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Improving Students' Green Energy Practical Skills Through Project-Based Industrial Electronics Learning for Sustainable Development Goals

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Abstract: This study aims to improve students' practical skills in green energy through the implementation of a Project-Based Learning (PjBL) model integrated with industrial electronics–based solar energy projects, supporting Sustainable Development Goals (SDGs) in higher education. The research employed a quantitative quasi-experimental design with a pre-test and post-test control group. Participants were second-semester Industrial Engineering students enrolled in an Industrial Electronics practicum course. The experimental group (n = 31) was taught using PjBL through the design and implementation of a microcontroller-based solar panel system, while the control group (n = 32) received conventional instruction. Data were collected using practical skill tests and performance observation rubrics. The results showed a substantial improvement in the experimental group, with the mean score increasing from 57.4 (pre-test) to 81.6 (post-test), whereas the control group showed a smaller increase from 56.9 to 65.3. Paired t-test analysis indicated a significant difference ($p < 0.05$), demonstrating the effectiveness of the PjBL model. These findings indicate that project-based industrial electronics learning effectively enhances students' green energy practical skills. In conclusion, the study confirms that contextual PjBL can strengthen work-oriented competencies and support sustainable education aligned with SDGs.

Keywords: Green energy education; Industrial electronics; Practical skills; Project-based learning; Sustainable development goals

Introduction

In recent years, higher education institutions have been increasingly challenged to align engineering education with the global transition toward sustainable and renewable energy systems (Soares et al., 2023; Achmad & Muslim, 2021). The demand for graduates who possess not only conceptual knowledge but also strong practical skills in green energy technologies has become a critical issue, particularly in engineering and applied science programs (Mukhtar et al., 2020). In this context, industrial electronics courses play a strategic role in preparing students to design, implement, and evaluate renewable energy systems that are relevant to current industrial and sustainability needs (Godoy et al., 2020; Mukhtar et al., 2020; Colmenares-Quintero et al., 2020).

Consistent with the aim stated in the abstract, this study focuses on improving students' practical skills in green energy through the implementation of a Project-Based Learning model integrated with industrial electronics–based solar energy projects (Dwiyanti &

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Setyasto, 2025). The research is conducted with second-semester Industrial Engineering students through an Industrial Electronics practicum, where learners are actively engaged in the design and implementation of microcontroller-based solar panel systems. By employing a quantitative quasi-experimental design with a pre-test and post-test control group, this study provides empirical evidence on the effectiveness of PjBL in enhancing measurable practical skills rather than merely theoretical understanding (Sutaryani et al., 2024).

Moreover, this research is explicitly aligned with the Sustainable Development Goals (SDGs), particularly SDG 4 on quality education and SDG 7 on affordable and clean energy (Indahwati et al., 2023; Artyukhov et al., 2021). Integrating project-based industrial electronics learning with green energy applications offers a contextual and practice-oriented learning environment that supports sustainable education in higher education (Ismaniati et al., 2025). This alignment establishes a clear research gap and contribution by demonstrating how a structured PjBL approach can strengthen work-oriented competencies in industrial electronics courses, providing a focused and evidence-based contribution to engineering education research within similar institutional contexts.

This research is motivated by the real conditions faced by many higher education institutions. Observations at the Faculty of Science and Technology, Ibnu Sina University, show that learning in the Physics II Practicum course, which is based on Industrial Electronics, is still dominated by a theoretical approach. This makes students tend to understand the basic concepts of electronics and electricity without getting direct experience in designing and implementing real systems based on renewable energy (Adriyawati et al., 2020). As a result, they are less prepared to face the competitive world of work (Maynard et al., 2021; Guo & Kors, 2021). The literature review conducted by the researcher also shows a significant gap between the learning curriculum and the job competency needs in the green energy sector, which requires mastery of control-based technology, energy efficiency, and the application of more complex integrated systems.

The urgency of this research lies in the pressing need to prepare graduates who not only understand theory but are also technically ready to face the world of work that demands practical skills, especially in the rapidly developing field of renewable technologies. A report from the International Renewable Energy Agency (IRENA) projects that by 2050 there will be more than 42 million jobs in the renewable energy sector, indicating great potential in creating sustainable careers in the future (Nițescu & Murgu, 2022). Initiatives in Indonesia, such as the National Movement for a Million Solar Roofs and the government's commitment to a sustainable energy transition, indicate a direction of development that is increasingly dependent on a workforce competent in green technologies (Munir et al., 2024). This shows that graduates with practical and theoretical skills in renewable energy are highly sought after by the job market

This research focuses on the application of Project-Based Learning (Afriyanti et al., 2025) in Physics II practicum learning, specifically in industrial electronics, with an emphasis on developing students' practical skills through green energy-based projects. Unlike previous research that applied PjBL generally in technical education, this study specifically targets the development of solar panel systems integrated with control technology, the use of microcontrollers, and energy efficiency prototypes relevant to real industrial contexts. It is hoped that this approach can prepare students to adapt to ever-changing technological developments (Syahriani et al., 2023; Azizi & Masitoh, 2024). The instruments used in this study combine direct practice observation approaches, technical competency assessment rubrics, and student reflections to evaluate the overall impact of learning, thereby providing constructive feedback for the development of the teaching and learning process.

Previous literature shows that the PjBL approach is very effective in enhancing students' active participation, team collaboration, and problem-solving skills. However, many PjBL implementations are still limited to simple projects that are not directly related to real challenges in the technology industry (Sudjimat et al., 2019; Warman et al., 2024). This study aims to fill this gap by designing a specific project based on the needs of the green energy industry, where students are not only involved in the planning stage, but also in the implementation and evaluation of the systems they develop. The involvement of industry practitioners as mentors is very important, because they can provide relevant insights and practical experiences that can enrich students understanding of the challenges and opportunities in the field (Badir et al., 2023; Hamman-Fisher & McGhie, 2023). In addition, the integration of simulations and hardware-based training, such as solar energy training kits, provides students with the opportunity to apply the theories they have learned in a more real and practical context (Zhong et al., 2020).

This approach not only enhances students' technical skills, but also prepares them to face more complex challenges in the industrial world, as well as encouraging them to innovate in creating sustainable solutions to today's increasingly pressing energy problems (Yunesman et al., 2024). Innovative integration of sustainable technologies in educational programs: Fostering freshwater production and environmental preservation awareness. Therefore, this research is expected to make a significant contribution to the development of higher education curricula that are more relevant and responsive to the needs of industry, as well as preparing the younger generation to become agents of change in the transition to more environmentally friendly energy.

The purpose of this research is to develop and implement a project-based learning model that can improve students' practical skills in the field of green energy, specifically through industrial electronics courses. This research also aims to evaluate the effectiveness of this approach in shaping students' work readiness, improving technical understanding, and building a deeper awareness of environmental sustainability (Olzhebayeva et al., 2024; Nikoloudakis & Rangoussi, 2024). This is very important considering the global challenges faced by future generations in addressing climate change and environmental.

The urgency of this research is evident from the urgent need for new learning approaches that not only bridge the gap between education and the world of work, but also ensure that graduates are ready to face the challenges in the industry (Lukita et al., 2023; Wardani et al., 2024). The expected contribution of this research is the development of a learning model that is not only innovative but can also be replicated and adapted by other educational institutions, providing evidence-based implementation guidance for educators and policymakers in designing more effective strategies. The expected significance of the findings includes improving students' practical skills, which are crucial in facing an increasingly competitive job market, as well as strengthening partnerships between education and industry, which are expected to create mutually beneficial synergies.

In addition, this research is also expected to contribute to the development of a curriculum that is more contextual and responsive to the development of green technology, so that graduates not only have theoretical knowledge but also practical skills that are relevant to the time (Suhendra et al., 2023). Thus, this research serves not only as an evaluation tool, but also as a driver of positive change in the current education system, in order to produce a generation that is not only ready to work, but also has social awareness and environmental responsibility. Anticipated limitations in this study include challenges in providing practical tools and simulations, full involvement of industry partners, and variations in students' initial skill levels. However, through adaptive research design and continuous evaluation, these limitations will be systematically managed to ensure the success of the program. Overall, this study provides a strong foundation for strengthening the relationship between vocational education and the needs of the green energy sector through learning innovation. The results of the study are expected to not only improve student competency but also contribute to national efforts in developing superior human resources that support sustainable development based on renewable energy (Indahwati et al., 2023).

Method

Research Design

This study employed a quantitative approach using a quasi-experimental design with a pre-test–post-test control group (Hardani, 2020). The research focused on examining the effectiveness of a Project-Based Learning (PjBL) model integrated with industrial electronics–based solar energy projects in improving students' practical skills. The design was selected because random assignment of participants was not feasible within the existing academic class structure, which is a common condition in educational research.

Research Setting and Control of Variables

The research was conducted during the odd semester (February–April 2025) in the Industrial Engineering Department, Faculty of Science and Technology, Ibnu Sina University. To avoid confounding variables, both the experimental and control groups were conducted in the same learning environment (offline/practicum-based) using identical laboratory facilities, learning duration, instructor, learning objectives, and assessment instruments.

Population and Research Sample

The population consists of all Semester 2 students taking the Practical Physics II course. The sample was chosen purposively, considering the availability of facilities and active involvement in the project-based learning process. One online class serves as the experiment, and an offline class serves as the control, where the control class consists of 32 students and the experimental class consists of 32 students.

Research Procedures

Table 1. Performance components measured

Rated aspect	Performance	Max Score	Item
Problem Understanding	Explaining the need for solar panel systems in small industries	10	5
System Planning	Create a scheme and calculate power according to load requirements	15	5
Tool Assembly	Assemble the system correctly and safely	20	10
Measurement and Observation	Using measuring tools correctly and recording the results	20	10
Analysis and Solutions	Analyze efficiency and provide technical solutions	15	10
Teamwork	Actively participate in discussions and group work	10	5
Presentation of Results	Delivering results in a coherent and logical manner	10	5

The research begins with a pre-test to measure initial skills. The experimental group receives project-based learning, such as designing a solar panel system using a microcontroller. The control group uses conventional methods. After the intervention, a post-test is conducted to measure skill improvement (Rabia et al., 2024; Yustina et al., 2020).

Accuracy and Validity of the Method

Mixed methods were chosen because they are suitable for evaluating skill improvement (quantitative) as well as exploring student learning experiences (qualitative). The instrument was validated by experts and tested for reliability with the Cronbach Alpha test to ensure the accuracy and clarity of the results (Gallo et al., 2024; Lestari & Munahefi, 2023).

Data Validity

Data validity is maintained through triangulation techniques: pre-posttest, direct observation, and student reflection. Reliability is guaranteed by inter-rater reliability and the use of standardized rubrics.

Data Analysis

Quantitative data were analyzed using paired t-test to see the improvement of skill scores. Qualitative data were analyzed using thematic analysis based on student response patterns during and after project activities.

Result and Discussion

This Results and Discussion section reports the empirical evidence on the effectiveness of Project-Based Learning (PjBL) integrated with industrial electronics–based solar energy projects in improving students' practical skills in green energy. In line with the research objective and abstract, the analysis prioritizes quantitative comparisons of pre-test and post-test performance between the experimental and control groups, supported by structured observation of practical activities. This focus ensures that the discussion remains centered on measurable practical skill outcomes rather than conceptual or attitudinal claims.

The comparison between groups is intended to demonstrate the instructional impact of contextual, project-based learning within an Industrial Electronics practicum. Students in the experimental group engaged directly in the design and implementation of a microcontroller-based solar panel system, enabling the application of industrial electronics concepts in a real-world green energy context. In contrast, the control group followed conventional practicum instruction, providing a clear basis for evaluating the contribution of the PjBL model to skill development. This analytical framing strengthens the internal validity of the findings and clarifies that observed differences are attributable to the applied learning model.

Furthermore, the results are discussed within the framework of Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 7 (Affordable and Clean Energy). Improvements in students' practical skills are interpreted as evidence that project-based industrial electronics learning can support sustainability-oriented education by enhancing work-relevant competencies in renewable energy applications. Thus, this section not only presents statistical outcomes but also explains their significance for sustainable engineering education in higher education contexts comparable to the study setting.

Data Summary

This study was conducted in one online class and one offline class with a total of 62 students participating. Each class was divided into two groups: an experimental group (online class) that followed green energy project-based learning and a control group (offline class) that followed conventional learning. Data were collected through pre-test and post-test, activity observation, and reflection questionnaire. The pre-test scores showed that students' initial practical skills were in the low category with an average score of 57.2. After the implementation of project-based learning, the post-test scores of the experimental group increased significantly to an average of 81.6, while the control group only reached 65.3.

Table 2. Results pre-test and post-test

Group	Pre-Test	Post-Test
Experiment	57.4	81.6
Control	56.9	65.3

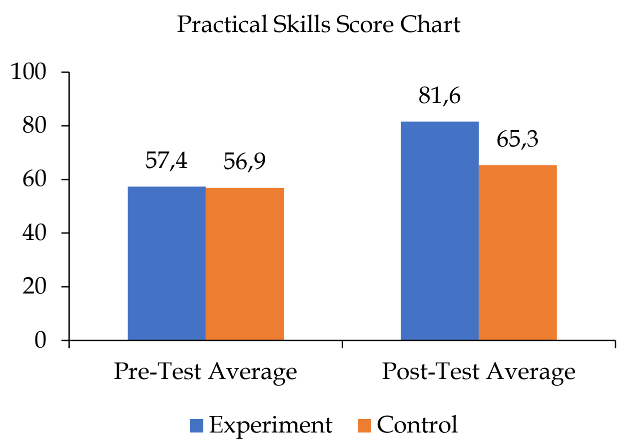

Figure 1. Practical skills score increase graph

The graph above shows a comparison of the average pre-test and post-test scores of two groups: the experimental group that participated in green energy project-based learning, and the control group that used conventional learning methods.

Key findings from the graph: experimental group experienced a significant increase in scores, from an average of 57.4 in the pre-test to 81.6 in the post-test. This increase shows that the project-based learning approach is able to significantly improve practical skills. The control group, although also increased from 56.9 to 65.3, but the increase was much smaller than the experimental group. This shows that conventional methods are not as effective as project-based methods in building the technical skills needed in the field of green energy.

The meaning of this graphic: Effectiveness of PjBL (Project-Based Learning) (Azhar et al., 2025): This graph provides visual evidence that PjBL is able to provide a significant positive impact on students' mastery of practical skills, Hypothesis Proof: These results support the research hypothesis that project-based learning provides higher skill improvement compared to conventional method, Practical Recommendations: These visual results reinforce the urgency to adopt the PjBL method in vocational curricula, especially in subjects related to renewable technologies such as industrial electronics.

The observation results showed that the experimental group was more active in discussing, had higher perseverance in completing the project, and was able to design a mini solar panel system with microcontroller control independently. Qualitative data from student reflections also showed that this approach made them better understand the concept of green energy and the role of industrial electronics in practice.

Data Analysis

Statistical analysis was conducted using a paired t-test to compare the pre- and post-test scores of the experimental group. The t-test results showed a significance value (p-value) = 0.000 < 0.05, which means there is a significant difference between before and after treatment. The results of the t-test comparison with the control group showed that the conventional approach only produced minimal improvement. This confirms that the project-based learning model is more effective in forming practical skills in the context of green energy. These results confirm the gap identified in the introduction, namely that conventional learning has not been able to bridge the need for practical skills demanded by the industry (Bondin & Zammit, 2025; Yao & Lin, 2025).

Hypothesis Testing

The research hypothesis states that green energy project-based learning significantly improves students' practical skills compared to conventional methods. The results of the statistical test prove that the hypothesis is accepted, because there is a significant difference in the improvement of practical skills between the experimental and control groups.

Discussion

This discussion focuses on interpreting the observed improvement in students' practical skills as a direct outcome of the applied Project-Based Learning (PjBL) model integrated with industrial electronics–based solar energy projects. In line with the quantitative findings, the substantial increase in post-test scores in the experimental group indicates that learning activities centered on real-world project implementation provide more effective skill acquisition than conventional practicum approaches. This finding confirms that hands-on engagement in designing and implementing microcontroller-based solar panel systems enables students to translate theoretical knowledge into practical competencies relevant to green energy applications.

The difference in learning outcomes between the experimental and control groups highlights the instructional value of contextualized projects in industrial electronics education. Rather than attributing skill improvement to general engagement or motivation, the results suggest that the structured stages of PjBL—problem definition, system design, implementation, testing, and evaluation—play a critical role in strengthening students' work-oriented practical skills. This interpretation is consistent with the study's focus on measurable practical performance, as assessed through skill tests and observation rubrics, without extending claims beyond the variables examined.

From a sustainability perspective, the findings support the role of project-based industrial electronics learning in advancing Sustainable Development Goals (SDGs), particularly SDG 4 and SDG 7. The improvement in green energy practical skills demonstrate how higher education learning models can contribute to sustainable education by preparing students with competencies relevant to renewable energy technologies. Within the context of Industrial Engineering education at Ibnu Sina University, this study provides evidence that PjBL can serve as an effective pedagogical approach for aligning technical skill development with sustainability-oriented educational goals.

Interpretation of Results

The increase in the average post-test score of the experimental group shows that direct involvement in designing and implementing green energy projects significantly strengthens students' understanding and practical skills. They not only learn theoretical concepts but also experience field challenges directly, such as power management, solar panel analysis, and technical problem solving (Tanjung & Louise, 2024). In addition to technical aspects, this learning also fosters soft skills such as collaboration, communication, cooperation, and leadership, which are very relevant in the modern workplace (Tanjung & Louise, 2024).

Relevance to Previous Studies

The results of this study strengthen previous findings stating that the Project-Based Learning approach is effective in improving students' vocational and problem-solving skills. Research at SMK Makassar also showed that PjBL was able to improve learning outcomes and real work skills (Syawal, 2024). However, this study provides added value because it specifically focuses PjBL on green energy and industrial electronics, which are still rarely used as the main context in PjBL implementation (Rahmanniar et al., 2024; Dewi et al., 2022). Thus, this study fills the gap in the literature related to the integration of PjBL and renewable energy technology in vocational education.

Implications and Recommendations

These findings have important implications for vocational education. Curricula need to be encouraged to adopt project-based learning approaches that are contextual and relevant to current industry needs, especially in the field of green energy. Teachers and instruct-tors also need to receive training in developing projects that are oriented to industry practices. Recommendations from this study include: Integration of green energy projects into industrial electronics courses or subjects; Provision of green energy trainer kits in school laboratories, strengthening partnerships between schools and industry to assist project implementation.

Strengths and Weaknesses of the Research

The main strength of this study is its applicable learning design and direction evolvement of students in developing real solutions. In addition, the use of combined data (quantitative and qualitative) provides a comprehensive picture of changes in student competencies (Hou, 2022). However, the weaknesses of this study are the limited implementation time which only lasted for one semester, as well as the limited tools and resources in some schools which caused variations in project implementation. In addition, generalization of the results needs to be done carefully considering that the sample was only taken from one city.

Logic and Consistency

All findings are arranged based on a logical flow that is in accordance with the research objectives, from problems in the field, interventions, to results and data analysis. interpretation is done proportionally without exaggerating the results.

Scientific Truth

The results and discussion are based on empirical evidence from the field and valid statistical data. No claims are made without sup-porting data or observations. The use of appropriate methods and strict instrument validation ensure that all conclusions are scientifically accountable.

Conclusion

This study concludes that the implementation of Project-Based Learning integrated with industrial electronics–based solar energy projects is effective in improving the practical skills of Industrial Engineering students in the Industrial Electronics practicum at Ibnu Sina University. The findings demonstrate a substantial improvement in the experimental group's practical skill performance, with mean scores increasing from 57.4 in the pre-test to 81.6 in the post-test, while the control group showed a more limited increase from 56.9 to 65.3 under conventional instruction. These results confirm that hands-on, project-based learning provides a more effective learning experience than traditional practicum methods in developing green energy–related practical competencies. The effectiveness of the model is supported by statistically significant differences between groups ($p < 0.05$), indicating that the observed improvement is attributable to the applied learning model rather than instructional conditions. Therefore, this study provides empirical evidence that contextual Project-Based Learning can strengthen work-oriented practical skills in industrial electronics courses, particularly in the context of green energy education, and offers a focused contribution to instructional practices for Industrial Engineering programs within similar higher education settings aligned with the Sustainable Development Goals.

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Author Contributions

Conceptualization, validation, investigation, resources, data curation, writing—original draft preparation, Y.; methodology, formal analysis, visualization, A. and H.; writing—review and editing, Y. and H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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