

Effects of Project-Based Learning (PjBL) Model on Learning Outcomes in Electrical Engineering Drawing

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Received: June 24, 2026

Revised: August 19, 2026

Accepted: August 27, 2026

Published: August 31, 2026

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DOI: [10.29303/jppipa.v12i8.15830](https://doi.org/10.29303/jppipa.v12i8.15830)

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Abstract: This study aims to investigate the effect of implementing the Project-Based Learning (PjBL) model assisted by the ProfiCAD application on cognitive, psychomotor, and affective learning outcomes in Electrical Technical Drawing among Class X TITL students at SMK Negeri 8 Palembang. A quantitative quasi-experimental design with a nonequivalent control group was employed. The sample consisted of 72 students, with 36 students in the experimental group receiving PjBL assisted by ProfiCAD and 36 students in the control group receiving conventional instruction. The instruments comprised a 20-item cognitive test, a nine-item psychomotor observation sheet, and affective instruments consisting of five teacher-observation items and 15 self-assessment items. The instruments were developed based on the TVET competency framework and validated using the Content Validity Ratio (CVR), with CVR = 1.00 across all domains. Rasch analysis confirmed acceptable reliability, with Person Reliability = 0.82 and Item Reliability = 0.76. Data were analyzed using the Shapiro-Wilk normality test, Levene's homogeneity test, paired-sample t-test, independent-sample t-test, and N-Gain analysis. Results showed that the experimental group achieved a significantly higher mean posttest score than the control group (mean difference = 31.667; $t = 13.079$; $p < 0.001$), with an N-Gain of 0.72 (high category), compared with 0.28 (low category) in the control group. The highest cognitive gain occurred in the Technique domain (N-Gain = 0.788). Psychomotor outcomes reached the very skilled category, particularly in technology application (81%) and data processing (80%). Affective outcomes demonstrated very good interpersonal and teamwork abilities (81%), while safety concern achieved the highest score (82%). These findings indicate that PjBL assisted by ProfiCAD effectively enhances cognitive, psychomotor, and affective learning outcomes and supports the development of industry-ready competencies in vocational electrical engineering education aligned with TVET principles.

Keywords: Electrical engineering drawing; Learning outcomes; Project-based learning; SMKN 8 Palembang; Vocational education

Introduction

The rapid advancement of digital technology has fundamentally transformed electrical engineering practices, particularly in the design, simulation, and documentation of electrical systems. Tasks that were traditionally performed manually using paper and pencil are increasingly being replaced by Electrical Computer-Aided Design (E-CAD) applications that enable more precise, efficient, editable, and shareable

technical documentation (Ricaurte & Vilorio, 2020). This transformation is closely associated with the demands of Industry 4.0, which require vocational graduates to possess not only theoretical knowledge but also practical competence in using industry-relevant digital technologies (Rizka & K, 2019). Therefore, electrical vocational education needs to continuously adapt its learning practices so that students can develop technical competencies that correspond to the digitalization of

How to Cite:

Pebrianti, L., Giatman, M., Sukardi, S., Elfizon, E., & Deskry, A. H. A. (2026). Effects of Project-Based Learning (PjBL) Model on Learning Outcomes in Electrical Engineering Drawing. *Jurnal Penelitian Pendidikan IPA*, 12(8), 278–288. <https://doi.org/10.29303/jppipa.v12i8.15830>

contemporary electrical engineering workplaces (Desky et al., 2026).

Electrical Technical Drawing is a fundamental competency in the Electrical Installation Engineering (TITL) program at Vocational High Schools (SMK), because it serves as a technical communication medium among designers, technicians, and field workers. Students are expected to accurately interpret and produce electrical symbols, wiring diagrams, installation layouts, and circuit schematics. Errors in symbol selection, circuit connectivity, or drawing layout can result in incorrect installations and potentially create serious safety risks (Prasetya et al., 2024). Consequently, learning Electrical Technical Drawing should not be limited to the ability to reproduce examples provided by teachers but should develop students' ability to design, analyze, revise, and evaluate electrical drawings using digital tools that reflect authentic industry practices. This requirement makes the integration of appropriate digital design applications into vocational learning increasingly important (Desky et al., 2025b).

From the perspective of Technical and Vocational Education and Training (TVET), vocational competence is multidimensional and extends beyond cognitive knowledge. Effective vocational learning should integrate technical skills, generic Industry 4.0 competencies, and career adaptability. These competencies include systematic work processes, appropriate technology application, problem-solving, communication, teamwork, ICT competence, safety awareness, curiosity, self-control, and confidence (Purnomo & Nuryanto, 2021). However, conventional demonstration-based instruction tends to position students as passive recipients who primarily observe and reproduce teacher demonstrations. Such an approach provides limited opportunities for students to independently solve authentic technical problems, make design decisions, collaborate, and evaluate the quality and safety of their work. Consequently, a pedagogical approach that simultaneously develops cognitive, psychomotor, and affective competencies is required to better reflect the competency demands of contemporary TVET (Putra et al., 2024).

This issue is particularly relevant at SMK Negeri 8 Palembang, where preliminary student perception data indicated substantial difficulties in Electrical Technical Drawing. Approximately 81% of students reported difficulty understanding and correctly applying electrical symbols, while 87% experienced difficulties in systematically constructing electrical installation diagrams using digital software. Furthermore, the use of ProfiCAD in the learning process has remained largely limited to introducing basic software features rather than facilitating authentic electrical design projects (Desky & Yulastri, 2026). This condition reveals a critical

gap between students' exposure to digital drawing technology and their ability to apply that technology to complete authentic electrical design tasks. More importantly, the existing learning process has not adequately connected software proficiency with the development of broader vocational competencies. This gap provides a strong rationale for developing a learning intervention that integrates digital technology, authentic projects, and multidimensional competency assessment (Zhang & Ma, 2023).

Project-Based Learning (PjBL) provides a theoretically and pedagogically appropriate approach to addressing this problem because it positions students as active participants in solving authentic and complex problems through structured project activities (Vaesar et al., 2026). In vocational education, PjBL can reproduce important elements of professional practice by requiring students to identify technical requirements, plan solutions, select appropriate components and symbols, construct electrical drawings, evaluate their outputs, and revise their work based on technical criteria. However, the effectiveness of PjBL depends substantially on the technological environment in which projects are implemented. PjBL without an authentic digital design environment may still restrict students to simplified drawing exercises. Therefore, integrating PjBL with an electrical-specific E-CAD application such as ProfiCAD offers an opportunity to connect pedagogical innovation with authentic technological practice (Sari et al., 2026).

ProfiCAD is specifically designed for developing electrical diagrams, wiring schematics, installation plans, and other forms of electrical documentation. Its electrical symbol library, wiring functions, and relatively simple interface make it suitable for introductory vocational learners while maintaining a workflow that resembles professional electrical design practices. Unlike more complex general-purpose CAD applications, ProfiCAD can provide students with a focused digital environment in which technical drawing concepts can be directly applied to authentic electrical design projects. Nevertheless, previous studies have generally examined either PjBL as a pedagogical model or digital drawing software as a learning tool, while limited attention has been given to their systematic integration for Electrical Technical Drawing at the vocational high school level. In addition, previous investigations have not sufficiently examined the simultaneous effects of such integration on cognitive, psychomotor, and affective learning outcomes within a TVET competency framework.

Accordingly, the novelty of this study lies in the integration of ProfiCAD-assisted Project-Based Learning as an authentic digital vocational learning environment and in the simultaneous evaluation of its effects across

cognitive, psychomotor, and affective competency domains. Rather than treating ProfiCAD merely as a software demonstration tool, this study positions the application as an integral technological scaffold within a project-based learning process that mirrors the workflow of electrical design professionals. The study is therefore important because it addresses the gap between students' knowledge of electrical drawing concepts, their practical ability to produce accurate digital designs, and their development of vocational attitudes such as safety awareness, teamwork, and

responsibility. By examining these outcomes simultaneously, this research provides empirical evidence regarding how technology-supported PjBL can strengthen industry-aligned competencies in Electrical Technical Drawing. The findings are expected to contribute both theoretically to the development of technology-integrated TVET pedagogy and practically to the design of more authentic, competency-oriented learning practices for vocational electrical engineering education (Arwizet et al., 2026).

Table 1. Comparison of ProfiCAD and AutoCAD electrical

Aspect	ProfiCAD	AutoCAD Electrical
Application focus	Specialized electrical & electronic diagrams	General CAD with electrical modules
Complexity level	Simple, easy to learn for beginners	Complex, requires extended professional training
Symbol library	Ready-to-use standard IEC electrical symbols	Available but more complex to navigate
Hardware requirements	Low runs on standard school computers	High requires specification hardware
Suitability for Class X	Highly suitable graduated complexity	Too challenging for entry-level learners
Usage orientation	Learning, understanding circuit logic, project design	Advanced professional practice & detailing
Learning curve	Short 1-2 sessions for basic proficiency	Long weeks of dedicated training required

The integration of Project-Based Learning (PjBL) with ProfiCAD addresses several important gaps in the existing vocational education literature. Although numerous studies have consistently reported the effectiveness of PjBL in improving students’ learning outcomes, engagement, and problem-solving skills in vocational education settings, limited attention has been given to its application in Electrical Technical Drawing courses using industry-relevant digital design software such as ProfiCAD. Most previous studies have focused on general vocational subjects or electrical installation courses, leaving the pedagogical potential of ProfiCAD-assisted PjBL largely unexplored. Furthermore, prior research has predominantly evaluated learning effectiveness based on cognitive achievement, while neglecting psychomotor competencies and affective attributes that constitute essential learning outcomes within the Technical and Vocational Education and Training (TVET) framework (Risna et al., 2026).

Consequently, empirical evidence regarding the simultaneous impact of PjBL and ProfiCAD on the three domains of learning remains insufficient. This study seeks to fill this gap by examining the effects of ProfiCAD-assisted PjBL on cognitive, psychomotor, and affective learning outcomes among Grade X Electrical Power Installation Engineering (TITL) students at SMK Negeri 8 Palembang. The findings are expected to contribute to the advancement of technology-enhanced vocational pedagogy and provide evidence-based recommendations for improving electrical technical drawing instruction in vocational secondary education.

Method

Research Design

This study employed a quantitative approach using a quasi-experimental method with a Nonequivalent Control Group Design (Sudianti et al., 2025). The design was selected because the participants were drawn from intact classes that had been administratively established by the school, making random assignment impractical. Two classes with comparable academic characteristics were selected, with one serving as the experimental group and the other as the control group. Prior to the intervention, both groups were administered a pretest to assess their initial competencies in Electrical Technical Drawing and to establish baseline equivalence. The experimental group received instruction through Project-Based Learning (PjBL) integrated with ProfiCAD software, whereas the control group was taught using conventional teaching methods consisting of lectures and demonstrations. The intervention was implemented throughout the instructional period in accordance with the approved lesson plans and learning objectives (Desky et al., 2025a).

Following the completion of the intervention, both groups were administered a posttest to measure cognitive learning achievement. In addition, psychomotor competencies were assessed through project performance evaluations, while affective competencies were measured using structured observation sheets. The collected data were analyzed to determine differences in learning outcomes between the experimental and control groups and to evaluate the

effectiveness of integrating PjBL with ProfiCAD in enhancing students' competencies. By simultaneously examining cognitive, psychomotor, and affective domains, this study provides a more comprehensive evaluation of learning effectiveness within the Technical and Vocational Education and Training (TVET) framework. Figure 1 illustrates the Nonequivalent Control Group Design employed in this study, where both groups completed a pretest before instruction and a posttest after the intervention, enabling a comparative assessment of the impact of PjBL assisted by ProfiCAD on students' learning outcomes.



Figure 1. Quasi-experimental pretest-posttest control group design research

The study was conducted during the even semester of academic year 2025/2026 (January–June 2026) at SMK Negeri 8 Palembang. The population comprised all students enrolled in the TITL (Electrical Installation Engineering) concentration. Using purposive sampling based on class equivalence in academic background and teacher assignment, two intact classes were selected: Class X TITL 1 ($n = 36$) as the experimental group and Class X TITL 2 ($n = 36$) as the control group, yielding a total sample of 72 participants.

Implementation of Learning Treatment

The experimental group received systematic PjBL instruction based on the Lucas et al. (2012) vocational pedagogy framework, integrated with ProfiCAD as the primary design medium. The PjBL implementation was structured across six sequential stages. In Stage 1 (Essential Questions), contextual triggering questions were presented to activate prior knowledge regarding electrical installation standards and practical workplace requirements. In Stage 2 (Design a Plan), students developed individual project blueprints specifying circuit components, symbol selections, and wiring logic for assigned electrical installation scenarios. In Stage 3 (Create a Schedule), project timelines and task responsibilities were established. In Stage 4 (Monitor the Project), the teacher provided guided scaffolding as students executed their ProfiCAD diagrams, offering technical feedback on symbol accuracy, wiring correctness, and layout organization. In Stage 5 (Assess the Outcome), students presented completed diagrams and received peer and teacher evaluation against

professional criteria. In Stage 6 (Evaluate the Experience), reflective discussion consolidated learning and identified areas for improvement. Project scenarios included residential lighting installation diagrams, single-phase distribution panel schematics, and motor control circuit wiring (Fattah & Islami, 2024).

The control group received conventional lecture and demonstration-based instruction on identical content. The teacher delivered direct explanations of electrical symbols and circuit logic, demonstrated ProfiCAD features through projected examples, and assigned individual replication exercises. Students in the control group did not engage in self-directed project planning, collaborative design, or reflective evaluation components (Deviana et al., 2025).

Research Instruments

Three categories of instruments were employed, all developed based on the TVET competency domains established by Irfan et al. (2025). The cognitive test comprised 20 multiple-choice items (five options each) distributed across five TVET domains: mastery of work methods Method (4 items: planning electrical installation work), understanding of work processes Process (4 items: identifying sequential work steps), correct use of techniques and tools Technique (4 items: analyzing component functions and symbol application), problem-solving ability (4 items: diagnosing and resolving electrical diagram problems), and ICT competence ProfiCAD technical knowledge (4 items: explaining ProfiCAD features and digital drawing workflows). Scoring used a dichotomous scale (correct = 1, incorrect = 0).

Table 2. Cognitive instrument grid based on TVET framework

TVET Domain	Aspect	Learning Indicator
Technical Skills	Method	Planning electrical installation work steps
	Process	Identifying sequential installation procedures
	Technique	Analyzing symbol functions and component selection
Generic IR 4.0 Skills	Problem Solving	Diagnosing and resolving circuit diagram issues
	ICT Competence	Applying ProfiCAD features for digital drawing

Content validity was assessed using the Content Validity Ratio (CVR) formula by Lawshe (1975), with five expert validators: two university lecturers in electrical engineering education, one vocational training specialist (Widyaiswara) from BBLK Medan, and two TITL subject teachers. All 20 items yielded $CVR = 1.00$ (Very Valid), confirming the instrument's content alignment. Item quality was further evaluated using

Rasch Analysis via Ministeps software, with acceptable infit and outfit MNSQ range of 0.6–1.4. All items met this criterion, with infit MNSQ ranging from 0.77 to 1.27 and outfit MNSQ from 0.75 to 1.31. Instrument reliability was confirmed by Person Reliability = 0.82 and Item Reliability = 0.76, both indicating acceptable internal consistency.

The psychomotor observation sheet comprised 9 items across two TVET Generic IR 4.0 Skills domains: technology application skills (4 items: symbol use, wiring connections, layout management, producing project-aligned diagrams) and data processing ability (5 items: component insertion, layout arrangement, diagram editing, data conversion to complete diagrams, and file management). The instrument used a five-point Likert scale (1 = Very Poor to 5 = Excellent). Expert validation produced CVR = 1.00 for all items, and Cronbach's Alpha = 0.912, indicating very high internal consistency.

The affective instruments comprised two components. The teacher observation sheet (5 items on a 5-point Likert scale) covered: interpersonal ability, teamwork skills, communication ability, and confidence (2 items). CVR = 1.00 for all items; Cronbach's Alpha = 0.765 (reliable). The student self-assessment questionnaire (15 items) covered five TVET Career Adaptability and Generic IR 4.0 domains: leadership ability (3 items), emotional intelligence and self-awareness (3 items), concern (3 items), curiosity (3 items), and self-control (3 items). CVR = 1.00 for all domains; Cronbach's Alpha = 0.953 (very high reliability).

Table 3. Summary of instrument validity and reliability

Instrument	CVR	Reliability	Category
Cognitive Test (Multiple Choice)	1.00	Person: 0.82 / Item: 0.76 (Rasch)	Acceptable
Psychomotor Observation Sheet	1.00	$\alpha = 0.912$	Very High
Teacher Observation (Affective)	1.00	$\alpha = 0.765$	Reliable
Self-Assessment Questionnaire	1.00	$\alpha = 0.953$	Very High

Data Analysis Procedures

Cognitive data analysis followed a sequential procedure. First, normality was assessed using the Shapiro-Wilk test, appropriate for samples with $n < 50$ per group, with the decision criterion Sig. > 0.05 indicating normal distribution. Second, homogeneity of variance was assessed using Levene's Test, with Sig. > 0.05 indicating homogeneous variances between groups. Third, within-group improvements were analyzed using paired sample t-test comparing pretest and posttest scores within each class. Fourth, between-group differences were analyzed using independent sample t-

test on posttest data, with H_0 rejected when Sig. < 0.05. Fifth, the magnitude of learning improvement was quantified using N-Gain analysis: $N\text{-Gain} = (\text{Posttest} - \text{Pretest}) / (\text{Maximum Score} - \text{Pretest})$. Interpretation categories: ≥ 0.70 = High; 0.30–0.69 = Medium; < 0.30 = Low.

Psychomotor and affective non-test data were analyzed descriptively using percentage score calculation: $\text{Percentage} = (\text{Total Score} / \text{Maximum Score}) \times 100\%$. Results were interpreted using a five-category criterion: 81–100% = Very Skilled/Very Good; 61–80% = Skilled/Good; 41–60% = Sufficient; 21–40% = Insufficient; 0–20% = Very Insufficient. All statistical computations were performed using IBM SPSS Statistics version 26.

Result and Discussion

Prerequisite Tests

Prior to hypothesis testing, normality and homogeneity assumptions were verified. The Shapiro-Wilk test results (Table 4) showed that all significance values exceeded 0.05 across both groups and both testing phases, confirming that the data were normally distributed and that parametric statistical tests were appropriate.

Table 4. Normality test results (Shapiro-Wilk)

Class	Data	Statistic	df	Sig.	Description
Control	Pretest	0.964	36	0.293	Normal
	Posttest	0.976	36	0.604	Normal
Experimental	Pretest	0.969	36	0.397	Normal
	Posttest	0.948	36	0.093	Normal

Source: SPSS Analysis Output (2026)

Table 5. Homogeneity test results (Levene's test)

Variable	Levene Statistic	df1	df2	Sig. & Decision
Pre-test	3.518	1	70	0.065 → Homogeneous
Post-test	7.052	1	70	0.012 → Not Homogeneous

Source: SPSS Analysis Output (2026)

Levene's homogeneity test (Table 5) revealed that pretest data were homogeneous (sig. = 0.065 > 0.05), while posttest data were not homogeneous (sig. = 0.012 < 0.05). The non-homogeneity of posttest variance was expected given the substantially different learning approaches applied to both groups. The t-test analysis remained valid because both groups had equal sample sizes ($n = 36$ each), a condition under which t-test is robust to violations of homogeneity assumptions.

Pretest Comparison

Table 6 presents the initial learning process indicators of the control and experimental groups prior

to the intervention. The results indicate that both groups exhibited relatively similar baseline characteristics across most indicators. The method indicator showed an identical score of 55% in both groups, while the technique and problem-solving indicators also demonstrated comparable values. Slight differences were observed in the process indicator, where the experimental group scored 54% compared to 45% in the control group. Meanwhile, ICT competence remained relatively low in both groups, with scores of 16% and 12%, respectively. These findings suggest that the two groups had comparable initial conditions before the implementation of the learning treatment.

Table 6. Pretest score comparison by TVET domain (%)

Learning Indicator	Control Group (%)	Experimental Group (%)
Method	55	5
Process	45	5
Technique	34	3
Problem Solving	24	2
ICT Competence	16	1

Source: Primary Data (2026)

Paired Sample t-Test

The paired sample t-test (Table 7) confirmed significant within-group improvements in both classes following their respective instructional treatments. The experimental group demonstrated a substantially greater mean improvement (46.528 points) compared to the control group (15.833 points), indicating that the PjBL-ProfiCAD integration produced nearly three times the within-group learning gain compared to conventional instruction. Both groups showed statistical significance at $p < 0.001$, indicating meaningful improvement under both conditions, though the magnitude difference is striking.

Table 7. Paired sample t-test results

Paired Comparison	Mean Diff.	Std. Dev.	t-value	Sig. (2-tailed)
Posttest-Pretest: Control Group	15.833	8.062	11.783	0.0001
Posttest-Pretest: Experimental Group	46.528	10.611	26.308	0.0001

Source: SPSS Analysis Output (2026)

Independent Sample t-Test and Between-Group Comparison

The independent sample t-test on posttest data (Table 8) confirmed a highly significant difference between both groups. The obtained t-value of -13.079 with a significance of $p = 3.04 \times 10^{-19}$ (far below the $\alpha = 0.05$ threshold) and a mean difference of -31.667 points in favor of the experimental group resulted in rejection of H_0 and acceptance of H_1 . This finding constitutes strong statistical evidence that PjBL assisted by

ProfiCAD produces significantly superior cognitive learning outcomes compared to conventional lecture-demonstration instruction.

Table 8. Independent sample t-test results on posttest data

Group Comparison	t-value	df	Sig. (2-tailed)	Mean Diff.
Experimental vs. Control (Posttest)	-13.079	70	3.04×10^{-19} (< 0.001)	-31.667

Source: SPSS Analysis Output (2026)

Presents the posttest score comparison across all five TVET domains, revealing substantially superior experimental group performance: Method (89% vs. 77%), Process (88% vs. 70%), Technique (86% vs. 47%), Problem Solving (74% vs. 37%), and ICT Competence (75% vs. 22%). The most dramatic performance gap appeared in the Technique domain (39 percentage points), which directly measures the ability to correctly select and apply tools, symbols, and materials. This domain most closely reflects ProfiCAD competence, highlighting the application software's critical contribution to technical drawing proficiency.

Table 9. Posttest score comparison by TVET domain (%)

Learning Indicator	Control Group (%)	Experimental Group (%)	Difference (Points)
Method	77	89	1
Process	70	88	1
Technique	47	86	3
Problem Solving	37	74	3
ICT Competence	22	75	5

N-Gain Analysis

N-Gain analysis (Table 10) provides the most comprehensive picture of differential learning improvement. The experimental group's overall N-Gain of 0.72 (high category) contrasts sharply with the control group's 0.279 (low category). All five TVET domains in the experimental group achieved the high category (≥ 0.70), except Problem Solving (0.606, medium category), indicating near-uniform advancement across all competency areas. In contrast, the control group achieved high-category gains in none of the domains, with Method (0.489) and Process (0.455) reaching medium category, and Technique (0.197), Problem Solving (0.182), and ICT competence (0.071) remaining in the low category.

The Technique domain's highest N-Gain (0.788) in the experimental group is particularly noteworthy. This domain assesses correct selection and application of tools, symbols, and materials – the precise intersection of technical knowledge and hands-on ProfiCAD proficiency. The control group's Technique N-Gain of

only 0.197 (low category) starkly illustrates the inadequacy of demonstration-only instruction for developing this level of technical competence. Similarly, the ICT competence domain showed a dramatic gap (Experimental: 0.716 vs. Control: 0.071), indicating that ProfiCAD's systematic integration in PjBL project cycles effectively developed digital tool mastery that passive observation alone cannot cultivate.

Table 10. N-Gain analysis results by TVET competency domain

Competency Domain	Control Group	Experimental Group	Category
Method	0.489	0.756	High
Process	0.455	0.739	High
Technique	0.197	0.788	High
Problem Solving	0.182	0.606	Medium
ICT Competence	0.071	0.716	High
Mean N-Gain	0.279	0.720	High

These cognitive findings align with Fiona et al. (2025), who found PjBL significantly more effective than conventional methods in electrical installation courses at SMK (Ermawalis et al., 2025), who confirmed PjBL's superiority for Electrical Power Installation at SMK Negeri 5 Makassar; and with Fiktoyana et al. (2018), who demonstrated PjBL's effectiveness across diverse vocational competency domains. The theoretical grounding in constructivism is clear: PjBL's authentic project context enabled students to build genuine conceptual understanding through active knowledge construction, rather than passive reception of teacher demonstrations (Taali et al., 2024).

The Rasch Model analysis of the cognitive instrument provided additional quality evidence. The Person Reliability of 0.82 indicates that the instrument is able to consistently distinguish between students of different ability levels – a critical requirement for pre-post measurement validity. The Item Reliability of 0.76 confirms that the item set would yield stable difficulty estimates if administered to different student samples from the same population. Together, these reliability indices confirm that the observed N-Gain differences are attributable to actual learning differences between the two instructional conditions, rather than to measurement inconsistency (Desky et al., 2026).

Psychomotor Learning Outcomes

Psychomotor skill assessment was administered exclusively to the experimental group through systematic teacher observation during live PjBL project activities using ProfiCAD. Results across both TVET Generic IR 4.0 Skill domains are presented in Table 11.

Table 11. Psychomotor skill assessment results (experimental group)

TVET Competency Aspect (IR 4.0 Generic Skills)	Score (%)	Category
Technology Application Skills	81	Very Skilled
Data Processing Ability	80	Skilled
Overall Mean	80.5	Very Skilled / Skilled

The technology application skills domain (81%, very skilled) assessed four specific competencies directly reflecting ProfiCAD's project-based application: accurate use of IEC-standard electrical symbols from ProfiCAD's library; correct wiring of component connections and installation paths; systematic layout management including layer settings, text labeling, and diagram structuring; and production of complete installation diagrams consistent with the assigned project specifications. The very skilled rating indicates that PjBL's structured project cycle – from planning through evaluation – effectively scaffolded the development of these technical drawing competencies to near-professional levels.

The data processing ability domain (80%, skilled) assessed five competencies: inserting symbols and components into ProfiCAD diagrams; organizing and positioning elements according to architectural floor plans; editing and correcting errors in digital diagrams; converting design plans into complete, coherent installation diagrams; and correctly saving, naming, and managing project files. The near-equivalent scores between technology application (81%) and data processing (80%) indicate balanced psychomotor development, suggesting that the PjBL framework successfully cultivated both the motor precision of software operation and the cognitive-procedural competence of data management simultaneously.

These results are consistent with Desky et al. (2026), who reported that PjBL significantly improves both technical and non-technical skills through project-oriented activities that simulate real workplace processes. Martini et al. (2024) similarly confirmed that PjBL in TVET bridges the theory-practice gap and prepares students for industrial requirements. The minor gap between the two domains likely reflects individual variation in prior ICT exposure, consistent with Prasetya et al. (2024), who noted that PjBL implementation may encounter challenges related to differential student technology backgrounds.

Affective Learning Outcomes

Affective outcomes were measured through two complementary instruments providing triangulated assessment of students' dispositional development during PjBL project activities. Teacher observations captured externally observable professional behaviors,

while the self-assessment questionnaire captured students' own metacognitive evaluation of their growth.

Table 12. Teacher observation results affective domain

TVET Affective Aspect	Score (%)	Category
Interpersonal Ability	81	Very Good
Teamwork Skills	81	Very Good
Communication Ability	79	Good
Confidence	79	Good
Overall Mean	80	Good – Very Good

Teacher observation results (Table 12) demonstrated that interpersonal ability and teamwork skills achieved the highest scores (81%, very good), both exceeding the 80% threshold into the very good category. Communication ability and confidence scored 79% (good category). The strong interpersonal and teamwork performance directly reflects PjBL's collaborative project structure, in which students must negotiate responsibilities, coordinate design decisions, and provide peer feedback throughout the project cycle. These activities are among the most powerful mechanisms for developing professional workplace behaviors in vocational learners (Desky et al., 2025b).

Table 13. Student self-assessment results affective domain

TVET Affective Aspect	Score (%)	Category
Leadership Ability	80	Good
Emotional Intelligence & Self-Awareness	79	Good
Concern	82	Very Good
Curiosity	80	Good
Self-Control / Control (Control)	80	Good
Overall Mean	80.2	Good – Very Good

Self-assessment results (Table 13) corroborated teacher observations, with the Concern (kepedulian) dimension achieving the highest score (82%, very good). This dimension reflects students' awareness of their learning environment, responsibility toward group outcomes, and orientation toward professional development – all competencies cultivated by PjBL's authentic project context (Deviana et al., 2025). Leadership ability, curiosity, and self-control each scored 80% (good), while emotional intelligence and self-awareness scored 79% (good). The slight gap between the concern dimension and emotional intelligence suggests that while students developed strong collective responsibility and interest in their technical work, individual self-regulatory depth particularly the ability to manage emotions during challenging project phases requires continued pedagogical attention.

The slightly lower scores for communication ability (79%) and confidence (79%) in teacher observations reflect a known challenge in PjBL implementation: not all students immediately develop comfort with public presentation and verbal articulation of technical design rationale. Triyasa et al. (2025) confirmed that while PjBL effectively improves conceptual understanding and critical thinking, communication skill development requires additional structured support. Irfan et al. (2025) further showed that technology-integrated PjBL enhances student motivation and positive attitudes, and that periodic formative feedback cycles strengthen affective engagement over time.

Discussion

The convergent findings across all three learning domains present a coherent picture of PjBL-ProfiCAD integration's educational effectiveness. The cognitive dimension confirmed by statistical analysis ($t = -13.079$; $p < 0.001$; $N\text{-Gain} = 0.72$), the psychomotor dimension evidenced by observational assessment (81% and 80%), and the affective dimension captured through dual-instrument triangulation (80% overall) collectively demonstrate that this approach produces comprehensive vocational competency development consistent with the TVET framework's tripartite model.

From a constructivist-experiential learning perspective, the effectiveness mechanism is clear: PjBL with ProfiCAD transforms abstract electrical concepts into concrete, executable project tasks. When students design a residential distribution panel or a lighting circuit in ProfiCAD, they engage simultaneously in technical reasoning (selecting the correct circuit breaker type and rating), procedural execution (using ProfiCAD's wiring tools correctly), collaborative negotiation (discussing design choices with peers), and reflective evaluation (comparing outcomes against professional standards). This full-cycle engagement activates all three domains of learning simultaneously, explaining the comprehensive outcome improvements observed (Fiona et al., 2025).

The Technique domain's exceptional $N\text{-Gain}$ (0.788) versus the Problem Solving domain's comparatively lower gain (0.606) offers a nuanced finding: tool-based technical drawing skills benefited most directly from ProfiCAD integration, while higher-order analytical reasoning about complex circuit problems – though significantly improved – requires additional instructional scaffolding. This is consistent with Ermawalis et al. (2025), who noted that analytical skill development in PjBL contexts benefits from deliberate problem-complexity escalation strategies that progressively challenge students' diagnostic reasoning.

The practical implications of these findings are significant for vocational education policy and practice

in Indonesia's Merdeka Curriculum framework. The dramatic performance gap in ICT competence (Experimental: 75% posttest; N-Gain: 0.716 vs. Control: 22% posttest; N-Gain: 0.071) directly addresses a core objective of the Kurikulum Merdeka and MBKM policies, which emphasize digital technology integration as a non-negotiable competency for SMK graduates (Fiktoyana et al., 2018). PjBL with ProfiCAD provides a pedagogically rigorous and practically implementable pathway to achieving this objective within existing school resource constraints

Conclusion

This study demonstrates that the implementation of the Project-Based Learning (PjBL) model assisted by the ProfiCAD application has a significant positive effect on cognitive, psychomotor, and affective learning outcomes in Electrical Technical Drawing for Class X TITL students at SMK Negeri 8 Palembang. On the cognitive domain, the experimental group achieved a significantly higher posttest score (mean difference = 31.667; $t = -13.079$; $p < 0.001$) and a high N-Gain of 0.72, compared to the control group's low N-Gain of 0.279. The Technique domain registered the highest cognitive gain (N-Gain: 0.788), reflecting ProfiCAD's transformative impact on symbol application and technical drawing proficiency. On the psychomotor domain, students achieved very skilled (81%) and skilled (80%) categories in technology application and data processing respectively, confirming TVET Generic IR 4.0 Skills development. On the affective domain, interpersonal ability and teamwork achieved 81% (very good) and the Concern dimension led self-assessment scores at 82% (very good). The integrated evidence from all three domains confirms that PjBL with ProfiCAD creates a comprehensive learning environment aligned with TVET principles: technical proficiency through authentic project work, digital competency through systematic software integration, and professional attitude development through collaborative and reflective learning cycles. This pedagogical model represents a practically implementable and theoretically grounded approach for improving vocational electrical engineering education quality in the context of Indonesia's industrial transformation demands. Future research should extend this study to larger, multi-school samples to improve generalizability, and should examine the long-term impact on industrial work readiness, employment outcomes, and professional certification attainment. Longitudinal studies tracking graduates' ProfiCAD proficiency utilization in workplace settings would provide the strongest evidence base for policy recommendations. The

integration of Augmented Reality for three-dimensional circuit visualization within the PjBL-ProfiCAD framework represents a promising extension for future development.

Acknowledgements

Thank you to the Dean of FT UNP, Chair of the Master of Education and Kejuruan Study Program, lecturers and students of Electrical Engineering Education at Universitas Negeri Padang and all parties so that this research can be carried out well.

Author Contributions

Laras Pebrianti designed and planned this study, collected and analyzed the data, and drafted the original manuscript; M. Giatman, Sukardi, Elfizon, and Abdul Habib Arrasyidi Desky supervised the research process, validated the methodology, and reviewed the manuscript. All authors have read, revised, and approved the final version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

There is no conflict of interest.

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