



Development and Evaluation of an AI-Integrated Project-Based Learning Model for Technical and Vocational Education

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ABSTRACT

The rapid advancement of Artificial Intelligence (AI) technologies presents significant opportunities for transforming pedagogical approaches in Technical and Vocational Education and Training (TVET). This study describes the systematic development and empirical evaluation of an AI-Integrated Project-Based Learning (AI-PjBL) model designed to enhance technical competency, problem-solving skills, and digital literacy among vocational students. Using an educational design research methodology, the model was developed through iterative cycles of design, implementation, and evaluation. Participants consisted of 120 vocational students across two cohorts. Data were collected through competency assessments, student engagement surveys, and teacher observation rubrics. Results indicate statistically significant improvements in technical skill acquisition ($p < 0.01$), higher-order thinking, and collaborative performance compared to conventional instruction. The findings suggest that the AI-PjBL model offers a viable and scalable framework for modernising TVET curricula and preparing students for Industry 4.0 demands.

1. Introduction

The global landscape of work and industry has undergone profound transformation driven by the Fourth Industrial Revolution (Industry 4.0), characterised by the convergence of digital, physical, and biological systems (Qobus et al., 2024). Central to this transformation is Artificial Intelligence (AI), which is increasingly embedded in manufacturing processes, service delivery, and knowledge production. In response, educational systems worldwide are under mounting pressure to produce graduates who are not only technically proficient but also capable of adaptive, critical, and AI-literate thinking (Zega et al., 2025).

Technical and Vocational Education and Training (TVET) occupies a critical yet often underresourced position in national education systems. Traditionally oriented toward skills transmission and occupational preparation, TVET is now expected to cultivate competencies that align with emerging technological demands. However, many TVET institutions continue to rely on

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didactic, teacher-centred pedagogies that inadequately prepare students for complex, technology-mediated work environments (Sudarsono, 2022).

Project-Based Learning (PjBL) has long been recognised as an effective constructivist pedagogy that engages learners in solving authentic, real-world problems through sustained inquiry and collaborative production (Wahjusaputri et al., 2024) ; (Budiarto, 2023). PjBL aligns well with TVET contexts, where students are expected to apply theoretical knowledge to practical challenges. Despite its promise, traditional PjBL implementation is often constrained by limited resources, inadequate scaffolding, and difficulty providing timely, individualised feedback at scale.

The integration of AI technologies into educational settings including intelligent tutoring systems, adaptive learning platforms, and generative AI tools offers compelling potential to address these constraints. AI can provide personalised feedback, scaffold complex cognitive tasks, track student progress in real time, and simulate authentic professional environments (Habib, Desky, Jalinus, et al., 2026). Nevertheless, systematic models for integrating AI within PjBL for TVET remain scarce in the literature.

This study, therefore, aims to develop and evaluate an AI-Integrated Project-Based Learning (AI-PjBL) model tailored for TVET contexts. The specific objectives are: (1) to design a theoretically grounded AI-PjBL model; (2) to implement the model within vocational education settings; and (3) to evaluate the model's effectiveness in terms of student technical competency, higher-order thinking skills, and engagement.

2. Methodology

2.1 Research Design

This study employed an Educational Design Research (EDR) approach, which integrates theory-driven design with iterative empirical refinement (Desky et al., 2025). EDR is particularly suited to developing innovative educational interventions, as it enables continuous improvement through cycles of analysis, design, implementation, and evaluation. The research unfolded across three phases: (1) preliminary analysis and model conceptualisation; (2) prototype development and expert validation; and (3) empirical implementation and evaluation (Habib, Desky, & Yulastri, 2026).

2.2 Participants

Participants comprised 120 students enrolled in vocational programmes at two government-accredited TVET institutions in Indonesia. Purposive sampling was employed to select sites with comparable infrastructure and student demographics. The control group (n = 60) received conventional project-based instruction without AI integration, while the experimental group (n = 60) participated in the AI-PjBL model. Participants ranged in age from 16 to 18 years, with no prior formal exposure to AI-assisted learning tools. Informed consent was obtained from all participants and institutional approval was secured prior to data collection.

Table 1. Participant Demographics and Group Characteristics

Characteristic	Experimental Group (n=60)	Control Group (n=60)
Age Range	16–18 years	16–18 years
Institution Type	Government-accredited TVET	Government-accredited TVET
Prior AI Tool Exposure	None	None
Sampling Method	Purposive	Purposive
Instruction Type	AI-PjBL Model	Conventional PjBL

2.3 Development of the AI-PjBL Model

The AI-PjBL model was developed through an iterative design process informed by the following theoretical foundations: (a) constructivist learning theory (Vygotsky, 1978), emphasising the role of social interaction and scaffolding; (b) the PjBL framework proposed by the Buck Institute for Education (Habib et al., 2023); (Risna et al., 2026), which integrates technological, pedagogical, and content knowledge.

The model comprises six sequential phases: (1) Driving Question and AI Orientation, in which students are introduced to authentic project challenges and AI tools available for inquiry; (2) AI-Assisted Inquiry, where students use intelligent search tools and generative AI for background research; (3) Collaborative Design and Planning, involving peer negotiation of project goals and AI-supported task allocation; (4) AI-Augmented Production, in which students execute project work with real-time AI feedback and simulation; (5) Critical Evaluation, where students assess AI-generated outputs and reflect on ethical dimensions; and (6) Presentation and Digital Showcase, involving multimodal presentation of project outcomes.

The prototype model underwent expert validation by a panel of five specialists in educational technology, vocational pedagogy, and AI systems. Expert feedback was synthesised using a content validity ratio (CVR) analysis, and revisions were incorporated prior to classroom implementation.

2.4 Instruments

Three instruments were employed to collect data. First, a Technical Competency Assessment (TCA) was developed to measure domain-specific skills aligned with national TVET competency standards. The TCA comprised 40 items combining multiple-choice, practical scenario, and performance-based tasks, with a Cronbach's alpha reliability coefficient of 0.87. Second, a Higher-Order Thinking Skills (HOTS) Rubric assessed students' abilities in analysis, evaluation, and creation as defined by Bloom's revised taxonomy (Mardiana et al., 2026). Third, a Student Engagement and Attitude Survey (SEAS) utilising a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) measured affective engagement, motivation, and perceived relevance of AI tools. Pre- and post-test administrations of the TCA enabled comparative analysis between groups.

2.5 Data Analysis

Quantitative data were analysed using IBM SPSS Statistics Version 27. An independent samples t-test was used to compare post-test TCA scores between the experimental and control groups, following confirmation of normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test). Effect size was calculated using Cohen's *d*. Analysis of Covariance (ANCOVA) was applied to control for pre-test differences. Descriptive statistics were used to summarise SEAS responses. Qualitative data from open-ended survey items and teacher observation notes were analysed thematically (Vaesar et al., 2026).

3. Results

3.1 Expert Validation of the AI-PjBL Model

Expert validation yielded a mean CVR score of 0.92 across all model components, exceeding the minimum acceptable threshold of 0.62 for a five-expert panel (Masdarini et al., 2024). Experts rated the model's theoretical coherence, instructional clarity, and technological integration as highly appropriate. Minor revisions were recommended regarding the sequencing of the AI-Augmented Production phase and the explicitness of AI ethics content within the Critical Evaluation phase. These revisions were incorporated prior to pilot implementation (Sudianti et al., 2025).

Table 2. Expert Validation CVR Scores by AI-PjBL Model Component

Model Component	CVR Score	Status
Driving Question & AI Orientation	0.96	Accepted
AI-Assisted Inquiry	0.92	Accepted
Collaborative Design & Planning	0.92	Accepted
AI-Augmented Production	0.88	Revised & Accepted
Critical Evaluation	0.92	Revised & Accepted
Presentation & Digital Showcase	0.96	Accepted
Overall Mean CVR	0.92	Exceeds Threshold (0.62)

Note. CVR = Content Validity Ratio. Minimum acceptable CVR for 5-expert panel = 0.62 (Lawshe, 1975).

3.2. Technical Competency Assessment Outcomes

Table 3. Competency Assessment

Measure	Experimental Group (n=60)	Control Group (n=60)
Pre-test Mean ± SD	58.3 ± 7.4	57.9 ± 7.1
Post-test Mean ± SD	81.6 ± 6.2	70.4 ± 7.8
Pre-test Comparison	t(118) = 0.29, p = .77	No significant difference
Post-test Comparison	t(118) = 8.74, p < .001	Significant difference
Effect Size (Cohen's d)	1.60	Large Effect
ANCOVA Result	F(1,117) = 76.43, p < .001, η ² = .395	Significant

These results suggest that AI-integrated scaffolding substantially enhanced students' acquisition of domain-specific technical competencies. The intelligent feedback mechanisms embedded within the AI tools enabled students to identify and correct technical errors in real time, reducing the latency between performance and corrective input that characterises conventional instruction (Ningsih et al., 2025).

3.3 . Higher-Order Thinking Skills

HOTS rubric scores similarly favoured the experimental group (M = 78.4, SD = 8.1) over the control group (M = 64.7, SD = 9.3), t(118) = 8.22, p < .001, Cohen's d = 1.50. Notably, experimental group students demonstrated markedly stronger performance on the Evaluation subscale (M = 79.1 vs. M = 62.3), which assessed students' capacity to critically assess AI-generated content for accuracy, bias, and relevance. This finding aligns with emerging literature on AI literacy, which emphasises that meaningful learning with AI requires critical interrogation rather than passive consumption (Deviana et al., 2025).

Table 4. Higher-Order Thinking Skills (HOTS) Rubric Results by Subscale

HOTS Subscale	Exp. Group (M ± SD)	Ctrl Group (M ± SD)	Cohen's d
Analysis	76.8 ± 8.4	65.1 ± 9.8	1.29
Evaluation	79.1 ± 7.9	62.3 ± 9.5	1.88
Creation	79.3 ± 8.2	66.7 ± 8.6	1.49
Overall HOTS	78.4 ± 8.1	64.7 ± 9.3	1.50 (Large)

Note. All between-group differences significant at p < .001. Scores are out of 100.

Thematic analysis of teacher observations identified three recurring patterns in the experimental group: (1) students engaged in spontaneous peer discussion about the reliability and limitations of AI outputs; (2) students exhibited iterative revision behaviours, using AI suggestions as starting points rather than final answers; and (3) students increasingly asked contextual 'why' questions, indicative of deeper conceptual engagement (Irfan et al., 2025).

3.4 Student Engagement and Attitudes

SEAS results revealed high levels of engagement and positive attitudes among experimental group students. Mean agreement scores were highest for items relating to perceived relevance ($M = 4.52$, $SD = 0.61$), AI usefulness for learning ($M = 4.48$, $SD = 0.59$), and motivation to complete project tasks ($M = 4.39$, $SD = 0.67$). Responses to the open-ended items highlighted that students valued the immediacy of AI feedback, the ability to explore ideas without fear of peer judgement, and the perceived authenticity of AI-assisted project scenarios.

Table 5. Student Engagement and Attitude Survey (SEAS) Descriptive Statistics

Survey Item	Mean (M)	SD
Perceived relevance of AI tools to my learning	4.52	0.61
AI tools were useful for completing project tasks	4.48	0.59
Motivation to complete project tasks	4.39	0.67
AI feedback was timely and helpful	4.35	0.72
I felt confident using AI tools during the project	4.21	0.84
Initial anxiety about using AI tools (18% of students)	2.41	1.10

Note. Scores based on 5-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). $n = 60$ (experimental group).

Conversely, a subset of students (approximately 18%) expressed initial anxiety regarding AI tool usage, citing concerns about accuracy and uncertainty about appropriate reliance on AI assistance. This finding underscores the importance of explicit AI literacy instruction within the model's orientation phase to manage student expectations and build metacognitive awareness.

4. Conclusions

The findings of this study provide robust empirical support for the effectiveness of the AI-PjBL model in enhancing technical competency and higher-order thinking within TVET contexts. The large effect sizes observed across both outcome measures suggest that AI integration within a structured PjBL framework confers substantial learning advantages beyond what conventional project-based instruction alone can achieve.

These results are consistent with and extend prior research on AI-enhanced learning. (Habib et al., 2025) identified personalised feedback and adaptive scaffolding as the most consistently effective AI applications in higher education. The present study corroborates this finding in a TVET context, demonstrating that real-time AI feedback during project production phases addresses a longstanding limitation of PjBL — the inability of teachers to provide individualised, timely feedback to all students simultaneously in complex, project-rich environments (Fiona et al., 2025).

The strength of the HOTS evaluation subscale findings is particularly noteworthy. A persistent concern in AI-assisted education is that AI tools may diminish cognitive effort by providing 'ready-made' answers, thereby undermining deep learning (Ermawalis et al., 2025). The present model explicitly counteracts this tendency through the Critical Evaluation phase, which requires students to analyse, interrogate, and justify or reject AI outputs. This pedagogical design decision appears instrumental in promoting critical AI literacy alongside technical skill development — a dual outcome increasingly demanded by Industry 4.0 employers (Taali et al., 2024).

The initial student anxiety around AI tools, while observed in a minority of participants, merits pedagogical attention. Research on technology adoption in education highlights that perceived usability and self-efficacy are significant predictors of effective technology integration (Habib et al., 2025). Future iterations of the AI-PjBL model should incorporate structured orientation activities, including peer-mediated AI exploration and reflective journaling, to build AI self-efficacy prior to project engagement.

From a systemic perspective, the AI-PjBL model's structured six-phase design offers TVET institutions a replicable and scalable implementation framework. Unlike ad hoc AI integration approaches that rely on individual teacher initiative, the model provides clear instructional sequences, assessment criteria, and teacher facilitation guidelines that can be embedded within existing curriculum frameworks. This structural coherence addresses a key barrier to sustainable educational technology adoption identified in the literature: the absence of institutional-level implementation support (Habib, Desky, & Yulastri, 2026).

Several limitations of the present study warrant acknowledgement. First, the 12-week implementation period may not fully capture the longitudinal effects of the AI-PjBL model on deep learning and skill retention. Longitudinal follow-up studies are recommended. Second, the study was conducted in Indonesian TVET institutions, and the generalisability of findings to other national contexts with different technological infrastructure and pedagogical traditions requires further investigation. Third, the reliance on researcher-developed instruments, while validated, introduces potential measurement bias that independent instrument validation would mitigate.

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