

DEVELOPMENT OF A PROBLEM-BASED LEARNING-BASED MULTI-CONFIGURATION SOLAR POWER GENERATION TRAINER WITH INTEGRATED JOBSHEET

Mohammad Bachrul Ullum¹, Yuni Rahmawati², Fathul Amin³

^{1,2} Pendidikan Teknik Elektro, Universitas Negeri Malang, Indonesia ,

³ Elektronika Industri, SMK Negeri 1 Kepanjen, Indonesia

yuni.rahmawati.ft@um.ac.id

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Abstrak

Penelitian ini bertujuan mengembangkan media pembelajaran berupa Trainer Pembangkit Listrik Tenaga Surya (PLTS) Multi-Konfigurasi yang terintegrasi dengan jobsheet berbasis Problem Based Learning (PBL) untuk mengatasi hambatan kognitif siswa dalam memvisualisasikan sistem tenaga surya. Metode penelitian yang digunakan adalah Research and Development (R&D) dengan model Design and Development Research (DDR) melalui alur Planning, Production, and Evaluation (PPE). Subjek penelitian melibatkan ahli validator dan siswa Teknik Elektronika Industri di SMKN Satu Kepanjen. Hasil validasi oleh ahli media dan ahli materi menunjukkan bahwa produk berada dalam kategori sangat valid. Uji coba lapangan menghasilkan tingkat praktisitas yang sangat tinggi, di mana fitur plug-and-play terbukti efektif mengefisiensikan waktu persiapan praktik. Simpulan penelitian menunjukkan bahwa media ini efektif mendukung nalar kritis dan kemampuan troubleshooting siswa pada berbagai konfigurasi sistem tenaga surya. Implikasi riset ini memberikan kontribusi nyata dalam penyediaan media laboratorium yang adaptif dan inovatif untuk meningkatkan kualitas pembelajaran teknis di sekolah kejuruan.

Kata Kunci: Trainer PLTS; Multi-Konfigurasi; Problem Based Learning

Abstract

This study aims to develop instructional media in the form of a Multi-Configuration Solar Power Plant (PLTS) Trainer integrated with Problem-Based Learning (PBL) jobsheets to address students' cognitive barriers in visualizing solar power systems. The research method employed is Research and Development (R&D) utilizing the Design and Development Research (DDR) model through the Planning, Production, and Evaluation (PPE) workflow. The research subjects involved expert validators and Industrial Electronics Engineering students at State vocational high school in Kepanjen. Validation results from both media and material experts indicate that the product falls within the highly valid category. Field trials demonstrated an exceptionally high level of practicality, where the plug-and-play features proved effective in streamlining practical preparation time. The study concludes that the media effectively supports students' critical reasoning and troubleshooting skills across various solar power system configurations. The implications of this research offer a significant contribution to the provision of adaptive and innovative laboratory equipment to enhance the quality of technical instruction in vocational schools.

Keyword: Multi-Configuration; PLTS Trainer; Problem Based Learning

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INTRODUCTION

The transition toward renewable energy technology has become a key determinant in enhancing human development and sustainable global economic growth (Nguyen et al., 2023). The utilization of clean energy not only contributes to mitigating the global climate crisis but also serves as a vital instrument in achieving the Sustainable Development Goals (SDGs), particularly through improving access to technical education and strengthening community income in the green energy sector (Zheng et al., 2025). In Indonesia, the urgency of this energy transition is strategically supported by green finance policies aimed at accelerating the adoption of environmentally friendly technologies across various industrial sectors (Monira, 2024; Purwanto & Endah, 2025). These policies create a massive market demand for photovoltaic technology; however, the growth of such infrastructure is often not accompanied by the availability of a ready-to-use workforce. The rapid evolution of technology in the photovoltaic industry demands a technically skilled workforce with high competency flexibility to address the complexity of modern energy systems, which are increasingly digitally integrated. Therefore, educational institutions now function as crucial experimental units to test the potential of solar energy while simultaneously preparing competent technical personnel through the provision of adequate and adaptive laboratory facilities (Chen et al., 2023).

The rapid dynamics of the renewable energy industry require a technical workforce that possesses not only basic mechanical skills but also competency flexibility to navigate continuously evolving green energy transition strategies (Yang et al., 2024). Consequently, vocational education institutions are now required to function as centers for development and innovation to produce graduates who are relevant to the needs of the modern energy industry (Hurtado-Pérez et al., 2024). Despite the increasing urgency of green technology at the national level, the STEM (Science, Technology, Engineering, and Mathematics) education sector still faces fundamental challenges in the form of significant competency gaps among students (Theobald et al., 2020). Mastery of green skills in the field of electrical engineering has become a mandatory requirement for vocational school graduates to support the acceleration of sustainable infrastructure development in Indonesia. In this context, the synergy between informative visual media and problem-based learning models becomes highly relevant to produce graduates who are not only skilled in assembling components but also capable of independently diagnosing system faults in accordance with global industry standards (Al Husaeni et al., 2024).

Without appropriate instructional approaches, the abstract complexity of renewable energy systems can become a significant barrier for students in understanding in-depth technical material. This phenomenon often leads to excessive cognitive load, which hinders knowledge transfer in the classroom. To address this cognitive barrier, the use of image-based instructional media and integrated visual aids has been proven effective in optimally supporting students' cognitive development (AlAli et al., 2024). Adequate visual stimulation through well-structured message design enables students to integrate abstract concepts, such as color spectra, current direction, and energy flow, into concrete and applicable technical understanding (Lo & Wang, 2024). Furthermore, innovation in instructional media design is a key factor in building students' situational awareness when facing real-world technical scenarios, where visual acuity in identifying system anomalies is essential (Snyder et al., 2019).

In addition to the visual aspect, the implementation of the Project-Based Learning (PBL) model is a crucial curricular strategy for developing problem-solving skills aligned with industry operational standards (Bin Abdul Wahab & Binti Husnin, 2025). The integration of PBL in renewable energy practicum requires the availability of non-static practicum devices. A modular curriculum approach that supports the concept of "plug-and-play" enables highly adaptive system

configurations across various laboratory practice scenarios, ranging from simple installations to complex systems (Mafukidze et al., 2024). With this modular system, instructors can develop more inclusive and dynamic simulation units that keep pace with global trends in solar-based automation in modern technical education (Mayub et al., 2025). This flexibility is essential to ensure that laboratory facility investments in schools remain sustainable and relevant to future solar technologies.

Although innovations in photovoltaic (PLTS) learning media continue to develop rapidly, most previous studies still focus partially on single functional aspects or merely on system data monitoring. For instance, research conducted by Ainah et al. and Ismawati et al. (2025) emphasizes the general impact of media on learning outcomes without exploring diverse system configurations in depth. Meanwhile, Febriyan et al. (2025) focus on developing IoT-based system integration for monitoring but have not addressed the aspect of physical configuration flexibility. On the other hand, Azizi Falaqi et al. (2024) developed a trainer specifically for smart microgrid simulation, which has high complexity but is difficult to apply to basic-level materials in secondary education. The research gap addressed in this study lies in integrating three main system configurations—Off-Grid, On-Grid, and Hybrid—into a single compact unit, which has not been extensively explored in technical education literature. In addition, in line with the focus of the *Jurnal Kajian Teknologi Pendidikan* on instructional design, this development also pays special attention to visual communication aspects and the effectiveness of message design in instructional materials to reduce students' cognitive load when learning complex hybrid systems. This aligns with strategic efforts to improve the quality of technical education through media that are adaptive to industry competency standards.

However, in reality, laboratory facilities in many vocational high schools currently fail to comprehensively represent photovoltaic system configurations, as existing equipment is typically limited to a single static system. A preliminary study conducted at SMKN 1 Kepanjen confirms this gap, revealing that 57.7% of students experience serious cognitive barriers in visualizing how photovoltaic systems work due to the lack of representative visual aids. This instructional problem is further exacerbated by time inefficiency in conventional practicum methods, which still heavily rely on loose components, causing practicum time to be spent mainly on basic assembly preparation rather than system analysis. This condition is highly detrimental to achieving students' competency targets. Therefore, this study aims to develop a Multi-Configuration Photovoltaic (PLTS) Trainer that innovatively integrates Off-Grid, On-Grid, and Hybrid systems into a single compact unit based on PBL jobsheets. This development is expected not only to provide a physical learning tool but also to bridge students' strategic competency gaps through a practical approach aligned with current renewable energy industry standards, thereby enhancing vocational graduates' work readiness in the green economy era.

METHOD

This study applies a Research and Development method by adapting the Design and Development Research (DDR) model (Richey & Klein, 2005). This research is categorized as type 1 research (Product and Tool Research), which aims to produce a specific product and to test its validity and practicality (Afriani et al., 2025). The relevance of this model is strengthened by previous studies that applied a similar systematic flow to produce vocational teaching materials that are valid and practical (Alsakarnah et al., 2023). The development procedure follows the systematic PPE model, consisting of three stages: Planning, Production, and Evaluation.

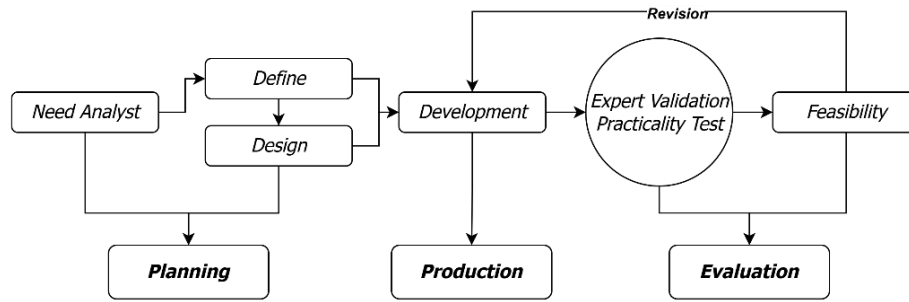


Figure 1. PPE Model Stages

The Planning stage involves a multidimensional gap analysis to determine product specifications. The needs analysis is conducted through student diagnostics to map cognitive constraints and learning preferences. Simultaneously, instructional analysis through teacher interviews identifies inefficiencies in current laboratory methods, while facility analysis inventories workshop assets as the basis for engineering design. In the Production stage, hardware development involves the fabrication of a Multi-Configuration PV Trainer (93 × 50 × 190 cm) using a modular architecture based on green design concepts and high-performance solar tracking principles (Afriani et al., 2025; Cao, 2023). At the same time, instructional materials and jobsheets are designed using visual communication innovation and design judgment principles to deliver accurate messaging in the digital era (Demiral-Uzan & Boling, 2024; Wynn & Maier, 2022). The Evaluation stage aims to verify the prototype quality through expert validation to assess construct and content integrity. Furthermore, practicality testing is conducted with a small group and a larger field sample to ensure user acceptance and tool functionality (Norliyana Md. Aris, 2024; Song et al., 2025).

This study was conducted at SMK Negeri (SMKN) 1 Kepanjen in the Industrial Electronics Engineering (TEI) department. The research subjects were determined using purposive sampling, involving 30 twelfth-grade students who possess prerequisite knowledge of solar energy systems to provide reliable user feedback (Ahmad & Wilkins, 2025; Ahmed, 2024). This selection process is vital to ensure that participants can provide representative functional evaluations of the tool within the context of vocational education (Baltes & Ralph, 2022; Crowley et al., 2023). To establish validity, an expert triangulation method was applied, involving academic and technical specialists to mitigate subjectivity (Barak et al., 2020; Chrobak et al., 2020). The instrumentation is segmented into media expert, material expert, and user response instruments, following strict guidelines to ensure the accuracy of qualitative measurement. All instruments use a 4-point Likert scale to eliminate neutral bias (Al-Mamary & Alshallaqi, 2022).

Quantitative data were analyzed using descriptive statistics to identify key performance features and determine the accuracy of the training system model. The mean score of each indicator was calculated and synthesized against the integrated curriculum framework to evaluate the effectiveness of the learning media (Lavado-Anguera et al., 2024; Picasso, 2002; Reeve & Cheon, 2021). This interpretative approach ensures that the sample size reaches adequate saturation to predict the reliability of the tool in complex energy environments (Ahmed, 2025; Lu et al., 2021). Data centralization (Mean, X) is calculated using the formula (Mean, X) (Joseph, 2022; Ni et al., 2024). The percentage results are then interpreted based on systematic classification guidelines detailed in Table 1. The product is declared pedagogically and technically feasible if it achieves a minimum threshold of $\geq 61.00\%$ based on the established interpretation criteria (Ahmadi et al., 2023; Milanez et al., 2023).

Table 1. Interpretation Criteria for Feasibility (Validity and Practicality)

Percentage (%)	Validity Criteria	Practicality Criteria	Follow-up
81,00 – 100,00	Very Valid	Very Practical	Eligible (No Revision)
61,00 – 80,00	Valid	Practical	Eligible (Minor Revision)
41,00 – 60,00	Less Valid	Less Practical	Major Revision
0,00 – 40,00	Not Valid	Not Practical	Not Eligible (Remake)

Based on the feasibility interpretation criteria, a development product is considered to meet technical and pedagogical feasibility standards if it achieves at least the “Valid” or “Practical” category with a percentage threshold greater than or equal to 61.00%. The determination of this standard is crucial to ensure that the Multi-Configuration PV Trainer produced is not only superior in terms of engineering but also possesses high reliability when implemented as a learning instrument in a complex workshop environment. If the evaluation results fall below this threshold, an iterative revision process is carried out following qualitative suggestions from experts in order to achieve the desired quality saturation before proceeding to a wider-scale trial.

RESULT

The implementation of the development framework through the Planning, Production, and Evaluation (PPE) model has successfully realized a prototype of the Multi-Configuration PLTS Trainer as an innovative laboratory learning medium. This main product is designed to bridge students’ cognitive gaps by providing a tangible visualization of complex solar power systems. The systematic transformation process from raw materials into a structured energy simulation unit is documented in Figure 2. The mechanical structure of the main frame utilizes galvanized hollow iron material measuring 4×4 cm with final dimensions of $93 \times 50 \times 190$ cm. To ensure corrosion resistance and meet laboratory aesthetic standards, the frame is coated with white duco paint. In the control panel fabrication stage, the use of 18 mm plywood covered with matte ritrama vinyl sticker serves as an important design intervention to eliminate light reflections that interfere with instrument readings. The electrical installation is carried out by organizing all main components, from monocrystalline solar panels to a pure sine wave inverter, where the rear panel wiring is neatly arranged within a cable duct to separate DC and AC 220V current paths in order to comply with Occupational Health and Safety (OHS) standards.

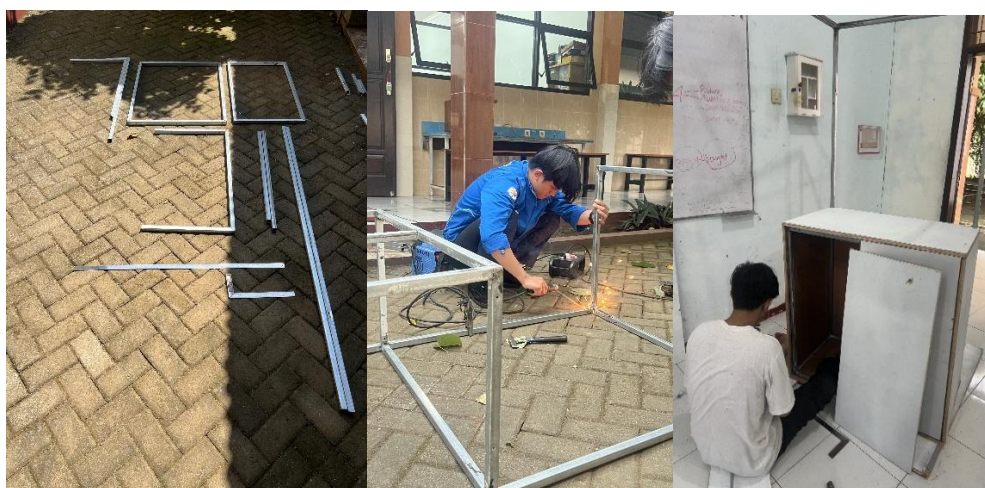


Figure 2. Fabrication process: (a) frame welding; (b) panel layout drilling; (c) electrical assembly and rear wiring

The final physical unit, which functions as a standalone mobile workstation, is presented in Figure 3. The most significant technical innovation of this prototype lies in its Multi-Configuration mechanism, facilitated by a banana plug safety connector terminal system. This feature enables rapid

reconfiguration between system topologies, including Off-Grid mode, On-Grid mode, and Hybrid mode utilizing an Automatic Transfer Switch (ATS). The implementation of this plug-and-play system is empirically designed to improve practicum setup time efficiency compared to conventional methods based on loose components.



Figure 3. Physical Appearance of the Multi-Configuration Solar Power Trainer

To strengthen the pedagogical value of the hardware, its development is synchronized with instructional software in the form of PBL-based practicum jobsheets, as shown in Figure 4. The structure of these jobsheets no longer relies on rigid procedural instructions but instead presents authentic problem scenarios that require students to perform systematic diagnosis of energy flow disruptions.

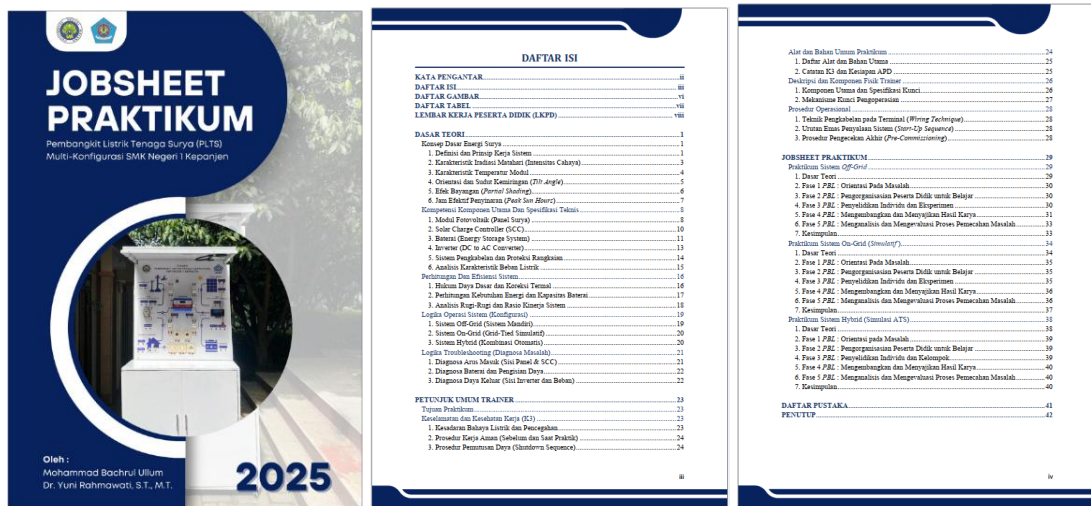


Figure 4. PBL-Based Jobsheet Display

The quality of the media was verified through expert triangulation involving academics and industry practitioners. The quantitative results of the media expert validation, which focused on technical quality and ergonomics, are summarized in Table 2.

Table 2. Summary of Media Expert Validation Results

Assessment Aspects	Percentage (%)
Technical Quality	95,23
Quality of Information & Symbols	95,00
Display Quality	95,00
Usefulness	95,83
Accessibility	95,83
Total Average	95,38

Based on the data in Table 2, the media validation achieved an average of 95.38%, placing the trainer in the very valid category. The highest scores were recorded in the domains of functional usability and accessibility, each obtaining a score of 95.83%. This empirically confirms that the developed plug-and-play connector system design is effective in facilitating laboratory practicum needs. The evaluation of the instructional software in the form of jobsheets was conducted by material experts to assess curriculum alignment and PBL syntax, with the results presented in Table 3.

Table 3. Summary of Material Expert Validation Results

Assessment Aspects	Percentage (%)
Material Quality	94,45
Presentation Quality	91,67
Application of the PBL Model	95,23
Learning Evaluation	87,5
Total Average	92,21

The indicators in Table 3 show that the material validation produced an average score of 92.21%, thereby being classified as very valid. A significant finding is observed in the aspect of PBL model implementation, which achieved a score of 95.23%. This high score confirms that the developed job sheets have successfully integrated the PBL syntax effectively to stimulate students' critical reasoning through authentic problem scenarios. The final stage of verification was conducted through a field trial involving 30 students to measure the level of practicality and user acceptance, as detailed in Table 4.

Table 4. Practical Results of Field Trials

Assessment Aspects	Percentage (%)
Learning Design	89,17
Visual Communication	92,50
Usefulness	88,75
Accessibility	90,42
Total Average	90,13

The results of the field trial in Table 4 indicate an overall practicality level of 90.13%. The visual communication aspect obtained the highest score of 92.50%, which indicates that the use of this visual instructional media greatly assists students in clarifying PLTS concepts that were previously abstract. In addition, the accessibility score of 90.42% confirms that the design of the physical unit and the readability of instructions in the jobsheets are able to effectively support independent learning processes in the workshop environment.

DISCUSSION

The success of developing the Multi-Configuration PLTS Trainer is rooted in the implementation of a systematic procedure based on the Planning, Production, and Evaluation (PPE) model, carried out in a measurable and methodological manner (Richey & Klein, 2005). This methodological rigor ensures that each phase of development, from initial gap analysis to empirical testing, is directed toward addressing real needs in the field. Theoretically, the integration of technology in educational research is a key factor in improving the quality of technical training in the digital era (Al Husaeni

dkk., 2024). During the planning stage, this study identified a significant “cognitive gap” at SMK Negeri 1 Kepanjen, where it was found that 57.7% of students experienced difficulties in visualizing photovoltaic processes due to the lack of integrative instructional tools. This finding highlights a critical issue in conventional vocational training, where the use of loose components tends to consume a significant amount of time merely for basic assembly (setup time). This inefficiency ultimately reduces students’ opportunities to engage in deeper system analysis and fault diagnosis, even though these skills are central to the green skills highly demanded by the industry today (Nguyen dkk., 2023).

In response to this inefficiency, the production stage focused on engineering solutions through the integration of main components into a single compact unit equipped with a plug-and-play connector system as its main feature. This innovation is strategically designed based on the principles of Cognitive Load Theory to reduce students’ cognitive load, which has previously been burdened by the complexity of repetitive basic technical assembly. Theoretically, modular design facilitates users in mapping the function of each component and accelerates understanding of complex system structures compared to monolithic systems (Zhang dkk., 2022). By minimizing technical assembly barriers through rapid connection terminals, students’ attention and cognitive resources can be fully directed toward understanding electrical logic and energy conversion characteristics more comprehensively. This validates the principle that ergonomically designed physical media are directly proportional to the effectiveness of mastering technical competencies, where modular learning environments support higher instructional efficiency and better curriculum flexibility (Mafukidze dkk., 2024).

The analysis of expert validation data, with media experts scoring 95.38% and material experts scoring 92.21%, provides strong empirical evidence of the product’s feasibility from both engineering and pedagogical perspectives. The product’s reliability is further reinforced by field trial results reaching 90.13%, indicating that this media is highly accepted by end users due to its user-friendly nature. An interesting finding emerges from the high visual communication score of 92.50%, which indicates that the physical design of the trainer successfully demystifies abstract PLTS concepts into tangible learning experiences for students. Structured visual stimulation through this innovative media design significantly aids in building students’ situational awareness when facing real-world technical scenarios (Snyder dkk., 2019). This is consistent with findings that the use of relevant instructional images is a vital pedagogical tool for enhancing technical understanding and accelerating the integration of information into students’ long-term memory.

The high media validation score of 95.38% is not solely based on quantitative data but is also supported by qualitative feedback from experts, reflecting the importance of feedback systems in product development (Wynn & Maier, 2022). Media expert validators stated that the installation of components on the panel is very neat and that the layout greatly facilitates students in understanding electrical pathways. However, to improve safety standards, validators suggested that the rear area of the trainer be equipped with a cover to protect sensitive components while also enhancing the tool’s aesthetics. In addition, the presence of visual boundary lines between PV components, control, and load blocks is considered highly beneficial for students’ visual orientation in the field. The use of clear labeling enables students to integrate abstract concepts such as energy flow, voltage changes, and power conversion into concrete technical understanding through adequate visual stimulation (Lo & Wang, 2024). Positive student responses indicating that they better understand PLTS processes in practice compared to theory alone further confirm the crucial role of interactive media in enhancing attention in vocational schools.

Beyond the physical aspects, the integration of PBL-based instructional tools provides a significant impact on strengthening critical reasoning. The structure of the jobsheets, which presents troubleshooting scenarios, requires students to independently diagnose anomalies in current and voltage flow, a competency that is difficult to achieve through conventional instructional methods. This shift from “passive assembly” to “active analysis” is essential in fostering Higher-Order Thinking Skills (HOTS). The implementation of active learning models supported by appropriate practicum media has been proven to reduce competency gaps and improve the ability to “learn how to learn” through direct interaction with equipment. These skills align with industry demands for “Green Talent” who are not only skilled in assembly but also capable of independently solving real-world technical challenges (Theobald dkk., 2020). The use of PBL has been shown to effectively enhance students’ critical thinking and collaboration skills in productive subjects, ultimately increasing productivity through real problem-solving (Bin Abdul Wahab & Binti Husnin, 2025).

From the material aspect, the integration of PBL syntax is considered highly systematic and relevant to learning outcomes in vocational schools. Another important finding is the urgency of strengthening Occupational Health and Safety (OHS) procedures in every practicum step. Material experts emphasized that each experiment should include an industry-standard Single Line Diagram as a primary reference for students. This confirms that the media functions not only as a practical tool but also as a means of instilling a professional work culture aligned with green energy transition standards. By habituating students to work using industry-standard protocols from an early stage, their transition from education to the workforce is expected to be smoother and more effective, especially amid the rapid evolution of photovoltaic industry technology.

The relevance of this development is also supported by industry demands for human resources capable of adapting to various energy scenarios in the field, including Off-Grid systems, grid synchronization (On-Grid), and automatic power management (Hybrid). By equipping students with multi-configuration simulations within a single practicum session, they gain a comprehensive perspective on modern energy system integration. This is crucial considering that educational institutions are now required to function as centers for development and innovation to prepare graduates who are relevant to the needs of the modern energy industry. Furthermore, mastery of solar energy adoption in both residential and industrial sectors is a vital element in supporting sustainable development. Overall, this innovation provides a solution to the limitations of practicum facilities in vocational schools and acts as a catalyst for transforming the quality of vocational education to produce a workforce ready to face the green energy transition era in alignment with sustainable development goals (Zheng dkk., 2025).

As a broader implication, the development of this trainer supports the achievement of sustainable development goals through the integration of green technology and digital innovation into the curriculum. Early understanding of renewable energy system operations and awareness of green finance policies prepares students to actively participate in a sustainable economy that is a primary focus of future development. In the future, the integration of Internet of Things (IoT)-based monitoring can be considered to enhance real-time data analysis capabilities in accordance with the demands of the Industrial Revolution 4.0 (Febriyan dkk., 2025). This step will ensure that vocational school graduates are not only manually competent but also adaptive to increasingly intelligent and connected industrial ecosystems, and capable of applying environmentally friendly automation technologies in various practical applications.

CONCLUSION

This study successfully concludes that the development of a Multi-Configuration Solar Power Plant (PLTS) Trainer integrated with PBL-based jobsheets is a highly feasible and effective learning

media solution for implementation in vocational high schools. The findings indicate a very high level of validity, with media expert scores reaching 95.38% and material expert scores at 92.21%, confirming that the product meets industrial engineering standards as well as curriculum alignment. In addition, the practicality level of 90.13% demonstrates that this media is highly user-friendly in assisting students to visualize complex solar energy conversion concepts into concrete learning experiences. The main implication of this development is the creation of practicum setup time efficiency through the plug-and-play feature, allowing the learning focus to be fully directed toward strengthening critical reasoning and troubleshooting skills relevant to the demands of the “Green Talent” workforce. As a recommendation for further development, the integration of Internet of Things (IoT)-based monitoring systems and the addition of more varied fault scenarios are suggested to enhance students’ analytical sharpness in line with the demands of the Industrial Revolution 4.0.

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