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Development and perceived evaluation of cooperative project-based learning for higher-order thinking skills in vocational mechanical engineering

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Abstract: This study developed and evaluated a Cooperative Project-Based Learning (CPjBL) model for the Energy Conversion Machine course in vocational mechanical engineering. The model was developed using the ADDIE framework and evaluated for validity, practicality, and effectiveness. Expert validation involved the CPjBL model, course guidance book, and instructional module, while practicality was examined from lecturer and student perspectives. Effectiveness was assessed using a non-equivalent post-test-only quasi-experimental design involving 40 students divided into experimental and control groups. Higher-order thinking skills (HOTS) were measured through project proposal, project product, overall project performance, and problem-solving ability. Aiken's V coefficients ranged from 0.842 to 0.917, indicating that the developed products met the validity criteria. Practicality scores were 86.67% from the lecturer and 86.00% from students, indicating good classroom feasibility. Significant post-intervention differences were found across all four HOTS outcomes ($p < .001$). However, the currently reported group means were higher in the conventional-instruction group than in the CPjBL group. These findings support the validity and practicality of CPjBL, while its comparative effectiveness remains inconclusive and requires further evaluation using baseline measures, larger samples, and stronger control of group equivalence. The model nevertheless offers a framework for authentic cooperative project learning in vocational education.

Keywords: Cooperative project-based learning; higher-order thinking skills; vocational education; mechanical engineering education; authentic assessment

1. Introduction

Rapid developments in automation, digitalization, smart manufacturing, and Industry 4.0 technologies have changed occupational structures and the competencies expected from vocational graduates. Industries now require workers who possess not only technical expertise but also problem-solving, critical thinking, creativity, communication, teamwork, adaptability, digital competence, and lifelong learning capabilities (González-Rico & Lluch Sintes, 2024; Kamaruzaman et al., 2025; Lemstra & Mesquita, 2023; Tushar & Sooraksa, 2023). Consequently, Technical and Vocational Education and Training, or TVET, must move beyond procedural instruction and prepare students to interpret information, evaluate alternatives, make informed decisions, and generate solutions to complex occupational problems (Karami & Rezvanian, 2026; Magagula & Awodiji, 2024).

This demand is particularly relevant to vocational mechanical engineering education. Mechanical engineering students must integrate scientific concepts, engineering principles, technical drawings, manufacturing procedures, occupational safety standards, and product-performance criteria when solving workplace problems (Barbosa et al., 2022; Dillenhöfer et al., 2025; van Gelder et al., 2021). Such activities require higher-order thinking skills (HOTS) rather than the mechanical reproduction of formulas or standard operating procedures. In the revised cognitive taxonomy, higher-order cognitive processes include analyzing, evaluating, and creating (Krathwohl, 2002). Contemporary studies further associate HOTS with critical thinking, creative thinking, problem-solving, reasoning, and decision-making (Febrianti et al., 2021; Sivakumar & Boon, 2026; Vafamehr et al., 2025). Accordingly, this study operationalizes HOTS as students' abilities to analyze authentic technical problems, evaluate alternative solutions, justify technical decisions, solve problems systematically, and create functional project outcomes.

Project-based learning, abbreviated as PjBL, provides a theoretically relevant instructional foundation for developing these competencies. PjBL organizes learning around authentic and open-ended driving questions, scaffolded investigation, disciplinary practices, collaboration, reflection, metacognition, and the production of tangible artifacts that represent students' understanding (Hinostroza et al., 2025; Le et al., 2025). Through these processes, students do not merely receive technical knowledge. They apply concepts, investigate practical constraints, collect and analyze information, test ideas, revise designs, and construct solutions that resemble professional engineering activities (Deng et al., 2026; Elaby et al., 2022; Huerta-Gomez-Merodio & Requena-Garcia-Cruz, 2025).

Empirical research generally supports the effectiveness of PjBL, although its effects vary across instructional contexts. A meta-analysis synthesized 66 experimental and quasi-experimental studies containing 190 effect sizes and found that PjBL produced a significant positive effect on overall learning outcomes, with a combined standardized mean difference of 0.441 (Zhang & Ma, 2023). Other empirical and systematic studies have also reported improvements in evaluation, creation, creative thinking, problem-solving, and higher-order thinking after students participated in structured PjBL activities (Guo et al., 2020; Suradika et al., 2023; Wijnia et al., 2019).

The cooperative component is critical because vocational projects commonly require students to exchange technical information, distribute responsibilities, negotiate design choices, evaluate competing ideas, and coordinate project implementation. Collaborative problem-solving can generate cognitive conflict, encourage explanation and justification, and expose students to alternative strategies that may not emerge during individual learning (Krajcik & Shin, 2014; M. M. Li & Tu, 2024; Xu et al., 2023). A meta-analysis of 36 studies found that collaborative problem-solving significantly improved critical thinking, with an overall effect size of 0.82, although its effectiveness was moderated by instructional type, intervention duration, subject area, group size, and learning scaffold (Xu et al., 2023). Structured pair or group cooperation, including discussion, brainstorming, peer feedback, project development, testing, revision, and reflection, has also been shown to support the development of creative thinking (M. M. Li & Tu, 2024).

However, assigning students to groups and asking them to complete a project does not automatically develop HOTS. Students may divide tasks mechanically, focus only on completing the product, depend on more capable group members, or follow procedures without analyzing the underlying problem. Effective cooperative projects therefore require explicit roles, authentic and cognitively demanding problems, continuous monitoring, appropriate scaffolding, formative feedback, individual accountability, and opportunities for reflection and revision (Gkintoni et al., 2025; Perzolli et al., 2026; Schutte et al., 2026). This distinction matters because instructional design quality, not the PjBL label alone, determines whether students engage in meaningful analysis, evaluation, problem-solving, and creation.

Despite growing evidence supporting PjBL, important research gaps remain. Definitions and measurements of HOTS, critical thinking, and related constructs vary substantially across studies, resulting in differences in assessment instruments and outcome indicators (D. Li et al., 2024; Loyens et al., 2023). Studies also vary in the extent to which essential PjBL components, scaffolding, authentic problem-solving, and appropriate comparison conditions are incorporated into their designs (Ferrero et al., 2021). Furthermore, research on PjBL and HOTS remains strongly represented in science and STEM education, while students' thinking is frequently measured through conventional cognitive tests rather than through both project processes and authentic technical outcomes (Aziz et al., 2023; Bacca et al., 2019; Cao et al., 2025; Orji & Ogbonnaya, 2026; Vlachopoulos & Makri, 2024; Yulianti & Herman, 2022).

A more specific gap exists in vocational education. The growing interest in PjBL within vocational education is reflected in 60 Scopus-indexed publications from 2010 to022 (Ahmad et al., 2023). Nevertheless, much of the existing literature discusses PjBL as a general instructional approach or examines individual outcomes such as achievement, creativity, critical thinking, or vocational competence (Ahmad et al., 2023; Lesmana et al., 2023; Song et al., 2025). Research remains comparatively limited on a domain-specific model that integrates occupational competency analysis, structured cooperation, authentic mechanical-engineering problems, project development, monitoring, feedback, reflection, and multidimensional HOTS assessment within a coherent instructional sequence.

To address this gap, this study developed a Cooperative Project-Based Learning (CPjBL) model for the Energy Conversion Machine course in a vocational mechanical engineering program. The model was developed using the ADDIE framework and consists of ten interconnected phases: (1) analyzing threshold and differentiating competencies and student characteristics; (2) understanding concepts of energy-conversion machines; (3) demonstrating relevant processes and principles; (4) determining the project job; (5) identifying authentic problems and essential questions; (6) designing the project framework; (7) implementing the project; (8) monitoring students and project progress; (9) providing feedback; and (10) evaluating and reflecting on the project experience.

The novelty of this research does not lie merely in combining cooperative learning and PjBL, since related combinations have been examined previously. Rather, its novelty lies in the domain-specific operationalization of cooperative project learning through a ten-phase instructional sequence aligned with vocational mechanical-engineering competencies. The model integrates conceptual learning, technical demonstration, authentic problem identification, cooperative project design, product development, monitoring, feedback, and reflection. HOTS are evaluated through four complementary forms of authentic assessment: project proposal, project product, overall project performance, and problem-solving ability. This approach enables examination of students' higher-order thinking through both cognitive performance and observable technical-project outcomes. Accordingly, the study addresses the following research questions:

RQ1. To what extent does the developed CPjBL model meet the validity criteria for vocational mechanical engineering instruction?
RQ2. How practical is the CPjBL model when implemented in the Energy Conversion Machine course from lecturer and student perspectives?
RQ3. Do students receiving CPjBL demonstrate significantly higher post-intervention higher-order thinking performance than students receiving conventional instruction, as assessed through project proposals, project products, overall project performance, and problem-solving ability?

This study makes three contributions. Theoretically, it operationalizes the relationship among project-based learning, cooperative learning, and HOTS within vocational mechanical engineering. Methodologically, it combines expert-based model validation with quasi-experimental effectiveness evaluation and multidimensional authentic assessment rather than relying exclusively on conventional written HOTS tests. Practically, it provides vocational lecturers with a structured instructional sequence for engaging students in cooperative technical projects involving analysis, evaluation, problem-solving, decision-making, product creation, feedback, and reflection.

2. Methods

2.1 Research design and procedure

This study employed an instructional-model development approach followed by a quasi-experimental evaluation to develop, validate, and evaluate Cooperative Project-Based Learning (CPjBL) in the Energy Conversion Machine course at the Department of Mechanical Engineering, Universitas Negeri Padang, Indonesia.

The CPjBL model was developed using the ADDIE framework, comprising Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). During the analysis phase, the team examined relevant theories, curriculum requirements, occupational competencies, student characteristics, and authentic mechanical-engineering project activities. The design and development phases produced the CPjBL instructional syntax, course guidance book, instructional module, project activities, and assessment instruments. Experts subsequently validated the developed products, which were revised before classroom implementation. The implementation and evaluation phases examined the model's practicality and compared students' post-intervention HOTS performance between CPjBL and conventional instruction. Figure 1 presents the overall research procedure.

2.2 Expert validation

Expert validation was conducted on three main products: the CPjBL model, course guidance book, and instructional module. Senior experts in relevant subject areas and academic language evaluated the theoretical rationale, supporting theories, instructional syntax, model characteristics, principles of reaction, supporting system, instructional effects, format, and language. Content validity was analyzed using Aiken's V coefficient (Aiken, 1985), which ranges from 0 to 1, with values closer to 1 indicating stronger agreement among validators. The Aiken's V coefficient was calculated based on the proportion of agreement among experts by considering the rating scores assigned by each validator. The mathematical formulation of the coefficient is presented in Equation (1), while the calculation of the adjusted score (s) used in the Equation is described in Equation (2).

$$V = \Sigma s \;/\; [n(c - 1) \tag{1}$$

where:

$$s = r - l_0 \tag{2}$$

In this formula, r represents the rating assigned by a validator, l_0 is the lowest possible rating, c is the number of rating categories, and n is the number of validators. Expert comments and recommendations were also used to revise the model and supporting materials before implementation.

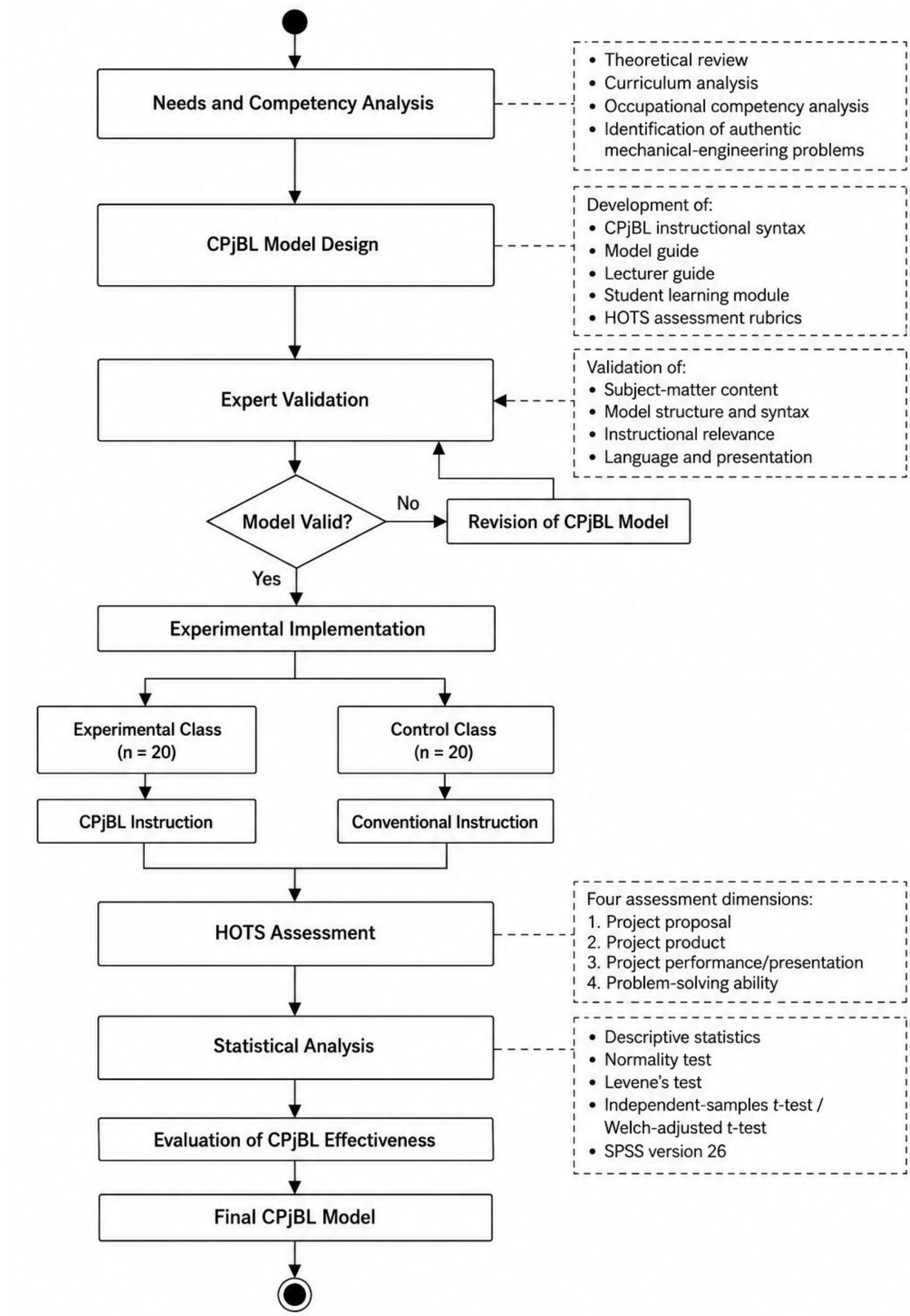

Figure 1. Research procedure for developing and evaluating CPjBL

2.3 Practicality testing

Following expert validation and revision, the practicality of CPjBL was evaluated during classroom implementation from both lecturer and student perspectives. Practicality data were collected using response questionnaires designed to examine the usability of the model and its supporting materials. The lecturer assessment focused on the attractiveness of the learning design, the implementation process, and ease of use. Students also evaluated their experience in using the CPjBL learning activities and supporting materials. The questionnaire scores were summarized as percentage scores, with higher values indicating greater practicality. These data were used to determine whether the developed model could be implemented feasibly in the Energy Conversion Machine course.

2.4 Participants and experimental design

The effectiveness evaluation involved 40 students from the Department of Mechanical Engineering, Universitas Negeri Padang, Indonesia. Participants were purposively selected from two existing classes enrolled in the Energy Conversion Machine course. One class consisting of 20 students served as the experimental group and received CPjBL instruction, while the other class consisting of 20 students served as the control group and received conventional instruction covering the same course content.

Because intact classes were used without individual random assignment and no baseline pretest was administered, the effectiveness evaluation employed a nonequivalent posttest-only quasi-experimental design (Shadish et al., 2002). Table 1 presents the design.

Table 1. Nonequivalent posttest-only quasi-experimental design

Group	Instructional Condition	Post-Intervention Assessment
Experimental	CPjBL	O_1
Control	Conventional instruction	O_2

The analysis therefore focused on differences in post-intervention performance between the two instructional conditions rather than changes from a pre-intervention baseline.

2.5 CPjBL implementation and HOTS assessment

The experimental group followed ten CPjBL phases: competency and student analysis, conceptual understanding, technical demonstration, determination of the project job, identification of authentic problems and essential questions, project design, project implementation, progress monitoring, feedback, and project evaluation and reflection. Students worked cooperatively to analyze authentic technical problems, develop solutions, construct and test project outcomes, justify technical decisions, respond to feedback, and reflect on their project experience. The control group studied the same course content through conventional instruction.

Higher-order thinking skills (HOTS) were operationalized as students' abilities to analyze technical problems, evaluate alternative solutions, justify decisions, solve problems systematically, and create functional project outcomes. This operationalization is consistent with the higher cognitive processes of analyzing, evaluating, and creating in the revised cognitive taxonomy (Krathwohl, 2002). HOTS were evaluated through four authentic assessment components. Table 2 summarizes their main indicators.

Table 2. HOTS assessment components and main indicators

Assessment component	Main indicators
Project proposal	Problem formulation, theoretical justification, technical calculations, project planning, and design
Project product	Quality of the technical solution, originality, construction, detailed design, and testing
Overall project performance	Project mastery, technical justification, technical communication, responses to questions and feedback, and teamwork
Problem-solving ability	Problem identification and formulation, strategy selection, interpretation of technical conditions, and implementation of solutions

Each component was assessed using a structured rubric and expressed on a 1–100 scale. The resulting student scores were used for subsequent statistical analysis.

2.6 Data Analysis

Data were analyzed using IBM SPSS Statistics version 26. We calculated descriptive statistics, including mean and standard deviation, for the four HOTS outcomes in both groups. Practicality data were summarized as percentages, while expert-validation data were analyzed using Aiken's V.

Before comparing the experimental and control groups, we examined normality using the Shapiro–Wilk test (Shapiro & Wilk, 1965), and homogeneity of variance was examined using Levene's test. The Shapiro–Wilk procedure is an established test of departure from normality.

Differences in post-intervention performance were analyzed using an independent-samples t-test at a significance level of $p < .05$. When the assumption of equal variances was not satisfied, the unequal-variance or Welch-adjusted result was interpreted because Welch's procedure provides more robust inference when group variances differ (Delacre et al., 2017). Because no baseline HOTS pretest was administered, the effectiveness analysis was interpreted as a comparison of post-intervention performance rather than as a direct measure of individual improvement over time.

3. Results

3.1 Validity of the CPjBL model

Expert validation was conducted to determine the appropriateness of the CPjBL model and its supporting learning materials before classroom implementation. The assessment covered the theoretical rationale, supporting theories, instructional syntax, model characteristics, principles of reaction, supporting system, instructional effects, format, and language. Table 3 summarizes the validation results for the three developed products.

Table 3. Expert validation results for the CPjBL model and supporting materials

Developed product	Aiken's V	Interpretation
CPjBL model	0.917	Valid
Course guidance book	0.842	Valid
Instructional module	0.847	Valid

As shown in Table 3, the CPjBL model obtained the highest Aiken's V coefficient (V = 0.917), followed by the instructional module (V = 0.847) and the course guidance book (V = 0.842). All coefficients were relatively close to 1.00, indicating strong agreement among the validators regarding the appropriateness of the developed products. These results indicate that the CPjBL model and its supporting materials met the validity criteria adopted in this study and were therefore considered suitable for classroom implementation.

3.2 Practicality of the CPjBL model

Following validation and revision, the practicality of CPjBL was evaluated from lecturer and student perspectives. The lecturer questionnaire addressed the attractiveness of the instructional design, implementation process, and ease of use, whereas the student questionnaire examined their experience with the learning activities and supporting materials. Table 4 presents the practicality results.

Table 4. Practicality of the CPjBL model

Respondents	Practicality score (%)	Interpretation
Lecturer	86.67	Practical
Students	86	Practical

Table 4 shows that the lecturer assessment produced a practicality score of 86.67%, while the students reported a score of 86.00%. The similarity between the two results indicates consistently positive perceptions of CPjBL's usability from both instructional and learner perspectives. Thus, the model was considered practical for implementation in the Energy Conversion Machine course.

3.3 Effectiveness of CPjBL on higher-order thinking skills

The effectiveness analysis compared the post-intervention performance of the CPjBL and conventional-instruction groups across four HOTS components: project proposal, project product, overall project performance, and problem-solving ability. We examined normality before inferential testing and used Levene's test to assess homogeneity of variance. Because the variance assumption was not met for the first three outcomes, we used Welch-adjusted results for those comparisons. Table 5 summarizes the post-intervention results.

Table 5. Comparison of post-intervention HOTS performance

HOTS component	CPjBL group M (SD)	Control group M (SD)	*t* (df)	*p*
Project proposal	68.70 (2.55)	80.18 (1.15)	−18.36 (26.41)	< .001
Project product	73.32 (1.59)	80.18 (1.15)	−15.66 (34.62)	< .001
Overall project performance	71.40 (1.83)	86.63 (0.27)	−36.78 (19.84)	< .001
Problem-solving ability	75.84 (2.17)	85.84 (2.17)	−14.58 (38.00)	< .001

As presented in Table 5, statistically significant differences were found between the two groups for all four HOTS components ($p < .001$). For project proposal performance, the CPjBL group obtained a mean score of 68.70, compared with 80.18 for the control group. Significant differences were also found for project product performance, with mean scores of 73.32 and 80.18, respectively.

The largest difference occurred in overall project performance, where the CPjBL group obtained a mean of 71.40 compared with 86.63 for the control group. Problem-solving ability also differed significantly, with mean scores of 75.84 for the CPjBL group and 85.84 for the control group.

Therefore, based on the group labels and numerical values currently reported, the findings demonstrate significant differences in all four HOTS outcomes. However, they do not support the expectation that the CPjBL group achieved higher post-intervention performance than the conventional-instruction group. Verify the direction of these results against the original dataset before final interpretation.

4. Discussion

The validation results indicate that the developed CPjBL model and its supporting materials were appropriate for implementation in vocational mechanical engineering instruction. Aiken's V coefficients ranged from 0.842 to 0.917, with the highest value obtained for the CPjBL model. These results suggest strong expert agreement on the model's theoretical rationale, instructional syntax, supporting system, content, and presentation. The validity of the ten-phase structure is particularly important because effective project-based learning requires coherent alignment among authentic problems, project activities, cooperation, feedback, and reflection rather than merely assigning students to complete a project (Gkintoni et al., 2025; Perzolli et al., 2026; Schutte et al., 2026).

The practicality results also showed positive responses from both lecturers and students, with scores of 86.67% and 86.00%, respectively. This finding indicates that CPjBL and its supporting materials could be implemented within the Energy Conversion Machine course with acceptable usability. The result is consistent with the view that well-structured PjBL can facilitate authentic investigation, collaboration, reflection, and production of tangible outcomes when learning activities are sufficiently scaffolded (Hinostroza et al., 2025; Nguyen, 2025). The similarity between lecturer and student evaluations further suggests that the model was feasible from both instructional and learner perspectives.

The effectiveness findings require more cautious interpretation. Significant differences were identified between the CPjBL and conventional-instruction groups across project proposal, project product, overall project performance, and problem-solving ability. However, based on the currently reported group labels, the control group obtained higher mean scores on all four outcomes. Therefore, although the assessment framework clearly differentiated the two instructional conditions, the present results do not demonstrate superior post-intervention HOTS performance for the CPjBL group.

This finding differs from the general tendency reported in previous PjBL research. A meta-analysis of 66 experimental and quasi-experimental studies found an overall positive effect of PjBL on learning outcomes, while other reviews have associated project-based learning with improvements in problem-solving, evaluation, creation, and higher-order thinking (Guo et al., 2020; Loyens et al., 2023; Zhang & Ma, 2023). This contrast does not necessarily invalidate CPjBL. Rather, previous evidence shows that PjBL outcomes vary according to instructional context, implementation characteristics, learning support, and assessment procedures (Loyens et al., 2023; Zhang & Ma, 2023).

Collaborative problem-solving can promote explanation, negotiation, evaluation of alternatives, and critical thinking, but these benefits depend on group structure, scaffolding, task characteristics,

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and instructional duration (M. M. Li & Tu, 2024; Xu et al., 2023). In the present CPjBL model, students were expected to identify authentic problems, formulate essential questions, design technical solutions, construct and test products, respond to feedback, and reflect on project outcomes. These activities are conceptually aligned with the analysis, evaluation, problem-solving, and creation processes that characterize HOTS. Nevertheless, participation in project activities alone does not guarantee higher measured performance when students' prior competencies, readiness for cooperative work, or quality of reasoning during project execution differ.

The multidimensional assessment used in this study adds another contribution. HOTS were examined through project proposals, project products, overall project performance, and problem-solving ability rather than through a single conventional cognitive test. This approach responds to concerns that HOTS and related constructs are often measured inconsistently and that authentic project processes and outcomes are not always captured adequately in PjBL research (W. A. Aziz et al., 2023; Loyens et al., 2023; Yulianti & Herman, 2022). For vocational mechanical engineering, such assessment is relevant because higher-order thinking is demonstrated not only through theoretical knowledge but also through technical planning, design decisions, testing, justification, and problem resolution.

The quasi-experimental design, however, limits causal interpretation of the effectiveness results. Because intact classes were used and no baseline HOTS pretest was administered, the post-intervention differences cannot establish whether the groups were equivalent before instruction (Shadish et al., 2002). Prior technical knowledge, previous project experience, group composition, and implementation conditions may therefore have contributed to the observed outcomes. Future investigations could reduce this uncertainty through baseline measurement, larger samples, and more systematic documentation of implementation fidelity.

Overall, the findings support the validity and practicality of the developed CPjBL model, whereas its comparative effectiveness remains inconclusive in the direction originally expected. The statistically significant differences across all four HOTS components indicate that the two instructional conditions produced distinguishable post-intervention outcome patterns, but the current mean scores do not demonstrate CPjBL superiority. Further evaluation may therefore focus on whether stronger baseline control, more consistent scaffolding, and closer implementation monitoring alter the observed relationship between CPjBL and vocational students' higher-order thinking.

5. Implications and limitations

The findings have theoretical and methodological implications for vocational mechanical engineering education. The ten-phase CPjBL model provides a domain-specific structure that integrates authentic technical problems, cooperative project work, monitoring, feedback, and reflection within a single instructional sequence. The use of four complementary assessments-project proposal, project product, overall project performance, and problem-solving ability- also offers an alternative way to examine HOTS through authentic technical performance rather than relying solely on conventional written tests. This approach may better represent analyzing, evaluating, problem-solving, and creating in vocational learning contexts.

From a practical perspective, the high validity and practicality scores indicate that CPjBL and its supporting materials can be implemented in the Energy Conversion Machine course. The model may help vocational lecturers organize cooperative technical projects in which students identify authentic problems, formulate solutions, develop products, justify technical decisions, and respond

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to feedback. However, successful implementation requires adequate scaffolding, clear student responsibilities, continuous monitoring, and sufficient time for project development and reflection. Therefore, adaptation to other vocational disciplines should consider differences in occupational competencies, project complexity, student readiness, and available learning resources.

Several limitations should be considered when interpreting the effectiveness findings. The study involved only 40 students from two intact classes at one institution, used purposive sampling, and did not include a baseline HOTS pretest or individual random assignment. Consequently, the observed post-intervention differences cannot establish whether the groups were equivalent before instruction or whether the differences were attributable solely to CPjBL. Future studies should use larger, more diverse samples, include baseline measurements, examine implementation fidelity, and evaluate the model across different vocational disciplines and institutional contexts to establish its effectiveness more conclusively.

6. Conclusion

This study developed and evaluated a ten-phase Cooperative Project-Based Learning (CPjBL) model for the Energy Conversion Machine course in vocational mechanical engineering. Expert evaluation indicated that the CPjBL model, course guidance book, and instructional module met the validity criteria, with Aiken's V coefficients ranging from 0.842 to 0.917. Practicality evaluation also produced positive results from both lecturers (86.67%) and students (86.00%), indicating that the model and its supporting materials were feasible for classroom implementation.

The effectiveness analysis identified statistically significant differences between the CPjBL and conventional-instruction groups across all four HOTS outcomes: project proposal, project product, overall project performance, and problem-solving ability. However, based on the group labels and numerical values currently reported, the control group achieved higher post-intervention mean scores across all four assessments. Therefore, the present evidence supports the validity and practicality of CPjBL but does not establish its superiority over conventional instruction in enhancing post-intervention HOTS performance.

The study nevertheless contributes a domain-specific instructional framework that integrates vocational competencies, authentic technical problems, structured cooperation, project development, feedback, reflection, and multidimensional authentic assessment. Further experimental evaluation with baseline measurements, larger samples, and stronger control of group equivalence is required before firm conclusions can be drawn regarding the effectiveness of CPjBL for developing higher-order thinking skills in vocational mechanical engineering.

Author's declaration

Author contribution

Aznil Mardin: Conceptualization, Methodology, Investigation, Development of the Cooperative Project-Based Learning (CPjBL) model, Development of instructional materials, Data collection, Formal analysis, Visualization, Writing – Original Draft, Writing – Review & Editing. **Nizwardi Jalinus:** Conceptualization, Supervision, Validation, Methodological guidance, Critical revision of the manuscript, Writing – Review & Editing, Project administration. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no known financial or non-financial competing interests that could have influenced the design, implementation, analysis, or interpretation of this research.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. Due to institutional and participant confidentiality considerations, the complete dataset is not publicly deposited but may be accessed for academic verification purposes following appropriate requests.

Ethical clearance

This study was conducted under institutional research authorization from Universitas Negeri Padang through Research Permit Letter No. 643/UN35.8/PL/2017, dated 4 April 2017. Participant confidentiality and responsible data handling were maintained throughout the study. No separate ethics committee approval number was issued.

AI statement

During the preparation of this manuscript, the authors used artificial intelligence (AI)-assisted tools only for language improvement, grammar checking, and manuscript refinement. The authors remain fully responsible for the originality, accuracy, interpretation of results, and scientific integrity of the published work. AI tools were not used to generate research data, perform scientific analysis, or replace the authors' intellectual contributions.

Publisher's and Journal's note

Universitas Negeri Padang, as the publisher, and the Editor of Jurnal Pendidikan Teknologi Kejuruan state that there is no conflict of interest towards this article publication.

References

Ahmad, S. T., Watrianthos, R., Samala, A. D., Muskhir, M., & Dogara, G. (2023). Project-based Learning in Vocational Education: A Bibliometric Approach. *International Journal of Modern Education and Computer Science*, *15*(4), 43–56. https://doi.org/10.5815/ijmecs.2023.04.04

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, *45*(1), 131–142. https://doi.org/10.1177/0013164485451012

Aziz, N. I. S. A., Ab Latiff, D. S., Maon, S. N., & Anuar, A. (2023). Mobile Learning in Medical Coding Course: Intention to Use MedCoS. *International Journal of Online and Biomedical Engineering*, *19*(9), 15–29. https://doi.org/10.3991/ijoe.v19i09.40913

Aziz, W. A., Wulansari, R. E., Putra, R. P., Tun, H. M., Tin, C. T., & Ya, K. Z. (2023). Project-based learning module on creativity and entrepreneurship products subject: Validity and empirical effect. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(3), 216–227. https://doi.org/10.24036/jptk.v6i3.34323

Bacca, J., Baldiris, S., Fabregat, R., & Kinshuk. (2019). Framework for designing motivational augmented reality applications in vocational education and training. *Australasian Journal of Educational Technology*, *35*(3), 102–117. https://doi.org/10.14742/ajet.4182

Barbosa, F. V., Lobarinhas, P. A. M., Teixeira, S. F. C. F., & Teixeira, J. C. F. (2022). Project-Based Learning in a Mechanical Engineering Course: A new proposal based on student's views. *International Journal of Mechanical Engineering Education*, *50*(4), 767–804. https://doi.org/10.1177/03064190221078259

Branch, R. M. (2009). *Instructional Design: The ADDIE Approach* (pp. 1–203). Springer New York, NY. https://doi.org/10.1007/978-0-387-09506-6

Cao, X., Lu, H., Wu, Q., & Hsu, Y. (2025). Systematic review and meta-analysis of the impact of STEM education on students learning outcomes. *Frontiers in Psychology*, *16*, 1–15. https://doi.org/10.3389/fpsyg.2025.1579474

Delacre, M., Lakens, D., & Leys, C. (2017). Why psychologists should by default use welch's t-Test instead of student's t-Test. *International Review of Social Psychology*, *30*(1), 92–101. https://doi.org/10.5334/irsp.82

Deng, Y., Lucas, C., & Liu, W. (2026). A systematic review of design thinking implementations in higher engineering education. *European Journal of Engineering Education*, *3797*, 1–41. https://doi.org/10.1080/03043797.2026.2640060

Dillenhöfer, F., Kossack, F., Sersch, A., Künne, B., Bender, B., & Gust, P. (2025). Focused competencies in higher education for engineering product development and its different activities. *Proceedings of the Design Society*, *5*, 1843–1852. https://doi.org/10.1017/pds.2025.10198

Elaby, M. F., Elwishy, H. M., Moatamed, S. F., Abdelwahed, M. A., & Rashiedy, A. E. (2022). Does design-build concept improve problem-solving skills? An analysis of first-year engineering students. *Ain Shams Engineering Journal*, *13*(6), 101780. https://doi.org/10.1016/j.asej.2022.101780

Febrianti, W., Zulyusri, & Lufri. (2021). Meta Analisis: Pengembangan Soal HOTS Untuk Meningkatkan Kemampuan Berpikir Kritis Peserta Didik. *Bioilmi: Jurnal Pendidikan*, 7(I), 39–45.

Ferrero, M., Vadillo, M. A., & León, S. P. (2021). Is project-based learning effective among kindergarten and elementary students? A systematic review. *PLoS ONE*, *16*, 1–14. https://doi.org/10.1371/journal.pone.0249627

Gkintoni, E., Antonopoulou, H., Sortwell, A., & Halkiopoulos, C. (2025). Challenging Cognitive Load Theory: The Role of Educational Neuroscience and Artificial Intelligence in Redefining Learning Efficacy. *Brain Sciences*, *15*(2), 1–101. https://doi.org/10.3390/brainsci15020203

González-Rico, P., & Lluch Sintes, M. (2024). Empowering Soft Skills through Artificial Intelligence and Personalised Mentoring. *Education Sciences*, *14*(7), 1–11. https://doi.org/10.3390/educsci14070699

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

Hinostroza, J. E., Armstrong-Gallegos, S., Soto-Valenzuela, P., & Villafaena, M. (2025). Phases and Activities of Technology-Integrated Project-Based Learning in K-12: Findings from a Systematic Literature Review. *Education Sciences*, *15*(8), 1–24. https://doi.org/10.3390/educsci15081021

Huerta-Gomez-Merodio, M., & Requena-Garcia-Cruz, M. V. (2025). Integrating Theory and Practice in Engineering Education: A Cross-Curricular and Problem-Based Methodology. *Education Sciences*, *15*(9), 1–18. https://doi.org/10.3390/educsci15091253

Kamaruzaman, F. M., Othman, N. N. J. N., & Omar, M. (2025). Future Generic Skills for Technical Vocational Education Graduates. *International Journal of Learning, Teaching and Educational Research*, *24*(3), 312–332. https://doi.org/10.26803/ijlter.24.3.15

Karami, M., & Rezvanian, M. (2026). The kind of curriculum we need to develop integrated skills in technical and vocational training. *Education + Training*, 1–20. https://doi.org/10.1108/et-04-2025-0280

Krajcik, J. S., & Shin, N. (2014). Project-Based Learning. The Cambridge Handbook of the Learning. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 275–297). https://doi.org/10.1017/CBO9781139519526.018

Krathwohl, D. R. (2002). A Revision of Bloom's Taxonomy: An Overview. *Theory Into Practice ISSN:*, *41*(4), 212–218. https://doi.org/10.1207/s15430421tip4104_2

Le, H. T., Nguyen-Dinh, C. H., Van, H. T., & Nguyen, M. D. (2025). The Evolution of Online Physics Education: Insights from a Bibliometric Study. *International Journal of Learning, Teaching and Educational Research*, *24*(4), 221–249. https://doi.org/10.26803/ijlter.24.4.11

Lemstra, M. A. M. S., & Mesquita, M. A. de. (2023). Industry 4.0: a tertiary literature review. *Technological Forecasting and Social Change*, *186*, 122204. https://doi.org/10.1016/j.techfore.2022.122204

Lesmana, I., Mulianti, M., Primawati, P., & Kassymova, G. K. (2023). Implementation of project-based learning (PjBL) model to increase students' creativity and critical thinking skill in vocational creative product subjects. *Jurnal Pendidikan Teknologi Kejuruan*, *6*(3), 202–215. https://doi.org/10.24036/jptk.v6i3.34023

Li, D., Fan, X., & Meng, L. (2024). Development and validation of a higher-order thinking skills (HOTS) scale for major students in the interior design discipline for blended learning. *Scientific Reports*, *14*(1), 1–20. https://doi.org/10.1038/s41598-024-70908-3

Li, M. M., & Tu, C. C. (2024). Developing a Project-Based Learning Course Model Combined with the Think–Pair–Share Strategy to Enhance Creative Thinking Skills in Education Students. *Education Sciences*, *14*(3). https://doi.org/10.3390/educsci14030233

Loyens, S. M. M., van Meerten, J. E., Schaap, L., & Wijnia, L. (2023). Situating Higher-Order, Critical, and Critical-Analytic Thinking in Problem- and Project-Based Learning Environments: A Systematic Review Sofie. *Educational Psychology Review*, *39*, 1–44. https://doi.org/10.1007/s10648-023-09757-x

Magagula, M. M., & Awodiji, O. A. (2024). The implications of the fourth industrial revolution on technical and vocational education and training in South Africa. *Social Sciences and Humanities Open*, *10*, 100896. https://doi.org/10.1016/j.ssaho.2024.100896

Nguyen, D. T. (2025). Project-Based Learning (PJBL) as an Experiential Pedagogical Methodology in Interdisciplinary Education: A Review of the Literature. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *13*(4), 1016–1039. https://doi.org/10.46328/ijemst.4869

Orji, E. I., & Ogbonnaya, U. I. (2026). Systematic Review: Evaluation of Impacts of Project-Based Learning on Science Process Skills of STEM Students. *Prizren Social Science Journal*, *10*(1), 57–77. https://doi.org/10.32936/pssj.v10i1.756

Perzolli, S., Serbati, A., Venuti, P., Dimitriou, D., & Esposito, G. (2026). Reimagining inclusive education through challenge-based learning: Opportunities and barriers for students with learning disabilities. *Research in Developmental Disabilities*, *175*, 105343. https://doi.org/10.1016/j.ridd.2026.105343

Schutte, B. G., Bayram, D., Vennix, J., & van der Veen, J. (2026). Scaffolding for Challenge-Based Learning in Sustainability Education: A Multiple-Case Study. *Sustainability (Switzerland)*, *18*(7), 1–35. https://doi.org/10.3390/su18073273

Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). Experimental and quasi-experimental designs for generalized causal inference. In *Houghton, Mifflin and Company*. https://psycnet.apa.org/record/2002-17373-000

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3–4), 591–611. https://doi.org/10.1093/biomet/52.3-4.591

Sivakumar, K., & Boon, M. (2026). A preliminary higher order thinking skills (HOTS) framework for interdisciplinary problem solving and scientific research (IDPSSR) in engineering science education. *European Journal of Engineering Education*, *3797*, 1–34. https://doi.org/10.1080/03043797.2025.2609749

Song, X., Razali, A. B., & Jeyaraj, J. J. (2025). How project-based learning improves college EFL learners' critical thinking skills and reading comprehension ability: A case study. *Language Teaching Research*, 1–33. https://doi.org/10.1177/13621688251352275

Suradika, A., Dewi, H. I., & Nasution, M. I. (2023). Project-Based Learning and Problem-Based Learning Models in Critical and Creative Students. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 153–167. https://doi.org/10.15294/jpii.v12i1.39713

Tushar, H., & Sooraksa, N. (2023). Global employability skills in the 21st century workplace: A semi-systematic literature review. *Heliyon*, *9*(11), e21023. https://doi.org/10.1016/j.heliyon.2023.e21023

Vafamehr, V., Haghani, F., & Jamshidian, S. (2025). Basic Thinking Skills and Their Direct Instructional Approaches: A Narrative Review. *Advances in Medical Education and Practice*, *17*, 1–23. https://doi.org/10.2147/AMEP.S569680

van Gelder, P., Klaassen, P., Taebi, B., Walhout, B., van Ommen, R., van de Poel, I., Robaey, Z., Asveld, L., Balkenende, R., Hollmann, F., van Kampen, E. J., Khakzad, N., Krebbers, R., de Lange, J., Pieters, W., Terwel, K., Visser, E., van der Werff, T., & Jung, D. (2021). Safe-by-design in engineering: An overview and comparative analysis of engineering disciplines. *International Journal of Environmental Research and Public Health*, *18*(12), 1–28. https://doi.org/10.3390/ijerph18126329

Vlachopoulos, D., & Makri, A. (2024). A systematic literature review on authentic assessment in higher education: Best practices for the development of 21st century skills, and policy considerations. *Studies in Educational Evaluation*, *83*, 101425. https://doi.org/10.1016/j.stueduc.2024.101425

Wijnia, L., Loyens, S. M. M., & Rikers, R. M. J. P. (2019). The Problem‐Based Learning Process: An Overview of Different Models. In *The Wiley Handbook of Problem‐Based Learning* (pp. 273–295). https://doi.org/10.1002/9781119173243.ch12

Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications*, *10*(1), 1–11. https://doi.org/10.1057/s41599-023-01508-1

Yulianti, S., & Herman, T. (2022). Improving Mathematical Critical Thinking Skill through STEM-PjBL: A Systematic Literature Review. *International Journal of Research in STEM Education (IJRSE)*, *4*(2), 1–17. https://doi.org/10.31098/ijrse.v4i2.1141

Zhang, L., & Ma, Y. (2023). A study of the impact of project-based learning on student learning effects: a meta-analysis study. *Frontiers in Psychology*, *14*, 1–14. https://doi.org/10.3389/fpsyg.2023.1202728