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Strengthening physics teachers' green energy competence through solar cell-based teaching aids

Riza Ariyani Nur Khasanah, Rida Siti Nur' aini Mahmudah, Restu Widiatmono, Denny Darmawan, Mona Sari, Herliana Amanda Darmasanti, Daffa Malik Ashari, Ferdi Nugraha Pratama

Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta
Jl. Colombo No. 1, Karangmalang, Caturtunggal, Depok, Sleman, Special Region of Yogyakarta 55281, Indonesia

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ABSTRACT

Renewable energy remains an important topic in physics; however, it receives limited coverage in senior high school curricula in Yogyakarta, and teachers rarely use instructional media, which may hinder students' conceptual understanding of green energy. This community service program aims to enhance the understanding of green energy among physics teachers in Yogyakarta, particularly senior high school teachers, through training in the development of solar cell-based teaching aids. The program was implemented in two main sessions: an onsite workshop and online monitoring. Thirty senior high school physics teachers participated in the program. The workshop included a pre-test, theoretical sessions, demonstrations of solar cell-based teaching aids with Arduino integration, group practice in developing a simple solar cell-based, and a post-test. Results showed a significant improvement in the understanding of green energy among participants, with the average score increasing from 82.2 to 97.1 and a normalized gain of 0.84. Participant satisfaction reached 93 percent for training materials, 86.7 percent for instructors/facilitators, and 73 percent for facilities/media. These findings indicate that training and teaching aid in developing solar cell improved teachers' understanding of green energy and supported the dissemination of renewable energy knowledge to students, ultimately strengthening science education in senior high schools.

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1. INTRODUCTION

Physics teachers play a crucial role in helping students understand renewable energy by demonstrating its connection to fundamental physical principles. Renewable energy provides a relevant context for physics education through energy conversion, electricity generation, and the application of scientific concepts to real-world technologies (Bustomi et al., 2025; Pambudi et al., 2024; Pramartaningthyas et al., 2026; Widagdo et al., 2024). Effective instructions regarding this supports students' conceptual understanding and energy literacy while fostering awareness of sustainable energy use at the same time (Pramartaningthyas et al., 2026; Sianturi et al., 2024). However, facilitating such learning requires instructional media that enable students to observe physical phenomena, conduct measurements, and connect theoretical concepts with practical applications (Irfan et al., 2025).

✉ Corresponding Author: **Riza Ariyani Nur Khasanah**: Tel. +62 274 586168 | E-mail: rizaariyani@uny.ac.id

Teaching aids are therefore essential for making abstract physical concepts more accessible through direct observation and experimentation (Istiqomah et al., 2024; Lukma et al., 2023; Widagdo et al., 2024). In this matter, solar cells are particularly relevant because they demonstrate the conversion of sunlight into electricity through the photovoltaic effect and enable students to investigate electrical circuits and the connection between light intensity and electrical output through direct measurement (Sumarah & Wulandari, 2025; Wahidin et al., 2024). However, a preliminary needs assessment involving three physics teachers from three senior high schools in Yogyakarta identified limitations in the availability of solar cell teaching aids. The teachers also reported difficulties in demonstrating the photovoltaic effect, conducting electrical measurements, and utilizing Arduino-based systems. These findings indicate a need for practical training and support to help teachers develop and use solar cell-based instructional media for renewable energy education.

Solar cell kits are commercially available, yet their instructional capabilities vary depending on their design and features. Some kits primarily support demonstrations of photovoltaic energy conversion, whereas their capacity to support deeper investigations of underlying physical mechanisms, inquiry-based learning, and adaptation to different educational levels may vary (Lukma et al,, 2023; Sumarah & Wulandari, 2025; Widagdo et al., 2024; Yulia, et al., 2024). Therefore, providing teachers with appropriate technical knowledge and hands-on experience is important to enable them to integrate solar cell technology into physics learning activities (Wahidin et al., 2024). Training programs that combine conceptual explanations, practical assembly, electrical measurements, and Arduino-based activities may help address the needs identified in the preliminary assessment (Lukma, et al., 2023; Wijaya et al., 2023).

In response to these needs, this community service program was designed to strengthen the knowledge and practical skills of senior high school physics teachers in Yogyakarta, Indonesia, in designing, assembling, and using solar cell-based teaching aids. The program supports the senior high school physics curriculum in Indonesia by promoting contextual, inquiry-based, and project-based learning approaches (Husnadi et al., 2024; Wijaya et al., 2023). Through this activity, teachers are expected to enhance their competence, inspire student engagement, and foster understanding of renewable energy (Siswanto et al., 2024). Ultimately, this initiative contributes to the national goal of cultivating an environmentally conscious generation capable of supporting the transition of Indonesia toward renewable energy. The results show that the training effectively improved the understanding and skills of senior high school physics teachers in solar cell technology, enhanced their confidence through Arduino-based learning, and promoted green energy understanding and sustainable education.

2. METHODS

The methods consisted of four stages, as shown in the diagram in Figure 1. The first stage was pre-implementation (planning), including the preparation of learning materials, the development of solar cell-based teaching aids integrated with Arduino, as well as the preparation of a user manual and tutorial videos for teaching aids. Learning materials included presentation slides on green energy, solar cell applications, and Arduino basics. The solar cell-based teaching aid integrated with Arduino was designed and assembled to demonstrate automatic light tracking, energy storage, and real-time electricity generation. A simplified version of the teaching aid was developed for group practice, and all tools and components were organized to ensure smooth execution of the training.

The second stage was partner identification through preliminary online discussions on July 1-2, 2025, with three physics teachers from three public senior high schools in Yogyakarta: Hadi Siswoyo, S.Pd., from SMA Negeri 2 Yogyakarta, who serves as the head of the physics teacher association; Budi Hayati, M.Pd.Si., from SMA Negeri 5 Yogyakarta; and Dra. Sri Lestari from SMA Negeri 6 Yogyakarta. The

discussions focused on current physics teaching practices, the use of instructional aids, and teachers' needs for solar cell-based learning media. Preliminary data were collected through open-ended discussions conducted via WhatsApp rather than through a formal interview protocol. Preliminary findings indicated that the use of teaching aids, particularly solar cell-based teaching aids, remained limited in classroom practice, highlighting the need for training to support teachers in developing and utilizing such media in physics instruction. The collaboration was then formalized through official approval, scheduling of the training, and distribution of invitations to the participating teachers.



Figure 1. Community service program methodology, consisting of four stages: (a) Pre-implementation (planning); (b) Partner identification; (c) Implementation training; and (d) Evaluation and sustainability

The third stage was implementation training, consisting of two main sessions: an onsite workshop and online monitoring. Workshop activities included a pre-test, theoretical sessions, demonstrations of solar cell-based teaching aid, and a post-test. The training program involved 30 teachers from 19 secondary educational institutions in Yogyakarta and the surrounding area. Taken together, the participants represented 17 senior high schools and 2 Islamic senior high schools, comprising both public and private institutions. A one-day workshop was conducted on August 9, 2025, at the Basic Physics Laboratory of Universitas Negeri Yogyakarta. The workshop began with a pre-test consisting of 15 multiple-choice questions, including 10 on green energy concepts and 5 on solar cell principles, along with one essay question addressing the working principle of solar cells. Theoretical sessions covered green energy, solar cell mechanisms, and Arduino basics. The solar cell-based teaching aid integrated with Arduino was demonstrated in the class, showcasing automatic tracking and power storage functions.

Participants then worked in small groups to assemble simpler versions of teaching aid and each group presented their aid in a demonstration. The workshop concluded with a post-test to evaluate changes in participants' understanding of green energy and the results were analyzed using the N-gain test and compared with the mastery criterion of 80, which was established by the program team (Gare, 2025). In addition to knowledge assessment, the development of teaching aids was intended to provide practical experience in assembling the devices and understanding their operation. Following the workshop, the teachers implemented the learning activities in their senior high schools by guiding their students to build solar cell-based teaching aids, conduct demonstration and voltage measurement experiments, and provide explanations. These activities were monitored online through a WhatsApp group. The teachers were required to submit photo and video documentation via Google Forms. The program outcomes, indicators, and evidence of achievement are summarized in Table 1.

Table 1. Program outcomes, indicators, and evidence of achievement

Outcomes	Indicator
Knowledge improvement	Pre-test and post-test questions
Functional teaching-aid development and group presentation	Direct observation and functional testing of the assembled devices and group presentations. explaining the assembled device and its results
School-level implementation	Photographs documenting implementation activities

The subsequent evaluation and sustainability stage included distributing questionnaires through Google Forms to assess participant satisfaction and collect suggestions for future training programs. Participants completed a satisfaction questionnaire covering the training materials, instructors and facilitators, facilities, and instructional media. The questionnaire was used solely for program evaluation and feedback to improve future training sessions and did not contribute to participants' grades or assessment scores.

3. RESULTS AND DISCUSSION

Workshop Design and Implementation

The implementation of this community service program was designed to provide comprehensive learning experiences for the participants. The program consisted of two main sessions: a one-day onsite workshop followed by online monitoring. The onsite workshop on the development of solar cell-based teaching aids was held on Saturday, August 9, 2025, at the Basic Physics Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta. A total of 30 senior high school physics teachers from 19 secondary educational institutions in Yogyakarta participated in the program, representing diverse school backgrounds and teaching experiences (Figure 2). The workshop included a pre-test, theoretical sessions, demonstrations of solar cell-based teaching aids with Arduino integration, group practice in assembling a simplified solar cell-based teaching aid, and a post-test. Learning materials, including green energy, solar cell applications, and Arduino basics, were delivered within 3 hours duration. This integrated approach aimed to enhance participants' conceptual understanding of green energy and solar cell technology, which in turn strengthening their practical skills and confidence in incorporating renewable energy experiments into physics instruction (Pramartaningthyas et al., 2026). Both experienced educators and enthusiastic early-career teachers actively participated throughout the workshop. The participants' 100 percent attendance and active engagement indicated strong interest among teachers in developing innovative instructional media, particularly those related to renewable energy applications in physics education (Siswanto et al., 2024).



Figure 2. Participants in the workshop on the development of solar cell-based teaching aids: (a & b) Indoor session; and (c) Outdoor session

Demonstration and Hands-on Practice of Solar Cell-Based Teaching Aids

The solar cell-based teaching aids were designed to demonstrate the conversion of light energy into electrical energy and explain the underlying microscopic physical mechanisms, such as electron-hole pair generation and charge carrier behavior in silicon semiconductors (Lukma et al., 2023; Wahidin et al., 2024). During the preparation stage, two types of teaching aids were developed to support the workshop activities. The first was an Arduino-integrated solar cell-based miniature house, as shown in

Figure 3(a). The solar panel was controlled by an Arduino system, allowing the panel to automatically track the direction of incoming light (Wijaya et al., 2023). The electrical energy generated by the solar panel was stored in a rechargeable battery and subsequently used to power a light-emitting diode (LED) and a miniature water fountain. The teaching aid was also equipped with a multimeter to monitor the electrical output during operation. In addition, a separate solar panel was directly connected to a small DC fan, enabling participants to observe the direct conversion of solar energy into electrical in absence of intermediate energy storage, such as batteries.

A simplified version of teaching aid was also developed for the hands-on workshop activities, as shown in Figure 3(b). In this model, the electricity generated by the solar panel was used to power an LED and a small DC fan connected in parallel, while a voltmeter was installed to measure the output voltage of the solar panel. The simplified design enabled participants to assemble the teaching aid easily and provided a practical model that could be readily replicated in school laboratories.

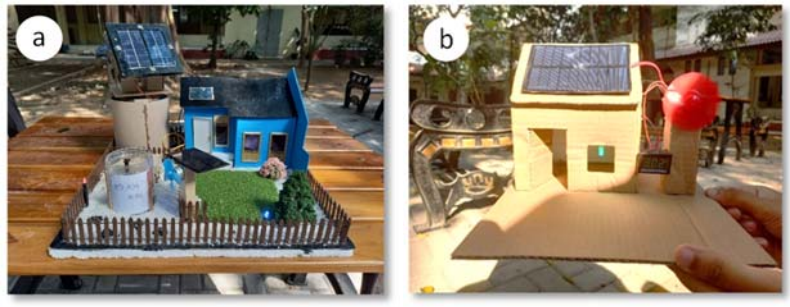


Figure 3. Solar cell-based teaching aids developed for the training:
(a) Arduino-integrated model; and (b) Simplified model for school laboratory practice

During the demonstration session, the participants showed enthusiasm by actively asking questions about the working principles of solar cells, Arduino integration, and the application of the teaching aids in physics education. During the hands-on session, the participants worked in small groups to assemble the simplified solar cell-based teaching aid shown in Figure 3(b). This practical activity provided participants with direct experience in constructing teaching aids while enhancing their understanding of photovoltaic energy conversion and its application in physics learning. The developed solar cell-based teaching aids offered a visual and interactive means of explaining the photovoltaic effect, making physics instruction more contextual and engaging for students (Eliza et al., 2024; Pramartaningthyas et al., 2026; Yulia et al., 2024). In addition, the teaching aids supported inquiry-based laboratory activities, including electrical circuit experiments, quantitative measurements using multimeters, and analysis of solar cell electrical performance (Wahidin et al., 2024). To further support implementation in schools after the workshop, the development process was documented in an instructional video, enabling teachers to replicate the teaching aids and integrate them more easily into their own classrooms.

During the hands-on session, 30 participants were divided into six groups, each with five members. E ach group received a training module, electronic components, and the necessary tools to assemble a simplified solar cell-based teaching aid in the form of a miniature house (Figure 4(a). Guided by the facilitators, each group assembled the teaching aid and tested its performance under the sunlight, as shown in Figure 4(b). This practical activity enabled participants to directly observe the conversion of light energy into electrical energy and its application in powering electrical devices. Table 2 summarizes the practical outcomes.

One group required more time to complete the assembly, even so, all six groups eventually assembled functional teaching aids and successfully measured voltage under stronger and weaker light conditions. Two groups demonstrated particularly good performance. Each group also presented and demonstrated teaching aid, explaining the observed voltage responses to different light conditions. Through this guided practice, participants developed technical skills in assembling the teaching aids and gained practical experience in integrating renewable energy experiments into physics lessons, further deepening their understanding of renewable energy (Husnadi et al., 2024; Siswanto et al., 2024).

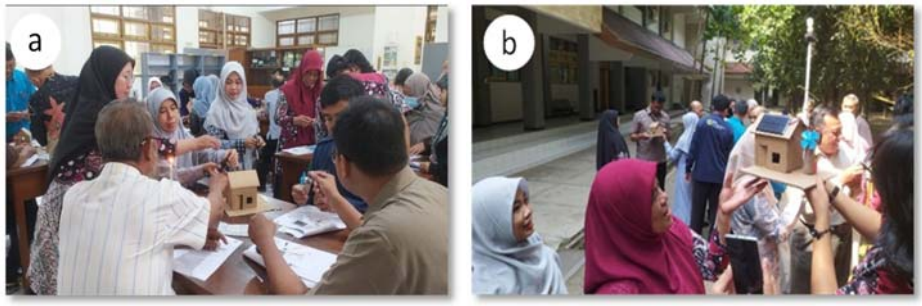


Figure 4. Hands-on practice during the workshop: (a) Assembling the solar cell-based teaching aid; and (b) Testing the solar cell under sunlight

Table 2. Results of the hands-on assembly, testing, and presentation activities

Assessment indicators	Result
Participants	30 teachers in six groups of five
Assembly of teaching aids	All six groups completed the assembly
Assembly process	One group required more time and additional guidance
Voltage measurement	All six groups successfully measured voltage under stronger and weaker light exposures
Presentation and demonstration	All six groups presented their work and demonstrated their teaching aids
Group performance	Two groups demonstrated particularly good performance

Online Monitoring of Post-Workshop Classroom Implementation

The participants submitted their implementation documentation, representing 19 schools. The submitted documentations then provided evidence that the workshop outcomes were brought into school learning activities, including practical activities involving groups of students. Figure 5 presents the implementation of the workshop outcomes in senior high schools following the solar cell training program.

Following the workshop, participating teachers applied the knowledge, skills, and instructional approaches they had acquired to their classroom teaching. In Figure 5(a), a teacher at SMA N 6 Yogyakarta introduced solar cell concepts to students, integrating renewable energy topics into physics lessons, thereby enhancing conceptual understanding among students. In Figure 5(b), a teacher at SMA N 2 Yogyakarta facilitated solar cell-based learning activities that drove student engagement through observation, discussion, and hands-on exploration of solar energy applications. These examples illustrate how the workshop equipped teachers to implement innovative teaching practices centered on renewable energy in actual classroom settings, contributing to the broader goal of strengthening sustainable science education (Pozuelo-Muñoz et al., 2025; Rahayu et al., 2025). However, the monitoring data did not systematically record the total number of students involved or the number of teaching aids

produced and implemented. Consequently, the monitoring results demonstrate the dissemination and implementation of the workshop outcomes across participating schools, but do not establish quantifiable student participation or teaching aid production.



Figure 5. Representative examples of classroom implementation of solar-cell-based learning by participating teachers, selected from 30 teachers who conducted the school-based implementation: (a) SMA N 6 Yogyakarta; and (b) SMA N 2 Yogyakarta

Conceptual Understanding of Green Energy

The training program aimed to strengthen physics teachers' understanding of green energy and solar cell operating principles by connecting theoretical physics concepts with practical applications. The average pre-test and post-test scores in Figure 6 showed a significant improvement from 82.2 (SD = 9.8) to 97.1 (SD = 4.9). All 30 participants achieved scores of at least 80 in the post-test, compared with 76.67 percent before the training. As shown in Table 3, the paired sample *t*-test revealed that this improvement was statistically significant ($t(29) = 7.45$, $p < 0.001$).

This result indicates that the training program had a significant positive impact on the conceptual understanding of green energy among participants. The effect size, calculated using Cohen's *d*, was 1.92, which is categorized as a very large effect ($d > 0.8$). This finding suggests that the intervention produced not only statistical significance but also substantial practical significance. Furthermore, the gain analysis yielded $g = 0.84$, which falls into the high category ($g \geq 0.7$). These findings indicate that the training was associated with improved conceptual understanding of green energy and solar cell operation.

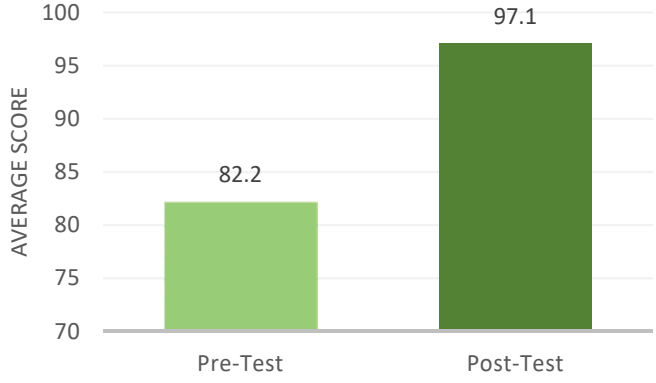


Figure 6. Average pre-test and post-test scores

Following conceptual improvement, the training provided teachers with hands-on experience in assembling solar cell-based teaching aids and testing their utilizations through practical demonstrations. The activities connected theoretical concepts of photovoltaic energy conversion with practical applications involving electrical circuits and Arduino-based measurements. Furthermore, photographic documentation in Figures 4 and 5 illustrates how participating teachers implemented the teaching aids in their respective schools, demonstrating the application of the workshop outcomes beyond the training sessions. These activities provided opportunities to introduce renewable energy concepts through practical classroom demonstrations (Pramartaningthyas et al., 2026; Widagdo et al., 2024). The integration of Arduino technology also provided a contextual learning approach, linking abstract physical concepts with real-world applications in renewable energy (Lubis et al., 2024; Wijaya et al., 2023). Such experiential learning aligns with constructivist learning theory, in which active engagement enhances the understanding and retention of scientific concepts (Pambudi et al., 2024; Sumarah & Wulandari, 2025).

Table 3. Results of the pre-test and post-test analyses: *t*-test, Cohen's *d*, and normalized gain (*g*)

Comparison	*t*	df	*p*-value	Cohen's *d*	*g*	Category
Post-test versus Pre-test	7.45	29	<0.001	1.92	0.84	High

Participant Satisfaction with the Workshop

The participant satisfaction survey revealed highly positive responses (Figure 7). The training materials received a satisfaction rating of 93 percent, indicating that participants perceived the content as relevant, innovative, and valuable. The instructors and facilitators received a satisfaction rating of 86.7 percent, reflecting effective delivery, responsiveness, and thorough support during the hands-on sessions. Meanwhile, facilities and instructional media received a satisfaction rating of 73 percent, suggesting that improvements could be made in equipment availability and workspace comfort. These findings confirm that the training met expectations of participants and provided meaningful professional development. The teachers also expressed strong motivation to implement solar cell-based experiments in their schools and to promote green energy topics in their physics teaching (Pozuelo-Muñoz et al., 2025; Siswanto et al., 2024).

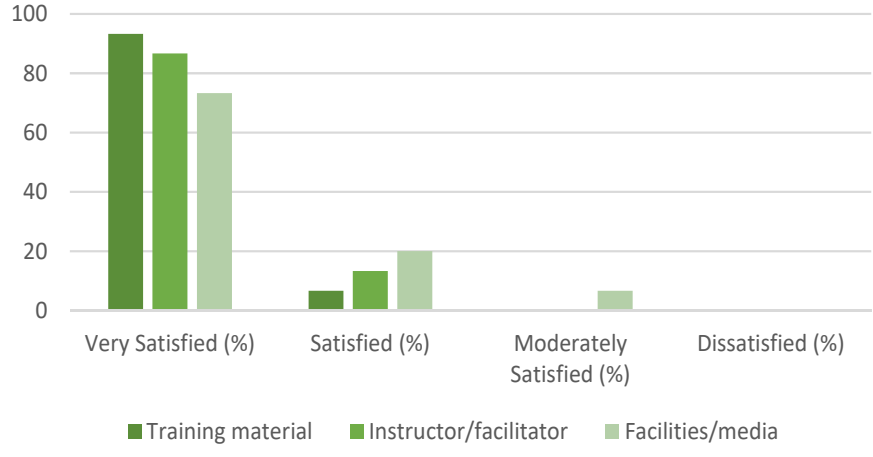


Figure 7. Participant satisfaction with the training program

The program focused on the integration of green energy and sustainability into physics education. Discussions during the workshop emphasized the importance of renewable energy in addressing environmental challenges and reducing dependence on fossil fuels. By understanding how solar cells works and how they can be demonstrated in the classroom, teachers were better equipped to introduce sustainability topics to students in a tangible and engaging way. The integration of Arduino-based solar cell kits into physics lessons not only supports conceptual understanding but also cultivates creativity among students, problem-solving skills, and environmental responsibility (Irfan et al., 2025; Sumarah & Wulandari, 2025; Wardana et al., 2024). This program therefore contributes to sustainable education by equipping teachers with practical resources to integrate green technology into physics instruction, align teaching practices with curriculum objectives, and support SDG 4 and SDG 7 by promoting energy literacy and sustainable teaching practices.

4. CONCLUSION AND RECOMMENDATIONS

This community service program enhanced high school physics teachers' understanding of green energy in Yogyakarta through integrated, hands-on training in the use of solar cell-based teaching aids. The average pre-test score of 82.2 and post-test score of 97.1, along with a normalized gain of 0.84, demonstrate a significant improvement in conceptual and procedural knowledge. Before the training, 23 participants (76.7 percent) achieved the minimum mastery criterion (score e" 80), while only 3 participants (10 percent) could correctly explain the working principles of solar cells. After the training, all participants (100 percent) achieved the mastery criterion and able to correctly explain the working principles of solar cells.

The results also revealed high satisfaction levels across all aspects, including the training materials (93 percent), instructors/facilitators (86.7 percent), and facilities (73 percent), indicating strong participant engagement and perceived value. The hands-on approach, supported by well-prepared teaching modules, Arduino-based demonstrations, and online monitoring, effectively bridged theory and practice. Moreover, the post-training follow-up ensured sustainability through classroom implementation and peer collaboration. Beyond improving competencies of teachers in renewable energy education, this program also fostered their motivation to innovate and integrate green technology topics into physics learning.

Future community service programs should further assess teachers' practical skills in assembling and using solar cell-based teaching aids through structured performance assessment rubrics. In addition, quantitative monitoring should be employed to quantifiably assess the implementation and sustained use of these teaching aids in physics classrooms. Further evaluation should also examine the impact of the teaching aids on student engagement and understanding of green energy concepts through classroom observations and pre-test and post-test assessments.

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