of the findings, extend the duration of the intervention to evaluate long-term effects, and use mixed methods (observation and interviews) to gain a deeper understanding of students' and teachers' experiences. Additionally, retention assessments through follow-up tests (delayed posttests) should be conducted to measure how well learning is retained after the intervention.

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