

Enhancing Students' Critical Thinking Skills Through STEM-Integrated Project-Based Learning Modules: A Quasi-Experimental Study of Vocational Financial Mathematics

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Received: July 4, 2026

Revised: August 5, 2026

Accepted: September 22, 2026

Abstract

Strengthening students' critical thinking skills has become an important objective of vocational mathematics education, particularly in preparing learners to solve authentic and interdisciplinary problems. This study investigated the effectiveness of STEM-integrated Project-Based Learning (PjBL) modules in supporting students' critical thinking skills in vocational financial mathematics. A quasi-experimental pretest-posttest control group design was conducted with Year 11 students from a vocational high school in Lampung Province, Indonesia, involving an experimental group ($n = 30$) and a control group ($n = 32$). Students' critical thinking skills were assessed using pretest and posttest essay tests, and the data were analysed using normalized gain (N-gain) analysis and the Mann-Whitney U test. The STEM-integrated PjBL modules engaged students in authentic vocational financial projects, including motorcycle installment calculations, loan interest analysis, investment planning, and annuity problem-solving. The experimental group demonstrated greater improvement than the control group, with the mean score increasing from 34.13 to 60.47 (N-gain = 0.588), compared with 33.37 to 47.07 (N-gain = 0.304) in the control group. The difference in learning gains was statistically significant ($U = 1.00$, $Z = -6.782$, $p < 0.001$, $r = 0.86$). These findings suggest that the use of STEM-integrated Project-Based Learning modules was associated with greater improvements in students' critical thinking skills and provide practical evidence for mathematics teachers seeking to implement contextual STEM-integrated project-based learning in vocational financial mathematics.

Keywords: Critical Thinking Skills; Mathematics Education; STEM-PjBL; Vocational Mathematics; Vocational Financial Mathematics

INTRODUCTION

Critical thinking is widely recognised as a fundamental competency in contemporary education, enabling students to analyse information, evaluate evidence, construct logical arguments, and make informed decisions when confronting complex problems. In this study, critical thinking is operationally defined according to the framework proposed by Ennis (2011) and Facione (2015), encompassing five dimensions: providing elementary clarification, building basic support, making inferences, advanced clarification, and strategy and tactics. Within mathematics learning, these dimensions enable students not only to perform mathematical procedures but also to interpret relationships, justify solutions, evaluate alternative strategies, and apply mathematical reasoning to authentic situations. The development of these competencies is particularly important in vocational education, where students are expected to transfer mathematical understanding to workplace-related contexts that require analytical reasoning, problem-solving, and sound decision-making in response to rapidly evolving technological and industrial demands (Ennis, 2011; Facione, 2015; OECD, 2023; Papagiannis & Pallaris, 2024).

Despite the recognised importance of critical thinking, its development in vocational mathematics classrooms remains challenging. Mathematics instruction continues to emphasise

procedural fluency and routine exercises, providing limited opportunities for students to engage in mathematical reasoning, evaluate alternative solutions, and solve authentic problems collaboratively. As a result, many students experience difficulties in transferring mathematical concepts to vocational and real-world contexts that require analytical judgement and reflective decision-making. Recent studies have consistently reported that teacher-centred instructional practices, limited contextual learning experiences, and insufficient opportunities for mathematical reasoning remain major obstacles to developing students' critical thinking skills in mathematics education (Amanah et al., [2023](#); Baidowi et al., [2024](#); Kurniawan et al., [2021](#); Meilani et al., [2026](#)).

To address these challenges, mathematics educators have increasingly adopted student-centred instructional approaches that actively engage learners in solving authentic problems. Among these, Project-Based Learning (PjBL) has received considerable attention because it encourages students to investigate real-world issues, collaborate in developing solutions, and construct knowledge through meaningful learning experiences. Rather than focusing solely on procedural mastery, PjBL promotes mathematical reasoning, reflective thinking, and the application of concepts in practical contexts. Recent empirical studies and meta-analyses have consistently reported that PjBL contributes positively to students' critical thinking, problem-solving ability, learning motivation, and overall mathematics achievement, highlighting its potential as an effective pedagogical approach for developing higher-order thinking skills in mathematics education (Chen & Yang, [2019](#); Feziyasti et al., [2025](#); Guo et al., [2020](#); Santhosh et al., [2023](#)).

While Project-Based Learning provides a strong foundation for active and contextual learning, integrating STEM principles further enriches the learning process by connecting mathematics with science, technology, and engineering in solving authentic problems. This interdisciplinary integration encourages students to apply mathematical concepts within meaningful contexts, evaluate alternative solutions, and develop evidence-based reasoning through collaborative project activities. Recent systematic reviews and meta-analyses have consistently shown that STEM-integrated PjBL contributes more effectively to the development of critical thinking, problem-solving, and other higher-order thinking skills than conventional instructional approaches, particularly when learning activities are designed around real-world challenges and interdisciplinary inquiry (English, [2016](#); Feziyasti et al., [2025](#); Thibaut et al., [2018](#)).

Despite the growing body of evidence supporting STEM-integrated Project-Based Learning, several important research gaps remain. Previous studies have predominantly examined STEM-integrated PjBL as an instructional approach or focused on developing and validating STEM-based learning materials (Afifah et al., [2020](#); Portillo-Blanco et al., [2025](#)). However, relatively few studies have empirically evaluated the effectiveness of STEM-integrated Project-Based Learning modules in improving students' critical thinking skills within vocational mathematics classrooms. Moreover, existing studies rarely incorporate workplace-related financial mathematics projects, such as loan calculations, credit interest, investment planning, and annuity analysis, to contextualize mathematical learning according to students' future occupational needs (Papagiannis & Pallaris, [2024](#)). In addition, evidence regarding how STEM-integrated Project-Based Learning influences individual critical thinking indicators in Indonesian vocational high schools remains limited (Anta et al., [2025](#); Thibaut et al., [2018](#)). Addressing these gaps, the present study empirically examines the effectiveness of STEM-integrated Project-Based Learning modules specifically designed for vocational financial mathematics. Unlike previous studies that primarily evaluated STEM-PjBL as a general instructional approach, this study implemented a structured learning module centred on authentic financial projects, including motorcycle installment calculations, loan interest analysis, investment planning, and annuity problems. Furthermore, the study focuses on Indonesian vocational high school students and analyses improvements across five dimensions of critical thinking—elementary clarification, basic support, inference, advanced clarification,

and strategy and tactics—thereby providing a more detailed understanding of how STEM-integrated Project-Based Learning supports critical thinking development in vocational mathematics.

Based on the identified research gaps, this study addresses the following research question: To what extent do STEM-integrated Project-Based Learning modules enhance students' critical thinking skills in vocational mathematics? Accordingly, the study aims to evaluate the effectiveness of STEM-integrated Project-Based Learning modules in improving students' critical thinking skills among vocational high school students. The novelty of this study lies in its empirical evaluation of STEM-integrated PjBL modules within vocational mathematics learning, emphasising authentic vocational contexts that connect mathematical concepts with workplace-related problem-solving. By focusing on classroom implementation rather than instructional material development, this study provides new evidence regarding the role of STEM-integrated PjBL modules in fostering critical thinking skills in vocational mathematics education.

METHODS

This study employed a quasi-experimental design using a non-equivalent pretest-posttest control group design to examine the effectiveness of STEM-integrated Project-Based Learning (PjBL) modules in enhancing students' critical thinking skills in vocational mathematics. Two intact classes were assigned as the experimental and control groups. The experimental group received mathematics instruction using the STEM-integrated PjBL modules, whereas the control group was taught through conventional teacher-centred instruction. This design enabled comparisons of students' critical thinking improvement before and after the instructional intervention while maintaining the existing classroom organisation.

The study was conducted at SMK Negeri Padang Cermin, Lampung, Indonesia, during the 2025/2026 academic year. The participants consisted of 62 eleventh-grade students enrolled in the Motorcycle Engineering and Business (TBSM) programme. Purposive sampling was employed to select two classes with comparable academic characteristics. The experimental group comprised 30 students, while the control group consisted of 32 students. Both classes were taught by the same mathematics teacher, who was also the researcher, to minimise teacher-related variation during the implementation of the learning intervention.

The instructional intervention was implemented over five consecutive weeks, with one learning session per week lasting 135 minutes. The learning activities focused on vocational financial mathematics, particularly the application of arithmetic and geometric sequences and series to authentic financial situations, including motorcycle installment calculations, loan interest analysis, and future investment planning. These contexts were selected to reflect workplace-related financial decision-making commonly encountered in the automotive service industry. These financial scenarios are closely aligned with the vocational competencies of students in the Motorcycle Engineering and Business programme. Graduates are expected not only to possess technical expertise in motorcycle maintenance but also to understand financial aspects of the automotive industry, including vehicle financing, customer credit schemes, business investment, and financial planning for workshop management or entrepreneurship. Consequently, contextualising mathematics through these authentic financial situations increases the relevance of mathematical learning to students' future professional practice.

The experimental group learned using a STEM-integrated Project-Based Learning (PjBL) module organised according to the six phases of Project-Based Learning: (1) determining an essential question, (2) designing the project plan, (3) developing the project schedule, (4) monitoring project implementation, (5) presenting and evaluating project outcomes, and (6) reflecting on the learning experience. Students worked collaboratively in small groups to complete contextual financial mathematics projects, such as analysing motorcycle credit schemes and comparing future investment alternatives. The STEM integration was embedded by combining science (understanding financial phenomena), technology (using spreadsheets or

digital calculators for financial calculations), engineering (designing and evaluating alternative financial solutions), and mathematics (modelling and analysing financial problems). Throughout the learning process, the teacher acted as a facilitator by guiding discussions, monitoring project progress, and providing feedback while encouraging students to construct their own mathematical reasoning.

In contrast, the control group studied the same mathematical content using conventional teacher-centred instruction. Learning activities consisted primarily of teacher explanations, worked examples, question-and-answer sessions, and routine individual practice exercises based on the lesson plans agreed upon through the school's Mathematics Teacher Working Group (MGMP). Both groups received the same instructional duration, learning objectives, assessment procedures, and pretest-posttest instruments; the instructional approach was the only planned difference between the groups.

Students' critical thinking skills were assessed using a five-item essay test developed based on the critical thinking frameworks proposed by Ennis (2011) and Facione (2015). The instrument measured five dimensions of critical thinking: elementary clarification, basic support, inference, advanced clarification, and strategy and tactics. Each essay item was designed to assess one dominant critical thinking indicator within the context of vocational financial mathematics, including arithmetic and geometric sequences and series, compound interest, loans, investments, and annuities. Responses were evaluated using an analytic scoring rubric ranging from 0 to 4 for each scoring criterion, with a total maximum score of 80 points.

Prior to implementation, the instrument underwent content validation by three experts in mathematics education to ensure the relevance, clarity, and appropriateness of the items. The validators consisted of two senior lecturers in mathematics education from the University of Lampung and one lecturer from Makassar State University with expertise in mathematics education and instructional design. Empirical testing indicated that all items met the required validity criteria ($r = 0.674\text{--}0.802$, $r_{table} = 0.3598$). The instrument also demonstrated satisfactory internal consistency (Cronbach's $\alpha = 0.725$), while item difficulty indices were classified as moderate and discrimination indices ranged from good to very good, indicating that the instrument was appropriate for measuring students' critical thinking skills.

The collected data were analysed using descriptive and inferential statistics. Descriptive statistics summarised students' pretest scores, posttest scores, and normalized gain (N-gain) values. The N-gain index was interpreted according to Hake's (1999) classification. Before hypothesis testing, baseline assumptions were examined using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance at a significance level of 0.05. Because the N-gain scores violated the normality assumption, group differences were analysed using the non-parametric Mann-Whitney U test. In addition to statistical significance, effect size (r) was calculated using the standardized test statistic according to the formula $r = |Z|/\sqrt{N}$ to determine the magnitude of the treatment effect. All statistical analyses were performed using IBM SPSS Statistics.

Permission to conduct the study was obtained from the university and the participating school prior to data collection. Participation was voluntary, and students' data were analysed anonymously to ensure confidentiality throughout the research process.

RESULT AND DISCUSSION

Results

Students' Critical Thinking Performance

The effectiveness of the STEM-integrated Project-Based Learning (PjBL) modules was examined by comparing students' critical thinking performance before and after the instructional intervention. Figure 1 illustrates the mean pretest and posttest scores of the experimental and control groups.

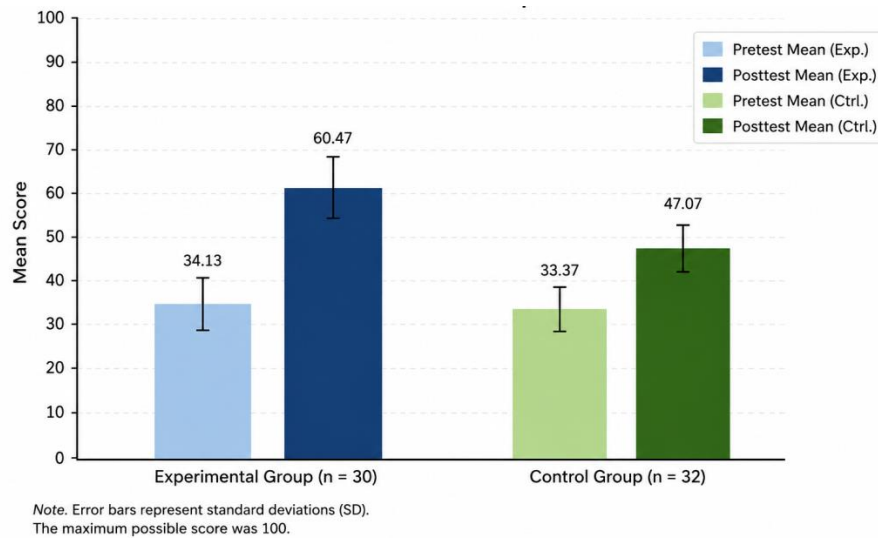


Figure 1. Mean Pretest and Posttest Scores of the Experimental and Control Groups

Figure 1 shows that both groups demonstrated higher mean scores after the learning intervention. However, the increase was more pronounced in the experimental group than in the control group. Students in the experimental group improved from a mean pretest score of 34.13 to a posttest score of 60.47, whereas the control group improved from 33.37 to 47.07. The descriptive statistics for both groups are presented in Table 1.

Table 1. Descriptive Statistics of Students' Critical Thinking Skills

Group	Test	N	Mean	SD	Median	IQR	Highest Score	Lowest Score
Experimental	Pretest	30	34.13	7.53	35.00	8.00	50	18
Experimental	Posttest	30	60.47	7.12	62.00	10.00	75	45
Control	Pretest	32	33.34	6.51	35.00	5.00	48	18
Control	Posttest	32	47.09	8.17	50.00	6.00	60	27

As presented in Table 1, both groups demonstrated improvements in their descriptive statistics following the instructional intervention. The experimental group achieved a higher posttest mean score (60.47 ± 7.12) than the control group (47.09 ± 8.17). Before the intervention, however, the two groups exhibited comparable baseline performance, as reflected by their similar pretest mean scores (34.13 ± 7.53 and 33.34 ± 6.51 , respectively), indicating that both groups started the study with relatively equivalent levels of critical thinking.

Improvement in Students' Critical Thinking Skills

Students' learning improvement was further examined using the normalized gain (N-gain) index. The results are summarized in Table 2.

Table 2. N-Gain of Students' Critical Thinking Skills

Class	Mean N-Gain	Category
Experimental	0.5877	Medium
Control	0.3044	Medium

The experimental group obtained a mean N-gain of .588, whereas the control group obtained 0.304. According to Hake's (1999) classification, both groups were categorized as demonstrating a medium level of improvement.

Hypothesis Testing

Prior to hypothesis testing, the N-gain scores were examined for normality and homogeneity. The results are presented in Table 3.

Table 3. Assumption Tests for N-Gain Scores

Test	Statistic	<i>p</i>	Decision
Shapiro-Wilk (Experimental)	W = 0.954	0.211	Normal
Shapiro-Wilk (Control)	W = 0.900	0.006	Not Normal
Levene's Test	F = 1.240	0.270	Homogeneous

As presented in Table 3, the N-gain scores of the experimental group satisfied the normality assumption (Shapiro-Wilk, $W = 0.954$, $p = 0.211$), whereas those of the control group did not ($W = .900$, $p = .006$). Levene's test indicated homogeneous variances between the two groups ($F = 1.240$, $p = 0.270$). Because the assumption of normality was violated, the Mann-Whitney U test was employed to compare students' learning gains. The results of the Mann-Whitney U test are presented in Table 4.

Table 4. Mann-Whitney U Test Results

Variable	U	Z	<i>p</i>	Effect Size (<i>r</i>)
N-Gain of Critical Thinking Skills	1.00	-6.782	< 0.001	0.861

The Mann-Whitney U test revealed a statistically significant difference in students' critical thinking improvement between the experimental and control groups ($U = 1.00$, $Z = -6.782$, $p < 0.001$). The calculated effect size ($r = 0.861$) indicates a very large practical effect according to Cohen (1988), suggesting that students who learned using the STEM-integrated Project-Based Learning module achieved substantially greater improvement than those receiving conventional instruction.

Critical Thinking Indicators

Students' performance on each critical thinking indicator was analysed to provide a more detailed description of learning outcomes. The comparison of mean scores before and after the intervention is presented in Table 5.

Table 5. Comparison of Critical Thinking Indicators

Critical Thinking Indicator	Maximum Score	Experimental Pretest	Experimental Posttest	Control Pretest	Control Posttest
Providing elementary clarification	20	8.83	15.63	8.66	12.50
Building basic support	20	7.83	14.57	7.66	11.44
Making inferences	20	6.90	13.67	6.59	10.50
Advanced clarification	12	6.53	9.70	6.53	8.19
Strategy and tactics	8	4.03	6.90	3.91	4.47

The posttest scores increased across all critical thinking indicators in both groups. The experimental group consistently achieved higher posttest scores than the control group across all five indicators. The greatest improvements were observed in providing elementary clarification, building basic support, and making inferences, indicating that the STEM-integrated Project-Based Learning module effectively supported students in identifying relevant information, analysing contextual problems, and drawing logical conclusions through collaborative investigations. In contrast, strategy and tactics remained the lowest-performing indicator despite showing improvement. This finding suggests that strategic and metacognitive aspects of critical thinking may require more prolonged and explicit instructional support than was provided during the five-week intervention.

The relatively modest improvement in the strategy and tactics indicator may be explained by the cognitive demands associated with strategic planning, monitoring solution processes, and evaluating alternative approaches, which represent higher-order metacognitive skills. Although students participated in contextual financial mathematics projects, most

learning activities were directed toward solving authentic problems rather than explicitly reflecting on the effectiveness of different problem-solving strategies. Previous studies have similarly reported that metacognitive regulation develops more gradually than analytical reasoning and requires repeated opportunities for self-monitoring, reflection, and evaluation throughout the learning process (Hattie & Donoghue, 2016; Schraw, 1998; Zimmerman, 2002).

These findings suggest that future revisions of the STEM-integrated Project-Based Learning module should incorporate more structured metacognitive activities. For example, students could be asked to justify the selection of solution strategies, compare multiple financial decision alternatives, conduct peer evaluations, and complete reflective journals documenting the strengths and limitations of their reasoning. Embedding these activities throughout each project phase may further strengthen students' strategic thinking and self-regulation while maintaining the authentic vocational context of the learning tasks.

Discussion

The findings of this study demonstrate that the implementation of STEM-integrated Project-Based Learning (PjBL) modules significantly enhanced vocational students' critical thinking skills compared with conventional mathematics instruction. Beyond statistical significance, the intervention produced a large practical effect ($r = .861$), indicating that the observed improvement was not only statistically reliable but also educationally meaningful. This result suggests that integrating STEM principles within project-based mathematics instruction provides learning experiences that effectively cultivate higher-order thinking skills required in vocational education.

One plausible explanation for these findings is that STEM-integrated PjBL shifts the focus of mathematics learning from procedural practice toward inquiry-oriented and problem-centered learning. Throughout the intervention, students were required to identify relevant information, formulate mathematical representations, analyse alternative solutions, justify their reasoning, and communicate their conclusions collaboratively. Such learning activities encouraged students to actively construct knowledge rather than merely reproduce mathematical procedures delivered by the teacher. This learning process is consistent with constructivist perspectives, which emphasize that meaningful understanding develops through active engagement with authentic problems and collaborative interaction (Dacumos, 2023; Loyens et al., 2025). Furthermore, a recent systematic review concluded that project-based learning consistently promotes higher-order thinking and critical thinking because students are continuously engaged in analysing, evaluating, and reflecting on real-world problems.

The present findings are consistent with previous evidence demonstrating the effectiveness of STEM-integrated Project-Based Learning (STEM-PjBL) in mathematics education. A recent systematic literature review concluded that STEM-PjBL consistently enhances students' mathematical critical thinking across different educational levels by integrating scientific inquiry, engineering design, and mathematical reasoning into authentic learning experiences. Similarly, empirical studies have reported that embedding STEM principles within project-based learning enables students to develop stronger analytical reasoning and problem-solving skills because mathematical concepts are constructed through meaningful investigation rather than isolated procedural exercises (Auliyani et al., 2025; Chen & Yang, 2019; Nasution et al., 2024). The consistency between the present findings and previous studies may be explained by the common instructional characteristics of STEM-PjBL, particularly the emphasis on authentic problem-solving, collaborative inquiry, and student-centred knowledge construction, all of which encourage learners to analyse evidence, evaluate alternative solutions, and justify mathematical reasoning.

Nevertheless, the present study extends previous research in several important ways. Whereas many earlier studies implemented STEM-PjBL in general mathematics or science classrooms, the current study situated learning within vocational financial mathematics through workplace-related projects involving motorcycle installment calculations, loan interest

analysis, investment planning, and annuity modelling. These contextualised projects required students not only to perform mathematical calculations but also to evaluate realistic financial alternatives that resemble decision-making situations encountered in the automotive service industry. Consequently, the improvement in critical thinking observed in this study reflects not only the pedagogical value of STEM-PjBL itself but also the contribution of contextualising mathematics within students' prospective occupational environments. This finding suggests that aligning STEM-integrated project-based learning with vocational workplace contexts may strengthen the relevance of mathematics learning while supporting the development of higher-order thinking skills.

A notable contribution of the present study lies in the vocational context in which the learning modules were implemented. Unlike many previous studies that employ general mathematical problems, this research embedded mathematical concepts within authentic financial situations closely related to vocational students' future professional experiences, including motorcycle installment calculations, credit interest analysis, investment planning, and annuity computations. These contextual projects required students not only to perform calculations but also to evaluate financial alternatives, interpret quantitative information, and make reasoned decisions using mathematical evidence. Consequently, mathematics became a practical tool for solving occupationally relevant problems rather than merely an abstract school subject (OECD, 2023; Papagiannis & Pallaris, 2024).

The authenticity of these learning activities appears to be an important factor underlying the improvement in students' critical thinking skills. Authentic learning environments encourage learners to connect classroom knowledge with real-life situations, thereby increasing cognitive engagement and promoting deeper conceptual understanding (Ennis, 2011; Lafifa et al., 2023; Loyens et al., 2025). When students perceive mathematics as directly applicable to decisions they may encounter in everyday financial or workplace contexts, they become more motivated to analyse problems critically and justify their solutions logically. This explanation aligns with recent studies highlighting that contextual vocational learning enhances students' reasoning ability, engagement, and readiness for professional practice.

Analysis of individual critical thinking indicators further provides insight into how students' thinking developed throughout the intervention. The greatest improvements were observed in providing elementary clarification, building basic support, and making inferences. These dimensions represent the initial stages of critical thinking, in which students identify relevant information, interpret problem conditions, analyse available evidence, and formulate logical conclusions (Loyens et al., 2025; Luchang et al., 2023). During project implementation, students repeatedly discussed mathematical ideas within their groups, interpreted financial information from project scenarios, and presented their solutions before receiving feedback from peers and the teacher. Such iterative learning processes likely strengthened students' ability to explain mathematical reasoning clearly and construct logical arguments supported by evidence.

In contrast, strategy and tactics showed the smallest improvement, although the experimental group still outperformed the control group. This finding is understandable because strategic thinking and metacognitive decision-making represent more advanced dimensions of critical thinking that generally require sustained learning experiences and repeated opportunities for reflection (Dacumos, 2023; Nasution et al., 2024). Within the five-week intervention, students had begun to formulate solution strategies independently; however, the development of metacognitive regulation and strategic planning may require longer instructional periods and more complex project experiences. Similar observations have been reported in previous studies indicating that while project-based learning effectively strengthens analytical reasoning, higher-order strategic thinking develops progressively through continuous practice and reflection.

From a pedagogical perspective, these findings reinforce the growing recognition that

vocational mathematics instruction should move beyond procedural competence toward authentic mathematical reasoning (OECD, [2023](#); Papagiannis & Pallaris, [2024](#)). The integration of STEM principles with project-based learning creates opportunities for students to apply mathematics collaboratively while addressing realistic vocational challenges (Dacumos, [2023](#)). Such learning experiences not only improve conceptual understanding but also prepare students to analyse workplace problems systematically, evaluate alternative solutions, and make evidence-based decisions. These competencies are increasingly recognised as essential for graduates entering technology-driven and industry-oriented workplaces (Auliyani et al., [2025](#); OECD, [2023](#)).

The present study also extends previous research by demonstrating that the effectiveness of STEM-integrated PjBL is not solely attributable to the instructional model itself but also to the contextual design of the learning modules. Rather than employing generic STEM projects, the modules incorporated financial mathematics problems directly related to vocational education, thereby increasing the relevance of mathematical concepts to students' future occupations. This contextualisation represents an important contribution because it illustrates how authentic vocational scenarios can serve as a mechanism for strengthening critical thinking while simultaneously supporting mathematical understanding. Although previous studies have established the effectiveness of STEM-PjBL in enhancing critical thinking, relatively few have examined its implementation within vocational mathematics through authentic financial projects (Auliyani et al., [2025](#); Bien et al., [2026](#)).

Finally, several limitations should be acknowledged. First, the study was conducted in a single vocational high school involving two intact classes with a relatively limited number of participants, which may restrict the generalisability of the findings to other vocational education contexts. Second, although the same teacher taught both groups to minimise teacher-related variation, the dual role of the teacher as the researcher may have introduced researcher expectancy bias despite the use of identical lesson duration, learning objectives, assessment procedures, and instructional content across groups. Third, the instructional intervention was implemented over only five weeks and focused on a single vocational financial mathematics topic; therefore, the findings primarily reflect short-term learning outcomes. In addition, this study relied mainly on quantitative test data and did not incorporate qualitative evidence, such as classroom observations, interviews, or analyses of students' mathematical reasoning processes, which could have provided deeper insights into how critical thinking developed during project implementation. Furthermore, no delayed posttest was administered, preventing the evaluation of the long-term retention of students' critical thinking skills following the intervention.

Future research is therefore encouraged to examine the implementation of STEM-integrated Project-Based Learning across different vocational programmes, broader mathematical topics, and more diverse educational settings involving larger samples. Longitudinal studies incorporating delayed posttests are recommended to investigate the sustainability of learning outcomes. In addition, mixed-methods research combining quantitative achievement data with qualitative evidence of students' reasoning, collaboration, and reflective thinking would provide a more comprehensive understanding of how authentic vocational STEM projects contribute to the development of critical thinking and other twenty-first-century competencies, including creativity, communication, collaboration, and mathematical literacy.

CONCLUSION

This study concludes that STEM-integrated Project-Based Learning (PjBL) modules effectively enhance vocational high school students' critical thinking skills in mathematics. Students who learned using the STEM-integrated modules demonstrated substantially greater improvement in critical thinking than those who received conventional instruction. These findings indicate that integrating STEM principles with project-based learning creates

meaningful learning experiences that enable students to analyse authentic vocational problems, evaluate alternative solutions, and construct mathematical reasoning within real-world contexts. Such learning experiences are particularly relevant for preparing vocational students to meet the analytical and problem-solving demands of technology-driven workplaces.

An important contribution of this study lies in the contextual implementation of STEM-integrated PjBL through authentic financial mathematics projects, including motorcycle installment calculations, loan interest analysis, investment planning, and annuity problems. Unlike many previous studies that have examined STEM-integrated PjBL in general mathematics settings, this research demonstrates that contextualising mathematics within vocational financial situations can strengthen students' engagement while promoting multiple dimensions of critical thinking. The findings provide empirical evidence that contextualising STEM-integrated project-based learning within authentic vocational financial problems can serve as an effective instructional strategy for developing higher-order thinking skills while strengthening the relevance of mathematics to students' future professional practice. Consequently, this study extends current knowledge on the pedagogical value of contextualised STEM-integrated project-based learning in vocational mathematics education.

Despite these contributions, several limitations should be acknowledged. The study was conducted in a single vocational high school involving a relatively small number of participants and focused on one mathematics topic over a five-week intervention. Therefore, the findings should be interpreted within these contextual boundaries and should not be generalized to all vocational education settings without further empirical evidence. Future research is recommended to examine the implementation of STEM-integrated Project-Based Learning modules across different vocational programmes, mathematical topics, and educational contexts involving larger and more diverse samples. Longitudinal studies are also needed to investigate the sustainability of students' critical thinking development and to explore the influence of authentic STEM-integrated project learning on other twenty-first-century competencies, including mathematical problem-solving, creativity, collaboration, and mathematical literacy.

REFERENCE

- Afifah, A. N., Ilmiyati, N., & Toto, T. (2020). Pengaruh Model Project Based Learning (PjBL) dengan Pendekatan STEM Terhadap Penguasaan Konsep dan Keterampilan Berpikir Kritis Siswa. *J-KIP (Jurnal Keguruan Dan Ilmu Pendidikan)*, 1(2), 33–40. <https://doi.org/10.25157/j-kip.v1i2.4400>
- Amanah, I., Ibana, L., & Haikal, M. (2023). Hubungan antara Keterampilan Metakognitif dan Keterampilan Berpikir Kritis Siswa Madrasah Aliyah. *Multi Discere Journal*, 2(2), 66–78. <https://doi.org/10.36312/mj.v2i2.2718>
- Anta, R., Asriati, W. W., & Julia, N. T. (2025). Enhancing Mathematical Critical Thinking through Problem-Based Learning: A Case Study at SMP Pangeran Antasari. *International Journal of Multidisciplinary Sciences and Arts*, 4(3), 166–172. <https://doi.org/10.47709/ijmdsa.v4i3.6904>
- Auliyani, C. N., Arianto, F., & Kholidya, C. F. (2025). Project-Based Learning Integrated with STEM Education: Examining Implementation Strategies, Outcomes, and Challenges. *Jurnal Visi Ilmu Pendidikan*, 17(1), 214–231. <https://doi.org/10.26418/jvip.v17i1.85610>
- Baidowi, Sridana, N., Made, N., & Kertiyani, I. (2024). Constructing Critical Thinking Module to Teach Math Logic for Vocational School Student. *Journal for The Mathematics Education and Teaching Practices*, 5(1), 13–21. <https://doi.org/10.5281/zenodo.12612661>
- Bien, Y. I., Suparta, I. N., Suharta, I. G. P., & Sudiarta, I. G. P. (2026). PjBL-STEM Model in Mathematics Education: Systematic Literature Review on Effectiveness , Differentiation , and Affective Dimensions. *Jurnal EDUCATIO*, 12(2), 126–135. <https://doi.org/10.31949/educatio.v12i2.17881>
- Chen, C.H. & Yang, Y. C. (2019). Revisiting The Effects of Project-Based Learning on Students'

- Academic Achievement: A Meta-Analysis Investigating Moderators. *Educational Research Review*, 26, 71–81. <https://doi.org/10.1016/j.edurev.2018.11.001>
- Cohen, J. (1988). *Statistical Power Analysis for The Behavioral Sciences (2nd ed.)*. Lawrence Erlbaum Associates.
- Dacumos, L. P. N. (2023). STEM Education and The Project-Based Learning. *STEM Education Review*, 1(9), 1–6. <https://doi.org/10.54844/stemer.2023.0385>
- English, L. D. (2016). STEM Education K-12: Perspectives on Integration. *International Journal of STEM Education*, 3(1), 1–8. <https://doi.org/10.1186/s40594-016-0036-1>
- Ennis, R. H. (2011). *The Nature of Critical Thinking: An Outline of Critical Thinking Dispositions and Abilities*. University of Illinois.
- Facione, P. A. (2015). *Critical Thinking: What It Is and Why It Counts*. Insight Assessment.
- Feziyasti, A., Saputri, I., Asrizal, & Mufit, F. (2025). The Effect of Project-Based Learning Model (PjBL) with STEM Approach to Promote Students' Critical and Creative Thinking Skills: A Meta-Analysis. *Jurnal Berkala Pendidikan Fisika*, 18(1), 11–22. <https://doi.org/10.37729/radiasi.v18i1.6004>
- Guo, P., Saab, N., Post, L.S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. *International Journal of Educational Research*, 102, 101586. <https://doi.org/10.1016/j.ijer.2020.101586>
- Hattie, J. A. C., & Donoghue, G. M. (2016). Learning Strategies: A Synthesis and Conceptual Model. *Npj Science of Learning*, 1(16013). <https://doi.org/10.1038/npjscilearn.2016.13>
- Kurniawan, N. A., Hidayah, N., & Rahman, D. H. (2021). Analisis Kemampuan Berpikir Kritis Siswa SMK. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, 6(3), 334. <https://doi.org/10.17977/jptpp.v6i3.14579>
- Lafifa, F., Rosana, D., Suyanta, S., Nurohman, S., & Dwi Astuti, S. R. (2023). Integrated STEM Approach to Improve 21st Century Skills in Indonesia: A Systematic Review. *International Journal of STEM Education for Sustainability*, 3(2), 252–267. <https://doi.org/10.53889/ijses.v3i2.219>
- Loyens, S. M. M., Meerten, J. E. van, Schaap, L., & Wijnia, L. (2025). Situating Higher-Order, Critical, and Critical-Analytic Thinking in Problem- and Project-Based Learning Environments: A Systematic Review. In *Educational Psychology Review* (Issue 2023). Springer US. <https://doi.org/10.1007/s10648-023-09757-x>
- Luchang, A. L., Binti, N., & Nasri, M. (2023). Project-Based Learning (PBL) in Enhancing Students' Higher-Order Thinking Skills (HOTS): Systematic Literature Review. *International Journal of Academic Research in Progressive Education and Development*, 12(4). <https://doi.org/10.6007/IJARPED/v12-i4/20404>
- Meilani, R., Nurcahyo, A., & Waluyo, M. (2026). Effects of Problem-Based and Guided Inquiry Learning on Vocational Students' Critical Thinking Skills. *Jurnal Inovasi Matematika*, 8(1), 132–151. <https://doi.org/10.35438/inomatika.v8i1.563>
- Nasution, S.L.S., & Setyaningrum, W. (2024). Enhancing Thinking Understanding through STEM-PjBL: Assessment of Its Impact on Education Conceptual A Comprehensive. *Indonesian Journal of Educational Research and Review*, 7, 656–666. <https://doi.org/10.23887/ijerr.v7i3.81285>
- Norlita, D., Nageta, P. W., Faradhila, S. A., Aryanti, M. P., Fakhriyah, F., & Ismayam, A. E. A. (2023). Systematic Literature Review (Slr): Pendidikan Karakter Di Sekolah Dasar. *JISPENDIORA Jurnal Ilmu Sosial Pendidikan Dan Humaniora*, 2(1), 209–219. <https://doi.org/10.56910/jispendiora.v2i1.743>
- OECD. (2023). PISA 2022 Results. In *Factsheets: Vol. I*. https://www.oecd-ilibrary.org/education/pisa-2022-results-volume-i_53f23881-en%0Ahttps://www.oecd.org/publication/pisa-2022-results/country-notes/germany-1a2cf137/
- Papagiannis, P., & Pallaris, G. (2024). *Evaluating 21st Century Skills Development through Makerspace Workshops in Computer Science Education*.

- Portillo-Blanco, A., Guisasola, J., & Zuza, K. (2025). Integrated STEM education: addressing theoretical ambiguities and practical applications. *Frontiers in Education*, 10(April), 1–14. <https://doi.org/10.3389/feduc.2025.1568885>
- Santhosh, M., Farooqi, H., Ammar, M., Siby, N., Bhadra, J., & Thani, N. J. Al. (2023). A Meta-Analysis to Gauge the Effectiveness of STEM Informal Project-Based Learning: Investigating the Potential Moderator Variables. *Journal of Science Education and Technology*, 32(5), 671–685. <https://doi.org/10.1007/s10956-023-10063-y>
- Schraw, G. (1998). Promoting General Metacognitive Awareness. *Instructional Science*, 26, 113–125. <https://doi.org/10.1023/A:1003044231033>
- Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education. *European Journal of STEM Education*, 3(1), 02. <https://doi.org/10.20897/ejsteme/85525>
- Zimmerman, B. J. (2002). Becoming a Self-Regulated Learner: An Overview. *Theory Into Practice*, 41(2), 64–70. https://doi.org/10.1207/s15430421tip4102_2