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Development of an IoT-Based Solar Power Plant (PLTS) Experimental Kit as a CPS–STEM Learning Media in Junior High School

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ABSTRACT

Science learning in junior high schools is still dominated by abstract and teacher-centered approaches, failing to realize the principles of pedagogical Deep Learning, which emphasizes mindful, meaningful, and joyful student understanding. This study aimed to develop an Internet of Things (IoT)-based Solar Power Plant (PLTS) experiment kit as a valid, practical, and effective Creative Problem Solving–STEM learning media. The study employed a 4D development model (Define, Design, Develop, Disseminate) with a one-group pretest-posttest design. The developed product consisted of solar panels, a Solar Charge Controller, a battery, and an inverter, integrated with an ESP32-based IoT module, relays, sensors, and the Telegram Bot platform. Validation was conducted by five experts using the Content Validity Index (CVI). The research subjects were 104 ninth-grade students at SMP Negeri 02 Semendawai Timur. The results showed that the IoT-based PLTS experiment kit was highly valid (CVI = 0.90) and very practical, with an average learning implementation of 84.75% and a positive student response of 89.03%. Furthermore, the kit was effective in improving students' Creative Problem Solving abilities, achieving an N-gain value of 0.53 (moderate category). This IoT-based PLTS experiment kit provides a learning experience that aligns with the demands of Industrial Revolution 4.0 and the principles of holistic educational Deep Learning.

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1. INTRODUCTION

Science learning in junior high schools still faces challenges in helping students understand abstract and less contextual concepts. As a result, students often perceive these concepts as difficult and irrelevant to everyday life, which contributes to Indonesia's low scientific literacy, consistently below the OECD average in PISA (Sinurat et al., 2026; Herlina et al., 2025; OECD, 2023). This challenge is particularly evident in topics such as work, energy, and electricity, where a predominantly theoretical approach reduces student engagement and limits the development of scientific literacy skills. Such literacy is essential in the 21st century for understanding phenomena, making data-based decisions, and solving real-world problems (Kholifatur Rosidah & Laily Rosdiana, 2019; Rahman, 2020).

To address these challenges, the Creative Problem Solving (CPS) learning model integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach is considered capable of creating learning experiences aligned with the principles of Deep Learning. The CPS model guides students through structured stages of thinking-fact finding, problem finding, idea finding, solution

finding, and acceptance findin -so that the learning process occurs systematically and creatively (Chen et al., 2021; Elma et al., 2022; Tupthong & Chatwattana, 2025). When applied within a STEM framework, thinking is stimulated through technical analysis and design; attitudes are developed through collaboration and environmental awareness; creativity is fostered through product design aesthetics; and psychomotor skills are engaged through hands-on activities such as assembling devices (Kelley & Knowles, 2016; Utari et al., 2023; BSKAP, 2025). Thus, the integration of CPS and STEM becomes a holistic pedagogical framework for promoting Deep Learning in science classes.

In the context of global issues, learning about renewable energy, such as solar power plants (PLTS), is crucial to introduce at an early stage to foster creative thinking (Kayohana et al., 2023; Marlina et al., 2025). However, energy-related learning tends to be theoretical and often lacks hands-on experience for students. The integration of Internet of Things (IoT) technologies, such as ESP32, sensors, and cloud-based applications, can enrich learning by providing real-time energy monitoring and control systems, thereby enhancing its relevance to current technological developments.

In conventional electricity learning, students generally rely on textbooks, static images, or simple experiments that only demonstrate electrical concepts passively without real-time interaction or automated system control. As a result, learning tends to be less contextual and does not fully represent how modern electrical systems operate in everyday life. In contrast, the integration of Internet of Things (IoT) technology enables students to monitor and automatically control electrical systems through smartphones using connected digital platforms. Through the ESP32 and Telegram Bot system, students can directly observe changes in electrical conditions and remotely control electrical loads in real time. This capability provides authentic and interactive learning experiences that cannot be achieved through conventional learning media. Therefore, IoT-based learning media offer significant advantages in supporting CPS–STEM learning and the implementation of Deep Learning principles in dynamic electricity learning.

In line with this, the modern educational paradigm emphasizes the importance of Deep Learning, an approach that values students through mindful, meaningful, and enjoyable learning experiences (Kovač et al., 2023; Y. Rahmawati et al., 2025). This approach holistically integrates intellectual, ethical, aesthetic, and kinesthetic dimensions of learning. Project-based learning in STEM has been shown to create contextual, active, and meaningful learning experiences, thereby aligning with the principles of Deep Learning (Azizah & Angelina, 2025).

Previous studies have shown that STEM-based learning media can improve students' scientific literacy (Rahmatina et al., 2019; Rahman, 2020; Lugi et al., 2026). However, research focusing on the design of solar power plant kits integrated with IoT modules as an implementation of the CPS–STEM learning model for junior high school students remains limited (Prabowo & Irwanto, 2023). Therefore, this study aims to develop an IoT-based solar power plant experimental kit as a CPS–STEM learning media in junior high schools using the 4D development model (Define, Design, Develop, Disseminate). The developed product is expected to meet the criteria of validity, practicality, and effectiveness in supporting the implementation of the CPS–STEM learning model.

2. METHODS

This study employed the 4D development model Define, Design, Develop, and Disseminate (Thiagarajan & Sivasailam, 1974; Pratama et al., 2022) with a one-group pretest–posttest design. The study examined the use of an IoT-based solar power plant (PLTS) experimental kit in implementing the CPS–STEM learning model and improving students' creative problem-solving abilities. The experimental kit was validated by three experts (two science teachers and one informatics teacher). The learning process was conducted through project-based activities using the Creative Problem Solving (CPS) model integrated with the STEM approach, including the stages of fact finding, problem finding, idea finding, and solution finding (Chen et al., 2021). The participants were 104 ninth-grade students from SMP Negeri 02 Semendawai Timur, East OKU, in the 2025/2026 academic year.

Most students were already familiar with basic digital technologies, such as smartphones and social media applications. However, they had limited experience with IoT systems, microcontroller programming, and real-time electrical monitoring technologies. Prior to the implementation of the learning activities, the students had never used ESP32-based devices or Telegram Bot systems in

science learning. Therefore, the developed IoT-based PLTS kit provided a new and contextual digital learning experience for the participants.

The developed product was a solar power plant (PLTS) experimental kit consisting of core components, namely solar panels, a Solar Charge Controller (SCC), batteries, and an inverter, which were integrated with an ESP32 microcontroller-based IoT module, relays, and light and voltage sensors, as well as a Telegram Bot platform for real-time monitoring via smartphones. The development of the PLTS and IoT experimental kit was complemented by a CPS–STEM student worksheet (LKPD) and an assessment instrument to measure students' Creative Problem Solving (CPS) abilities.

The following is the procedure for implementing the research.



Figure 1. Development Stages of an IoT-Based Solar Power Plant Experiment Kit

Data were collected using four instruments: (1) an expert validation sheet to assess validity, (2) a learning implementation observation sheet to assess practicality, (3) Creative Problem Solving (CPS) pretest–posttest questions to assess effectiveness, and (4) a student response questionnaire using a five-point Likert scale. The validity of the kit and the LKPD was analyzed using the Content Validity Index (CVI), with a minimum acceptable value of 0.78 (A. N. Rahmawati & Setiawan, 2025). Effectiveness was measured using the normalized gain (N-gain), categorized as high (>0.7), medium (0.3–0.7), and low (<0.3) (Hake, 1998; Evriza, 2025). Student responses were analyzed descriptively.

The following presents a grid of pretest and posttest questions designed to assess Creative Problem Solving (CPS) abilities in the form of essay items, along with the corresponding stages and

indicators of the CPS model. The pretest was administered before students participated in learning using the kit, while the posttest was administered after the completion of the CPS–STEM learning activities. Both sets of questions were based on the same indicators but used different stimuli and problem contexts to minimize memorization effects. The grid of the pretest and posttest instruments is presented in Table 1.

Tabel 1. CPS-STEM Pretest and Posttest Question Instrument Grid

Stages of CPS	Indicator	Question Format	Question Number
Fact finding	Presented with a picture of the PLTS kit circuit, students can identify the name and function of each component of the PLTS kit (solar panel, SCC, battery, and inverter) correctly.	Essay	1, 2
Fact finding	Presented with data from measuring the voltage and current of solar panels under different light conditions, students can read, record and interpret the data correctly.	Essay	3
Problem finding	When presented with a statement about a suboptimal PLTS kit condition, students are able to formulate problems in the PLTS system based on the provided observation data.	Essay	4, 5
Problem finding	Given a statement about a simple ESP32 based IoT circuit and a relay that is not responding properly, students can identify possible causes of problems in the system.	Essay	6
Idea finding	Presented with a problem of electrical energy needs in the school environment, students can produce at least three creative ideas that are original in nature related to the use of solar power kit energy using an ESP32 and Telegram-based IoT system.	Essay	7, 8
Idea finding	Presented with a simple problem in the surrounding environment, students can design a simple IoT system scheme using ESP32, relays, and Telegram Bots as a solution for utilizing solar power energy.	Essay	9
Solution finding	When presented with several alternative ideas for utilizing IoT-based PLTS energy, students are able to evaluate each alternative and determine the best solution based on criteria such as feasibility, efficiency, and benefits for everyday life	Essay	10, 11
Solution finding	When presented with a problem related to the utilization of PLTS energy in home or school environments, students are able to develop simple procedural steps to implement an IoT-based solution using available components such as ESP32, relays, sensors, and a Telegram Bot.	Essay	12
Total			**12**

3. RESULT AND DISCUSSION

3.1 Results

3.1.1. Product Description of IoT-Based Solar Power Plant Experiment Kit

The product developed in this study was an IoT-based solar power plant (PLTS) experiment kit designed as a CPS–STEM learning media for junior high school students. The kit consisted of two integrated subsystems: (1) the PLTS subsystem, which included solar panels, a Solar Charge Controller (SCC), a battery, and an inverter; and (2) the IoT subsystem, which included an ESP32 microcontroller, relays, light and motion sensors, and a Telegram Bot platform for real-time monitoring via smartphones. Students first assembled the PLTS subsystem and then independently explored the development of IoT applications based on the generated energy, following the stages of the CPS model. In addition to the kit, a Student Worksheet (LKPD) containing CPS–STEM syntax was developed to guide students' exploration during the learning process.

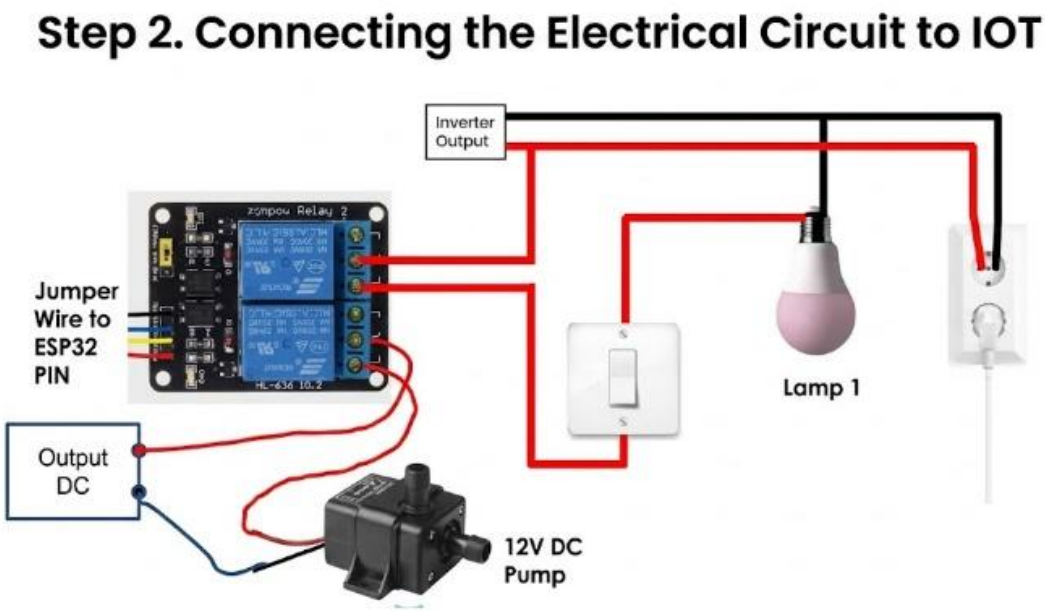


Figure 2. Student exploration guide



Figure 3. IoT-based solar power plant experiment kit product

3.1.2. Validity of IoT-Based Solar Power Plant Experiment Kit

The validity of the IoT-based solar power plant (PLTS) experimental kit and the student worksheets (LKPD) was evaluated by three experts two science teachers and one informatics teacher using a validation sheet and analyzed through the Content Validity Index (CVI). A summary of the validation results is presented in Table 2.

Tabel 2. CPS-STEM Pretest and Posttest Question Instrument Grid

Number	Validation Indicator	CVI	Category
1	Suitability of kit components with the basic science competencies of junior high school	0,92	highly valid
2	Safety and security of use of the kit	0,94	highly valid
3	Ease of assembling the PLTS subsystem	0,88	Valid
4	Ease of assembling IoT subsystems (ESP32, relay, Telegram Bot)	0,86	Valid
5	Compliance of LKPD with CPS model syntax	0,90	highly valid
6	Ease of readability of LKPD for junior high school students	0,89	Valid
7	Integration of kits with a STEM approach	0,93	highly valid
CVI Keseluruhan		0,90	highly valid

Based on Table 2, the overall CVI value of the IoT-based solar power plant (PLTS) experimental kit was 0.90, which falls into the highly valid category. All validation indicators achieved CVI values ≥ 0.86, exceeding the minimum validity threshold of 0.78 (Humairoh et al., 2025). The highest CVI values were observed in the safety and operational security indicators (0.94) and the integration of the kit with the STEM approach (0.93), while the lowest CVI value was found in the ease of assembling the IoT subsystem (0.86). This relatively lower score was attributed to the complexity of ESP32 programming, which validators indicated still required simplification for the junior high school level. Therefore, revisions were made by adding a step-by-step programming guide to the LKPD. These findings indicate that the IoT-based PLTS experimental kit is highly valid and suitable for use as a CPS–STEM learning media in junior high schools.

3.1.3. Practicality of IoT-Based Solar Power Plant Experiment Kit

The practicality of the experimental kit was evaluated using two instruments: a learning implementation observation sheet and a student response questionnaire. The results of the observation of the implementation of the CPS–STEM learning model syntax during the learning process are presented in Table 3.

Tabel 3. Observation Results of the Implementation of CPS-STEM Learning

Number	Stages of CPS	Implementation Indicators	Persentase (%)	Category
1	Fact finding	Students identify the components and output data of the solar power plant kit.	88	Very Good
2	Problem finding	Students formulate problems from the results of their observations.	85	Very Good
3	Idea finding	Students generate ideas for developing IoT applications	82	Good
4	Solution finding	very good	84	Very Good
Overall Average			84,75	Very Good

Student responses to the use of the IoT-based solar power plant (PLTS) experimental kit in CPS–STEM learning were evaluated using a five-item questionnaire. The results of the student response questionnaire are presented in Table 4.

Tabel 4. Observation Results of the Implementation of CPS-STEM Learning

Number	Statement	Yes (%)	No (%)
1	Represents a novel learning experience	92,30	7,70
2	Enhances interest in learning	88,46	11,54
3	Encourages task completion	84,61	15,39
4	Increases motivation	90,38	9,62
5	Enhances willingness to learn	89,42	10,58
Average		89,03	10,97

Based on Tables 3 and 4, the average implementation rate of all CPS–STEM stages reached 84.75%, categorized as very good. The highest level of implementation was observed in the fact-finding stage (88%), as activities such as identifying components and measuring the output of the solar power plant provided concrete learning experiences. Meanwhile, the lowest implementation was found in the idea-finding stage (82%), which still fell within the good category, due to the need for more intensive teacher guidance when students developed IoT application ideas independently. The questionnaire results showed that an average of 89.03% of students responded positively to all items. The highest positive response was recorded for the statement that the IoT-based solar power plant kit was a novel experience for students (92.30%), while the lowest was related to the statement that the kit encouraged task completion (84.61%), although this value remained well above the 75% threshold. These findings indicate that the IoT-based solar power plant experiment kit is practical for use in CPS–STEM learning in junior high schools.

3.1.4. Practicality of IoT-Based Solar Power Plant Experiment Kit

The effectiveness of the IoT-based solar power plant experimental kit was measured by improving students' CPS abilities using normalized gain (N-gain) from the pretest and posttest results. The results of the pretest and posttest of students' CPS abilities are presented in Table 5.

Tabel 5. Pretest and Posttest Results of Students' CPS Abilities

Number	Stages of CPS	Rata-rata Pretest	Rata-rata Posttest	*N-gain*	Kategori
1	Fact finding	55,2	80,1	0,56	Moderate
2	Problem finding	53,8	78,4	0,53	Moderate
3	Idea finding	50,6	75,2	0,50	Moderate
4	Solution finding	52,9	77,8	0,53	Moderate
Overall Mean		53,1	77,9	0,53	Moderate

Based on Table 5, the overall N-gain value of students' Creative Problem Solving (CPS) abilities was 0.53, which falls into the moderate category ($0.3 < \text{N-gain} < 0.7$). The highest improvement was observed in the fact-finding stage (N-gain = 0.56), as activities such as identifying components and measuring solar power plant output provided concrete learning

experiences that facilitated students' understanding of scientific concepts. The lowest improvement was found in the idea-finding stage (N-gain = 0.50), indicating that the ability to generate creative ideas divergently requires more intensive practice and stimulation. Nevertheless, all CPS stages fell within the moderate category and exceeded the minimum N-gain threshold of 0.30. Therefore, the IoT-based solar power plant (PLTS) experimental kit was effective in improving students' CPS abilities in STEM learning at the junior high school level (Hake, 1998; Evriza, 2025)

3.2 Discussion

3.2.1. Validity of the IoT-Based Solar Power Plant Experiment Kit

The validation results showed that the IoT-based solar power plant (PLTS) experimental kit achieved an overall CVI value of 0.90, categorized as highly valid. This finding is consistent with that of Rahman (2020), who reported a CVI value of 0.86 for STEM-based aquaponics–electromagnetic induction media, and indicates that project-based learning media systematically developed using the 4D model can produce products with a high level of validity. The high CVI score for the safety and operational security indicators (0.94) reflects that the IoT-based PLTS kit was designed with careful consideration of occupational safety aspects for junior high school students, given that the kit involves real electrical components such as solar panels, batteries, and relays. This finding is also aligned with the principles of Deep Learning, which emphasize the importance of a safe and supportive learning environment as a prerequisite for achieving mindful learning (Kemendikdasmen, 2025).

The high CVI value for the integration of the kit with the STEM approach (0.93) confirms that the IoT-based solar power plant (PLTS) kit successfully integrates the four STEM elements in an authentic manner: science through the concept of solar energy conversion, technology through the Telegram Bot platform, engineering through the assembly process of the PLTS and IoT systems, and mathematics through the measurement and analysis of voltage and current data. This authentic integration of STEM represents a key requirement of project-based learning for developing students' higher-order thinking skills (Kelley & Knowles, 2016; Humairoh et al., 2025).

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The lowest CVI value was observed in the indicator of ease of assembling the IoT subsystem (0.86), which provided constructive feedback. This issue was addressed through revisions by adding a step-by-step ESP32 programming guide to the LKPD, ensuring that technical complexity does not become a barrier for junior high school students in exploring the IoT system.

3.2.2. Practicality of IoT-Based Solar Power Plant Experiment Kit

The results of the learning implementation observation showed an average score of 84.75%, categorized as very good, while the average positive student response reached 89.03%. Both results exceeded the minimum practicality threshold of 75%, indicating that the IoT-based solar power plant (PLTS) experimental kit was practical for use in CPS–STEM learning at the junior high school level.

The highest level of implementation was observed in the fact-finding stage (88%), indicating that activities such as assembling and directly measuring the output of the solar power plant effectively positioned students as active learners who observe, record, and analyze real data. This finding reflects the realization of the intellectual dimension of Deep Learning, in which students do not merely receive information but actively construct knowledge through direct experience (Kemendikdasmen, 2025).

The lowest implementation rate was observed in the idea-finding stage (82%), which still falls within the good category, suggesting that divergent thinking skills particularly the ability to

generate diverse creative ideas for IoT application development require more intensive teacher scaffolding. This finding is consistent with that of (Chen et al., 2021), who reported that the idea-finding stage in the CPS model is the most challenging for students, as it requires them to think beyond conventional patterns. Therefore, the teacher's role as a facilitator who provides appropriate stimuli and encouragement, without restricting students' creativity, is crucial at this stage.

The highest positive student response was observed for the statement that the IoT-based solar power plant (PLTS) kit was a novel experience (92.30%). This finding indicates that students had not previously experienced science learning using real technological devices such as solar panels, ESP32, and IoT platforms, and that the kit successfully provided a fresh and engaging learning experience. The high positive responses to the statements related to motivation (90.38%) and increased willingness to learn (89.42%) are consistent with the findings of (Rahman, 2020), which showed that contextual STEM-based learning media can significantly enhance students' intrinsic motivation.

This condition reflects the realization of a joyful learning environment, as emphasized in the principles of Deep Learning (Y. Rahmawati et al., 2025). In contrast, the lowest positive response was observed for the statement that the kit encouraged task completion (84.61%), indicating that some students still required stronger external support from teachers in completing IoT assembly and programming tasks, particularly when facing technical challenges in ESP32 configuration and Telegram Bot integration.

3.2.3. Effectiveness of IoT-Based Solar Power Experiment Kit

The pretest and posttest results showed an improvement in students' Creative Problem Solving (CPS) abilities, with an overall N-gain value of 0.53, which falls into the moderate category. This result is comparable to the findings of Rahman, (2020) , who reported an N-gain of 0.36 in the moderate category for scientific literacy using STEM-based aquaponics–electromagnetic induction media, and even indicates a higher level of improvement in the present study.

The moderate category achieved across all CPS stages fact finding (0.56), problem finding (0.53), idea finding (0.50), and solution finding (0.53) suggests that a single learning cycle using the IoT-based PLTS kit had a significant positive impact on the development of students' CPS abilities, although it has not yet reached the high category.

The highest improvement was observed in the fact-finding stage (N-gain = 0.56), which can be explained by the advantages of hands-on, experimental kit–based learning. When students directly assemble solar panels, measure voltage using a multimeter, and monitor data via a Telegram Bot dashboard, they are exposed to concrete and measurable scientific facts. This type of learning experience is more effective in developing fact-finding skills than presenting information through textbooks or lectures (Sulistyawan, 2020). This finding is aligned with the principles of Deep Learning, which emphasize the activation of thinking through meaningful, hands-on experiences (Kemendikdasmen, 2025).

The lowest improvement was observed in the idea-finding stage (N-gain = 0.50), which is consistent with the results of the implementation observation that also showed the lowest achievement at this stage. The ability to generate creative ideas is a higher-order cognitive skill that cannot be developed instantly through a single learning cycle (Dian et al., 2024). Nevertheless, the improvement observed in the idea-finding stage remains significant, as students who were previously unexposed to IoT concepts (pretest = 50.6) were able to generate various ideas for solar power–based IoT applications after participating in the learning process (posttest = 75.2). This finding demonstrates that the authentic solar power–IoT context, which is closely related to students' daily lives, effectively stimulates their creative thinking skills.

Overall, the N-gain value of 0.53 confirms that the IoT-based solar power plant (PLTS) experimental kit is effective as a CPS–STEM learning media in junior high schools. The integration of the CPS model with the STEM approach through a concrete kit has been shown to shift science learning from a teacher-centered and abstract approach to a student-centered, contextual, and authentic learning environment (Kelley & Knowles, 2016; Sulistyawan, 2020). Moreover, by providing students with the opportunity to explore the development of IoT applications based on the

energy they generate, the learning process becomes fully mindful, meaningful, and joyful—three core principles of Deep Learning that form the philosophical foundation of this study (Kemendikdasmen, 2025).

4. CONCLUSION

This study successfully developed an IoT-based solar power plant (PLTS) experimental kit as a CPS–STEM learning media in junior high schools that meets the criteria of validity, practicality, and effectiveness. These criteria were consistently achieved: the kit was highly valid, with an overall CVI value of 0.90; highly practical, with an average learning implementation of 84.75% and an average positive student response of 89.03%; and effective in improving students' Creative Problem Solving abilities, with an N-gain value of 0.53 in the moderate category.

This achievement addresses the expectations outlined in the introduction of this study, namely that science learning in junior high schools requires learning media capable of realizing the principles of mindful, meaningful, and joyful Deep Learning through authentic and contextual learning experiences. Through the IoT-based solar power plant (PLTS) kit, students no longer learn science in an abstract and passive manner; instead, they actively assemble real components, analyze solar energy data in real time, and creatively develop IoT applications based on the energy they generate.

This process activates the four dimensions of Deep Learning holistically: cognitive engagement through data analysis and ESP32 programming, affective engagement through awareness of renewable energy issues, creative expression through the design of IoT solutions, and physical engagement through hands-on activities in assembling the PLTS system. Thus, the IoT-based PLTS kit serves as an effective medium for implementing the CPS–STEM learning model, aligned with the direction of national education policy in realizing the Graduate Profile dimensions as outlined in Permendikdasmen No. 10 of 2025.

Future research can be directed toward several development pathways. First, the development of kits with larger solar panel capacities and more diverse IoT components, such as weather sensors, cameras, and cloud connectivity, may enable the exploration of more complex applications and approach real-scale photovoltaic (PV) systems. Second, the integration of artificial intelligence into the Telegram Bot monitoring system can provide a learning experience that is more aligned with the demands of the Industrial Revolution 4.0. Third, the effectiveness of the kits can be tested on a broader scale through an experimental research design involving multiple schools in different regions, in order to obtain stronger empirical evidence regarding the generalizability of the kits' impact on students' CPS abilities. Fourth, the development of kit-based PLTS-IoT learning modules can be pursued.

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