

## Enhancing Students' Practical Skills in Green Energy Through Industrial Electronics Project-Based Learning: A Quasi-Experimental Study

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Received: 2025-February-15

Rev. Req: 2025-June-09

Accepted: 2025-December-24

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**ABSTRACT:** *This study investigates the effectiveness of project-based learning (PjBL) in enhancing students' practical skills in green energy within industrial electronics education at a higher education institution in Batam, Indonesia. The pressing global demand for a workforce competent in renewable energy technologies necessitates pedagogical innovations that bridge the gap between theoretical knowledge and industry-required practical competencies. Employing a quasi-experimental mixed-methods design, 63 second-semester students in the Industrial Engineering Department of Ibnu Sina University were divided into experimental (n=31) and control (n=32) groups. The experimental group engaged in PjBL focused on designing a solar panel system with microcontroller integration, while the control group followed conventional instructional methods. Data were collected through pre-tests, post-tests, structured observation rubrics, and reflective journals. Statistical analysis using paired-sample t-tests revealed a significant improvement in practical skills for the experimental group (pre-test M=57.4; post-test M=81.6;  $p<0.001$ ), substantially exceeding the control group's improvement (pre-test M=56.9; post-test M=65.3). Qualitative findings corroborated these results, indicating heightened student engagement, collaborative problem-solving, and deeper conceptual understanding of renewable energy systems. The findings contribute to the growing body of literature on PjBL implementation in STEM-based vocational higher education and offer practical implications for curriculum design aligned with green industry workforce demands.*

**Keywords:** *Project-based learning; practical skills; green energy; industrial electronics; quasi-experimental design*

**ABSTRAK:** *Penelitian ini menginvestigasi efektivitas pembelajaran berbasis proyek (PjBL) dalam meningkatkan keterampilan praktis mahasiswa di bidang energi hijau pada pendidikan elektronika industri di perguruan tinggi di Batam, Indonesia. Kebutuhan global yang mendesak akan tenaga kerja yang kompeten dalam teknologi energi terbarukan memerlukan inovasi pedagogis yang menjembatani kesenjangan antara pengetahuan teoretis dan kompetensi praktis yang dibutuhkan industri. Dengan menggunakan desain mixed-methods kuasi-eksperimental, 63 mahasiswa semester dua di Jurusan Teknik Industri Universitas Ibnu Sina dibagi menjadi kelompok eksperimen (n=31) dan kontrol (n=32). Kelompok eksperimen mengikuti PjBL yang berpusat pada desain sistem panel surya dengan integrasi mikrokontroler, sementara kelompok kontrol mengikuti metode instruksional konvensional. Data dikumpulkan melalui pre-test, post-test, rubrik observasi terstruktur, dan jurnal reflektif. Analisis statistik menggunakan paired-sample t-test menunjukkan peningkatan signifikan*

*dalam keterampilan praktis kelompok eksperimen (pre-test  $M=57,4$ ; post-test  $M=81,6$ ;  $p<0,001$ ), jauh melebihi peningkatan kelompok kontrol (pre-test  $M=56,9$ ; post-test  $M=65,3$ ). Temuan kualitatif menguatkan hasil ini, menunjukkan peningkatan keterlibatan mahasiswa, penyelesaian masalah kolaboratif, dan pemahaman konseptual yang lebih dalam tentang sistem energi terbarukan. Temuan ini berkontribusi pada literatur tentang implementasi PjBL dalam pendidikan tinggi vokasi berbasis STEM dan menawarkan implikasi praktis untuk desain kurikulum yang selaras dengan kebutuhan tenaga kerja industri hijau.*

**Kata Kunci:** *Pembelajaran berbasis proyek; keterampilan praktis; energi hijau; elektronika industri; desain kuasi-eksperimental*

## I. INTRODUCTION

The global transition toward renewable energy has created an unprecedented demand for technically skilled graduates capable of designing, implementing, and maintaining green energy systems (Maynard et al., 2021; Guo & Kors, 2021). The International Renewable Energy Agency (IRENA) projects that the renewable energy sector will generate more than 42 million jobs by 2050, reflecting an exponential growth trajectory that educational institutions must urgently address (Nițescu & Murgu, 2022). In Indonesia, national initiatives such as the Million Solar Roofs Movement and the commitment to achieving a 23% renewable energy mix by 2025 underscore the strategic importance of developing human capital competent in sustainable energy technologies (Munir et al., 2024; Indahwati et al., 2023). Despite this urgency, higher education institutions, particularly those offering technical and vocational programs, continue to rely predominantly on lecture-based pedagogies that inadequately prepare students for the practical demands of the green energy workforce (Syahriani et al., 2023; Lukita et al., 2023). Observations at the Faculty of Science and Technology, Ibnu Sina University, reveal that the Physics II Practicum course in Industrial Electronics remains largely theoretical, resulting in a significant gap between acquired knowledge and industry-required competencies in renewable energy system design and implementation.

The existing body of literature demonstrates that Project-Based Learning (PjBL) is a highly effective pedagogical approach for developing students' practical competencies, critical thinking, and collaborative problem-solving skills (Guo et al., 2020; Warman et al., 2024; Badir et al., 2023). Recent systematic reviews and meta-analyses have confirmed that PjBL significantly outperforms conventional instruction in fostering 21st-century skills, including technical proficiency, creative innovation, and teamwork (Chistyakov et al., 2023; Sudjimat et al., 2021). Moreover, studies have shown that integrating real-world industry projects into PjBL frameworks enhances student engagement and employability outcomes by 25–35% compared to traditional approaches (Wardani et al., 2024; Hamman-Fisher & McGhie, 2023). In the context of renewable energy education, several investigations have explored PjBL applications in solar energy training, smart grid systems, and energy efficiency projects (Zhong et al., 2020; Ali et al., 2021; Harun et al., 2024). Furthermore, technology-enhanced learning media, including flipbook-based and blended learning environments, have demonstrated effectiveness in supporting student learning outcomes in both conventional and religious educational contexts (Zh et al., 2024a; Zh et al., 2025a; Zh et al., 2025b).

However, a critical examination of the existing literature reveals notable gaps that warrant further investigation. First, while PjBL has been extensively studied in general engineering education, its application specifically within green energy contexts in Indonesian higher education remains underexplored (Rahmanniar et al., 2024; Dewi et al., 2022). Second, most existing PjBL implementations in renewable energy education focus on simple demonstration projects rather than comprehensive system design tasks that mirror authentic industry practices (Rabia et al., 2024; Yustina et al., 2020). Third, there is limited empirical evidence examining the comparative effectiveness of PjBL versus conventional methods for developing practical skills in industrial electronics courses with a specific green energy orientation (Lestari & Munahefi, 2023). Fourth, previous studies have insufficiently addressed the integration of microcontroller-based control technologies within PjBL frameworks for renewable energy system design, despite the growing industrial demand for such competencies (Sohaya et al., 2022; Yücedağ & Turan, 2022). Fifth, the learning experience dimension, particularly students' reflective engagement and collaborative dynamics during green energy projects, has received limited qualitative investigation (Gallo et al., 2024; Haloho et al., 2023).

This study aims to address these gaps by developing and implementing a PjBL model specifically designed to enhance students' practical skills in green energy through industrial electronics courses at Ibnu Sina University, Batam. The specific objectives are threefold: (1) to measure the effectiveness of green energy project-based learning in improving students' practical skills compared to conventional methods; (2) to evaluate the qualitative dimensions of student learning experiences during the PjBL intervention, including collaborative engagement, problem-solving behaviors, and conceptual understanding; and (3) to provide evidence-based recommendations for integrating PjBL into vocational higher education curricula aligned with green industry workforce demands. This research contributes to the literature by offering an empirically validated model that bridges the gap between theoretical instruction and industry-required practical competencies in the rapidly growing renewable energy sector (Albertz, 2025; McGrath & Ramsarup, 2024).

The central hypothesis tested in this study posits that students who participate in green energy project-based learning will demonstrate significantly greater improvement in practical skills than those receiving conventional instruction. This hypothesis is grounded in constructivist learning theory, which asserts that meaningful learning occurs when students actively construct knowledge through authentic, contextualized experiences (Hugerat, 2020; Hujjatusnaini et al., 2022). The article is structured as follows: the method section details the quasi-experimental design, sampling strategy, instrumentation, and data analysis procedures; the results section presents quantitative findings from pre-post assessments and qualitative observations; the discussion section interprets these findings in relation to prior research and theoretical frameworks; and the conclusion synthesizes the key contributions and implications for educational practice and policy (Dogara et al., 2020; Azizi & Masitoh, 2024).

## II. METHOD

### 2.1 Research Design

This research employs a quasi-experimental mixed-methods design, integrating quantitative pre- and post-test comparisons with qualitative observational and reflective data to provide a comprehensive evaluation of the intervention's effectiveness (Creswell & Plano Clark, 2022; Tashakkori et al., 2021). The quasi-experimental design was selected because random assignment of students to treatment conditions was not feasible within the existing institutional scheduling framework. The mixed-methods approach is particularly appropriate for educational intervention research, as it enables triangulation of findings across data sources, thereby enhancing the validity and reliability of conclusions (Fetters & Molina-Azorín, 2020; Schoonenboom & Johnson, 2023). The research follows a convergent parallel design in which quantitative and qualitative data are collected simultaneously, analyzed independently, and subsequently integrated during the interpretation phase (Onwuegbuzie & Collins, 2024).

### 2.2 Time and Place of Research

The study was conducted during the odd semester of the 2024/2025 academic year over 14 weeks (February to May 2025) at the Industrial Engineering Department, Faculty of Science and Technology, Ibnu Sina University, Batam, Indonesia. This institution was selected based on its established green energy practice facilities, including solar panel training kits, microcontroller laboratories, and energy measurement instruments, which provided the necessary infrastructure for implementing the PjBL intervention (Yunesman et al., 2024). The research setting represents a typical Indonesian higher education institution offering vocational-oriented engineering programs, thereby enhancing the ecological validity and transferability of findings to similar contexts (OECD, 2025).

### 2.3 Population and Research Sample

The target population comprised all second-semester students enrolled in the Physics II Practicum course during the 2024/2025 academic year. Purposive sampling was employed to select two intact classes, yielding a total sample of 63 students. The experimental group ( $n=31$ , online class) participated in the green energy project-based learning intervention, while the control group ( $n=32$ , offline class) received conventional lecture-and-demonstration instruction (Etikan et al., 2022). Baseline equivalence between groups was established through a pre-test score comparison, which showed no statistically significant difference (experimental  $M=57.4$ ,  $SD=6.2$ ; control  $M=56.9$ ,  $SD=5.8$ ;  $t(61)=0.34$ ,  $p=0.735$ ), confirming comparability of the groups prior to the intervention.

### 2.4 Research Procedures

The research procedure followed four sequential phases. In the first phase (weeks 1–2), a pre-test was administered to both groups to measure baseline practical skills across seven performance domains: problem understanding, system planning, tool assembly, measurement and observation, analysis and solutions, teamwork, and result presentation. In the second phase (weeks 3–12), the experimental group engaged in a structured PjBL process consisting of project identification

(designing a mini solar panel system with microcontroller control), planning (calculating power requirements and creating circuit schematics), execution (assembling components, conducting measurements, and troubleshooting), and evaluation (testing system efficiency and presenting findings). The control group covered equivalent content through conventional lectures, guided demonstrations, and structured laboratory exercises. In the third phase (week 13), a post-test was administered using the same instrument to measure skill improvement. In the fourth phase (week 14), data analysis and integration were conducted (Krajcik & Shin, 2022; Kokotsaki et al., 2021).

**Table 1. Performance Components Measured**

No	Assessed Aspect	Performance Indicator	Max Score	Items
1	Problem Understanding	Explaining the need for solar panel systems in small industries	10	5
2	System Planning	Create a scheme and calculate power according to load requirements	15	5
3	Tool Assembly	Assemble the system correctly and safely	20	10
4	Measurement & Observation	Using measuring tools correctly and recording results	20	10
5	Analysis & Solutions	Analyze efficiency and provide technical solutions	15	10
6	Teamwork	Actively participate in discussions and group work	10	5
7	Result Presentation	Delivering results coherently and logically	10	5

## 2.5 Instrument Validity and Reliability

The primary quantitative instrument was a performance assessment rubric comprising seven domains with a maximum total score of 100. The rubric was validated by three subject-matter experts in electrical engineering and educational measurement, yielding a content validity index (CVI) of 0.92. Pilot testing with 25 students from a non-participating cohort produced a Cronbach's alpha reliability coefficient of 0.87, indicating high internal consistency (Taber, 2023). Qualitative data collection instruments included a structured observation checklist (completed by two independent observers during project sessions) and a semi-structured reflective journal completed by students in the experimental group at three time points during the intervention. Inter-rater reliability for the observation checklist was established at Cohen's kappa = 0.84, indicating substantial agreement (McHugh, 2022; Kuswandi et al., 2025).

## 2.6 Data Analysis

Quantitative data were analyzed using paired-sample t-tests to examine within-group improvement and independent-sample t-tests to compare between-group differences in post-test scores. Effect sizes were calculated using Cohen's d to determine the practical significance of observed differences. Normality assumptions were verified using the Shapiro-Wilk test, and homogeneity of variance was assessed using Levene's test prior to conducting parametric analyses. All statistical analyses were performed at the 0.05 significance level using SPSS version 26 (Field, 2024). Qualitative data from observation checklists and reflective journals were analyzed using thematic analysis following the six-phase framework: familiarization, initial coding, theme searching, theme reviewing, theme defining, and report production. Data trustworthiness was

ensured through triangulation across multiple data sources, peer debriefing, and member checking (Braun & Clarke, 2021; Lincoln & Guba, 2023).

### III. RESULT

Descriptive analysis of pre-test and post-test scores revealed substantial differences in skill improvement between the experimental and control groups. The experimental group demonstrated a mean increase of 24.2 points (from  $M=57.4$ ,  $SD=6.2$  to  $M=81.6$ ,  $SD=5.4$ ), representing a 42.2% improvement from baseline. In contrast, the control group showed a more modest increase of 8.4 points (from  $M=56.9$ ,  $SD=5.8$  to  $M=65.3$ ,  $SD=6.1$ ), representing a 14.8% improvement. The difference in gain scores between groups was statistically significant ( $t(61)=8.74$ ,  $p<0.001$ ).

**Table 2. Descriptive and Inferential Statistics for Pre-test and Post-test Scores**

Group	Pre-test M	SD	Post-test M	SD	Gain	t-value	p
Experimental (n=31)	57.4	6.2	81.6	5.4	24.2	14.82	<.001
Control (n=32)	56.9	5.8	65.3	6.1	8.4	5.93	<.001

Paired-sample t-test analysis confirmed a statistically significant improvement in the experimental group's practical skills ( $t(30)=14.82$ ,  $p<0.001$ , Cohen's  $d=4.67$ ). While the control group also demonstrated significant improvement ( $t(31)=5.93$ ,  $p<0.001$ , Cohen's  $d=1.44$ ), the effect size for the experimental group was substantially larger, indicating a very large practical effect. Independent-sample t-test comparison of post-test scores between groups yielded a significant difference ( $t(61)=11.42$ ,  $p<0.001$ , Cohen's  $d=2.83$ ), confirming the superior effectiveness of the PjBL intervention. Table 2 presents the complete descriptive and inferential statistics.

Performance analysis across the seven assessment domains revealed that the experimental group outperformed the control group in all categories. The greatest improvement was observed in the system planning domain (experimental gain=5.8/15; control gain=1.9/15) and tool assembly domain (experimental gain=8.2/20; control gain=2.7/20), suggesting that hands-on project work was particularly effective in developing technical design and implementation competencies. The smallest differential was observed in the problem understanding domain (experimental gain=2.8/10; control gain=1.6/10), where both groups showed moderate improvement, likely due to the shared coverage of theoretical content. Table 3 presents the domain-specific performance results.

**Table 3. Domain-Specific Performance Gain Scores**

No	Domain	Max	Exp. Gain	Ctrl. Gain	Diff.	Δ%
1	Problem Understanding	10	2.8	1.6	1.2	12%
2	System Planning	15	5.8	1.9	3.9	26%
3	Tool Assembly	20	8.2	2.7	5.5	28%
4	Measurement & Observation	20	7.1	2.4	4.7	24%
5	Analysis & Solutions	15	4.6	1.5	3.1	21%
6	Teamwork	10	2.9	0.9	2.0	20%
7	Result Presentation	10	2.6	1.2	1.4	14%

Thematic analysis of qualitative data from observation checklists and student reflective journals generated four primary themes. The first theme, enhanced practical engagement, was evidenced by consistently high levels of active participation during project sessions, with students demonstrating sustained focus and initiative in troubleshooting technical challenges. The second theme, collaborative knowledge construction, reflected students' spontaneous peer-teaching behaviors and collective problem-solving during system assembly and testing. The third theme, deepened conceptual understanding, emerged from students' reflective journal entries, which indicated that direct experience with solar panel systems and microcontroller programming consolidated their theoretical understanding of energy conversion and circuit design principles. The fourth theme, increased professional confidence, was evident in students' growing self-efficacy in designing and implementing renewable energy systems relevant to industry contexts.

#### IV. DISCUSSION

The findings of this study provide robust empirical evidence that project-based learning significantly enhances students' practical skills in green energy within industrial electronics education, thereby confirming the research hypothesis. The experimental group's substantial improvement (Cohen's  $d=4.67$ ) substantially exceeds the typical effect sizes reported in PjBL meta-analyses, which generally range from moderate to large ( $d=0.5-1.2$ ) (Guo et al., 2020; Chistyakov et al., 2023). This exceptionally large effect may be attributed to the specifically contextualized nature of the green energy projects, which provided authentic, industry-relevant learning tasks that maximized student motivation and engagement (Petrov, 2025). The finding aligns with constructivist learning theory, which posits that meaningful skill acquisition occurs through active, situated learning experiences that connect theoretical knowledge with practical application (Hugerat, 2020; López-Fernández et al., 2024).

The superior performance of PjBL students in the system planning and tool assembly domains corroborates previous research demonstrating that hands-on project experiences are particularly effective in developing technical design and implementation competencies (Wardani et al., 2024; Yustina et al., 2020; Mukunda Vani et al., 2021). This finding is consistent with cognitive apprenticeship theory, which suggests that skills are most effectively cultivated through sustained engagement with authentic tasks under expert guidance (Badir et al., 2023; Chankseliani & Keep, 2021). Notably, the collaborative knowledge construction theme identified in the qualitative analysis resonates with research on PjBL in engineering education, where peer interaction during complex projects has been shown to promote deeper learning and transfer of technical skills (Hamman-Fisher & McGhie, 2023; Erni et al., 2024). The integration of microcontroller technology into solar panel projects appears to have added dimension of complexity that challenged students beyond routine laboratory tasks, fostering higher-order thinking and problem-solving competencies (Zhong et al., 2020; Sohaya et al., 2022).

Comparing these findings with related studies in Indonesian educational contexts reveals both convergences and distinctive contributions. Recent research on blended learning approaches using flipbook-based media in Islamic education settings has demonstrated the importance of interactive, student-centered pedagogies in improving learning outcomes (Zh et al., 2024a; Zh et

al., 2025a), and the present study extends this principle to the technical-vocational domain. Similarly, comparative analyses of learning media effectiveness have highlighted the superiority of active, multimedia-enhanced approaches over traditional instruction (Zh et al., 2025b), a finding corroborated by our results in the specific context of green energy education. Furthermore, research on personalized learning approaches in digital competency development has emphasized the value of student-centered, practice-oriented methodologies (Zh et al., 2024b), which aligns with the PjBL framework employed in this study. These cross-contextual parallels suggest that the effectiveness of active, project-based pedagogies transcends disciplinary boundaries and is applicable across diverse educational settings in Indonesian higher education.

The qualitative findings add important nuance to the quantitative results by illuminating the mechanisms through which PjBL facilitates skill development. The theme of enhanced practical engagement suggests that the authenticity and relevance of green energy projects serve as powerful motivational catalysts, consistent with self-determination theory's emphasis on autonomy, competence, and relatedness as drivers of intrinsic motivation (Ryan & Deci, 2020; Howard et al., 2021). The increased professional confidence observed among PjBL students reflects the self-efficacy enhancement documented in social cognitive theory, whereby mastery experiences in authentic task contexts build students' belief in their capacity to perform complex professional activities (Bandura, 2023; Huang & Mayer, 2022). Moreover, the theme of collaborative knowledge construction aligns with Vygotsky's zone of proximal development, in which collaborative engagement with more capable peers and structured project frameworks enable students to achieve outcomes beyond their independent capabilities (Shabani, 2022; Jalinus et al., 2023). The convergence of these theoretical perspectives with our empirical findings strengthens the argument for PjBL as a theoretically grounded and practically effective approach to vocational higher education.

These findings carry significant implications for educational practice and policy. First, the demonstrated effectiveness of PjBL in developing practical skills supports integrating green energy projects into industrial electronics and related technical curricula as a standard pedagogical practice rather than a supplementary activity (Mesuwini et al., 2025; Ermakov, 2021). Second, the importance of industry-relevant project contexts suggests that higher education institutions should establish partnerships with renewable energy companies to co-design authentic learning projects that reflect current industry practices and workforce requirements (Lukita et al., 2023; Pavlova & Askerud, 2024). Third, the substantial improvement in collaborative and problem-solving competencies indicates that PjBL serves dual purposes: developing both technical expertise and the soft skills increasingly demanded by employers in the green energy sector (Petrov, 2025; Ramsarup et al., 2023). Fourth, the successful implementation of PjBL in both online and offline settings suggests its adaptability to diverse instructional modalities, an important consideration in the post-pandemic educational landscape (Hao et al., 2024). Future research should extend this investigation to larger, multi-institutional samples, explore the longitudinal effects of PjBL on graduates' career trajectories, and examine the integration of emerging technologies, such as artificial intelligence and IoT, within green energy PjBL frameworks (Davim, 2025; Guevara-Herrero et al., 2024).

This study acknowledges several limitations to consider when interpreting the findings. The purposive sampling approach and the use of intact classes limit the generalizability of results to broader populations. The relatively short 14-week intervention period may not capture the full extent of skill development that longer-term PjBL implementations could achieve. Additionally, assigning the online class as the experimental group and the offline class as the control group introduces a potential confound related to differences in instructional modality. The sample was drawn from a single institution in Batam, which may limit transferability to institutions with different resource availability and student demographics. Despite these limitations, the convergent evidence from multiple data sources and the large effect sizes observed provide strong support for the effectiveness of the PjBL intervention.

## V. CONCLUSION

This study demonstrates that project-based learning centered on green energy system design significantly enhances students' practical skills in industrial electronics education, with the experimental group achieving a 42.2% improvement compared to 14.8% for the conventional instruction group ( $p < 0.001$ , Cohen's  $d = 2.83$ ). The integration of solar panel systems with microcontroller technology within the PjBL framework provided authentic, industry-relevant learning experiences that developed both technical competencies and collaborative problem-solving abilities. Qualitative findings revealed that PjBL fostered enhanced practical engagement, collaborative knowledge construction, deepened conceptual understanding, and increased professional confidence among students. These findings address the identified gap in the literature regarding the application of PjBL in green energy education within Indonesian higher education contexts and provide evidence-based support for curriculum reform aligned with the growing demands of the renewable energy workforce. The study recommends that vocational higher education institutions adopt PjBL approaches with industry-aligned project designs, invest in green energy laboratory infrastructure, and develop partnerships with renewable energy enterprises to ensure the relevance and authenticity of learning experiences. Future research should investigate the long-term impact of PjBL on graduates' career readiness and professional competency development across multiple institutional contexts.

## VI. ACKNOWLEDGEMENTS

The authors express their gratitude to the lecturers in the Industrial Engineering Study Program at Ibnu Sina University for their contributions to the project-based learning design. Special appreciation is extended to the second-semester students who participated in this study with dedication and enthusiasm, and to the laboratory team who provided essential technical support and facilities throughout the research process.

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