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Improving Teachers' and Students' Understanding of Solar Energy Using an Interactive PV Learning Kit

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ABSTRACT

Background: Solar energy utilization holds great potential to be introduced at an early age, especially for elementary school students in island regions such as Tidung Island, which receives high solar radiation throughout the year. However, the lack of hands-on, interactive learning media and limited teacher understanding of photovoltaic (PV) technology have become major obstacles in renewable energy education.
Contribution: This study proposes an interactive PV learning kit (SolarPuz-Kit) as a technology-enhanced educational intervention to enhance teachers' and students' competencies. It also contributes to the development of experiential learning approaches in renewable energy education.
Method: This study employed a pre-experimental one-group pretest–posttest design involving elementary school students. The implementation stages include the development of a portable PV trainer kit, and hands-on learning intervention sessions.
Results: The trainer kit consists of a 30 Wp solar panel and various electrical components for simulating DC energy distribution. Evaluation through pre- and post-tests revealed a significant improvement in student understanding—an 85% increase, from an average score of 36.47 to 67.64.
Conclusion: The results demonstrate that the interactive SolarPuz-Kit effectively enhances renewable energy literacy and technical problem-solving skills among students. This study highlights the effectiveness of hands-on, game-based learning in supporting conceptual understanding and provides a scalable instructional strategy for renewable energy education in remote island contexts.

1. Introduction

Amid the global energy crisis and climate change, learning about renewable energy (RE) from an early age is essential to build a generation that cares about sustainability and innovation. Renewable energy, such as solar, water, and wind power, offers clean and endless sources of energy [1]–[4]. Indonesia, as a tropical archipelago that receives abundant sunlight, has huge potential for solar energy, estimated at 3,294.4 GWp [2]. This potential has been mapped across several provinces, such as Aceh (7.881 MW), Bali (1.254 MW), Lampung (7.763 MW), and Papua & West Papua (20.991 MW) [5], [6]. Despite this high potential, the integration of renewable energy education into early-level curricula remains limited, particularly in terms of practical and technology-based learning approaches.

However, teaching abstract concepts like energy conversion and electricity to elementary students remains a challenge. Traditional lecture-based teaching methods often fail to build conceptual understanding and practical skills [7], [8]. Several initiatives have introduced renewable energy topics through learning media, such as wind energy modules [9] or micro-hydro power kits [10]. Nevertheless, most of these approaches rely on theoretical instruction or digital simulations, with limited implementation of hands-on, interactive learning tools that allow direct student engagement.

From a pedagogical perspective, experiential learning theory emphasizes that knowledge is constructed through direct experience, while constructivist learning highlights the active role of learners in building their own understanding. In addition, STEM education and technology-enhanced learning approaches have been widely recognized as effective strategies to improve students' engagement and problem-solving skills in science education [11]–[14]. However, the application of these approaches in renewable energy education at the elementary level, particularly using physical and game-based learning tools, remains underexplored.

This limitation is especially relevant in island regions such as SDN Pulau Tidung 01 Pagi, where students and teachers have limited access to practical learning tools. The school is located in a remote island area that still depends heavily on conventional energy sources. Therefore, hands-on and interactive learning is highly needed to make complex renewable energy concepts easier to understand [15]–[18].

To address this gap, this study proposes an educational intervention using an interactive photovoltaic learning kit, namely the SolarPuz-Kit, as a technology-based instructional innovation. This trainer enables students to experience how solar energy can be converted into electricity through a simple, puzzle-based circuit game. Students assemble puzzle blocks representing electrical components such as switches, lamps, and motors, powered by a real solar panel. This approach integrates experiential learning and game-based learning to enhance student engagement and conceptual understanding.

Accordingly, the main contribution of this study is to evaluate the effectiveness of the SolarPuz-Kit as a hands-on, game-based learning tool in improving renewable energy literacy among elementary students. In addition, this study positions the intervention within the framework of STEM education and technology-enhanced learning, contributing to the development of innovative instructional strategies for renewable energy education, particularly in remote and island contexts [19], [20]. These approaches have been widely recognized for their potential to enhance student engagement, digital interaction, and conceptual understanding in science learning environments.

2. Method

This study employed a pre-experimental one-group pretest–posttest design to evaluate the effectiveness of the SolarPuz-Kit as an educational intervention in improving students' understanding of renewable energy concepts. The activity was attended by 60 participants, consisting of students and several teachers from various subjects at SDN Pulau Tidung 01 Pagi. The program involved 50 students (from grades 5 and 6) out of a total of 147 students, along with 10 accompanying teachers. The intervention was conducted in a single session (one-day implementation on September 11, 2025), focusing on measuring immediate cognitive improvement after hands-on learning activities.

The development and testing of the SolarPuz-Kit took place from July to September 2025. The process began with the design of electrical components, including the solar panel, solar charge controller (SCC), miniature circuit breaker (MCB), battery, voltage regulator, power meter, and electrical loads used as testing modules. The block diagram of the SolarPuz-Kit is shown in Figure 1.

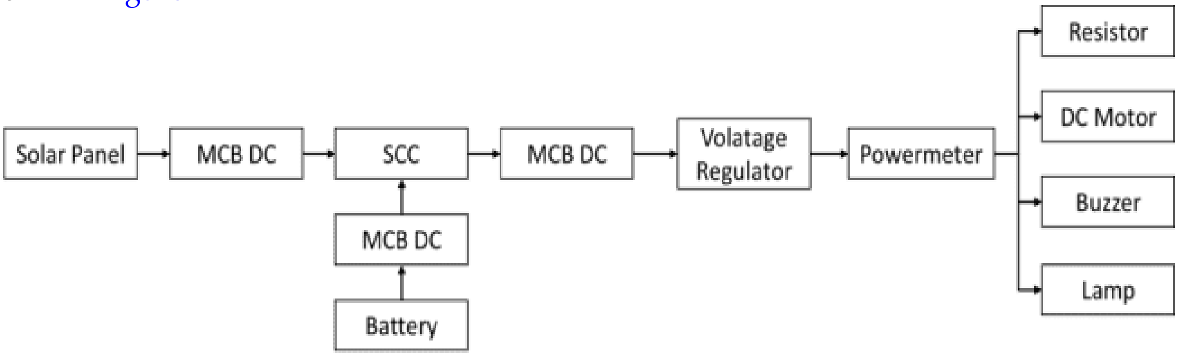

Figure 1. SolarPuz-Kit Block Diagram

The next stage was the design of the mechanical components, including the case, the tool frame (made of acrylic), the solar panel stand, and the puzzle cover. After completing the design stage, the process continued with assembly. This stage involved wiring each electrical component, followed by assembling the mechanical parts. The process took approximately two months to complete. The realization of the trainer kit and the 3D puzzle is shown in Figure 2 and Figure 3, while the component specifications of the SolarPuz-Kit are presented in Table 1.

The research instrument consisted of a set of structured multiple-choice questions designed to assess students' understanding of renewable energy, energy conversion, and basic electrical circuits [21], [22]. The instrument was developed based on predefined competency indicators. Content validity was evaluated through expert judgment, and reliability was tested to ensure internal consistency [23], [24].

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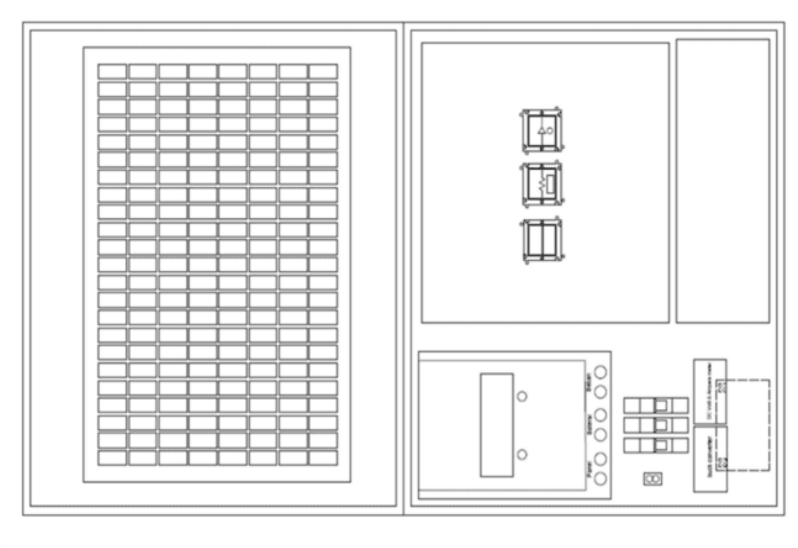

Figure 2. Trainer Kit Design

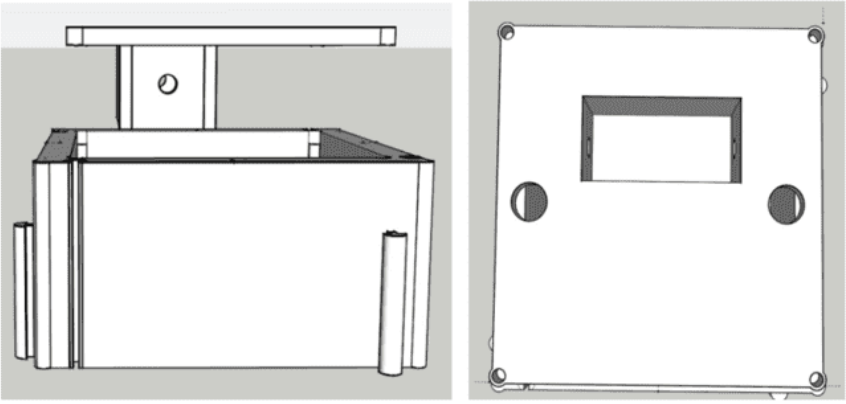

Figure 3. 3D Puzzle Design

Students completed a pre-test before the intervention and a post-test after the learning session. The collected data were analyzed using both descriptive and inferential statistics [25], [26]. A paired sample t-test was conducted to determine whether the difference between pre-test and post-test scores was statistically significant ($p < 0.05$). In addition, effect size (Cohen's d) was calculated to measure the magnitude of the intervention effect.

$$d = \frac{\bar{X}_{post} - \bar{X}_{pre}}{S_p} \tag{1}$$

As seen in Eq. (1), where $\bar{X}$_post and $\bar{X}$_pre represent the mean post-test and pre-test scores, respectively, and Sp is the pooled standard deviation. The effect size interpretation follows Cohen's criteria, where d = 0.2 indicates a small effect, d = 0.5 a medium effect, and d ≥ 0.8 a large effect. The use of a short-duration intervention is pedagogically justified, as experiential and hands-on learning approaches are known to produce immediate cognitive gains, particularly in introductory science concepts.

Table 1. SolarPuz-Kit Specification

Component	R
Solar Panel	Dimension: 530mm x 350mm x 17mm P_{mp}: 30 WP V_{mp}: 18.94V I_{mp}: 1.88A
MPPT Solar Charge Controller	V_{nom}: 12/24 Vdc Batt. Type: Lithium / Lead-Acid Max PV charging current: 10A Maximum discharge current: 10A
Battery	Batt. type: Lithium Iron Phosphate (LiFePO4) Batt. Capacity: 10Ah V_{out}: 12V
Potentiometer	Resistance: 100kΩ
MCB DC	I_{nom}: 2A I_{fault}: 10kA
Resistor	Resistance: 33Ω, 68Ω, dan 100Ω
Lamp	V_{in}: 2,5V I_{in}: 0,3A
DC Motor	V_{in}: 4V I_{in}: 0,15A

3. Results and Discussion

3.1. Educational Intervention Activities

The implementation began with the preparation, introduction, and pre-test stages. During this phase, the community service team, coordination team, and representatives from SDN Pulau Tidung 01 Pagi determined the schedule, technical details, and prepared all SolarPuz-Kit units. In the classroom introduction session, students first completed a pre-test to measure their initial understanding level, as shown in Figure 3. This was followed by a verbal and visual introduction to the concepts of renewable energy and electricity, where students were allowed to observe and directly handle physical components such as solar panels, switches, lamps, buzzers, and DC motors to build foundational knowledge before entering the practicum session.

Figure 3. Pre-test Activity Documentation

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The second stage was the main guided practicum session, where students were guided to perform four main experiments sequentially using the learning module. The session began with the conversion of solar energy into electrical energy, where students set up the solar panel and connected it to the main module to observe the activation of the SCC and Power meter. It was followed by the conversion of electrical energy into kinetic energy, where students assembled a circuit using DC motor and switch puzzle blocks to observe the propeller rotation. Next, students converted electrical energy into sound energy by replacing the DC motor block with a buzzer block [27], [28]. The practicum session concluded with the most comprehensive experiment, the series and parallel circuit. The guided practicum session is shown in Figure 4.

Figure 4. Student Participation

After completing the previous stage, the next step was conducting the post-test. The main purpose of the post-test was to measure the improvement in students' understanding of renewable energy concepts and electricity after the introduction and guided practicum sessions using the SolarPuz-Kit. The following stage involved filling out surveys and closing the activity. In this stage, all students and teachers from SDN 01 Pagi, Pulau Tidung were asked to complete a questionnaire survey. The primary goal of this survey was to gather their direct feedback, as well as constructive suggestions and comments related to the SolarPuz-Kit learning module and the entire series of activities they participated in. The survey data were highly valuable for the service team, serving as an evaluation tool to assess the program's success and identify areas for improvement in the future. The survey activity is shown in Figure 5.

Figure 5. Student Survey Activity

After completing all stages of the material delivery and practicum, the activity concluded with a documentation session. This session aimed to capture every important moment from interactions during the practicum to the handover of souvenirs serving as a visual record and evidence of the community service activity's implementation. The documentation session is shown in Figure 6.

Figure 6. Closing Ceremony

3.2. Competency Improvement Measurements for Students and Teachers

In the evaluation and conclusion stage (closing phase), all qualitative data from the "Student Worksheet and Observation Sheet" filled out during the practicum were collected and used as the main evaluation tool to analyse the achievement of learning objectives. The session was then followed by a survey to obtain feedback on the activity after completing the entire practicum series. This activity concluded with a documentation session involving all participants and stakeholders.

The students' level of knowledge about renewable energy was analysed using pre-test and post-test. As seen in Eq. (2) and Eq. (3), the average pre-test score was 36.47, which increased to 67.64 in the post-test, indicating an improvement of approximately 85%. To further validate the effectiveness of the intervention, inferential statistical analysis was conducted using a paired sample t-test. The t-test is calculated using the following formula.

$$t = \frac{\bar{d}}{s_d/\sqrt{n}} \tag{2}$$

Based on the collected data, the average difference between post-test and pre-test scores.

$$\bar{d} = 67.64 - 36.47 = 31.17 \tag{3}$$

Assuming the standard deviation of the differences is approximately s_d ≈ 22.0 and the number of students is n = 50, the t-value can be calculated.

$$t = 31.17 / (22.0 / \sqrt{50})$$
$$t \approx 31.17 / (22.0 / 7.07)$$
$$t \approx 31.17 / 3.11$$
$$t \approx 10.02$$

The calculated t-value is greater than the critical t-value at $\alpha = 0.05$, indicating that the improvement is statistically significant ($p < 0.05$). This confirms that the increase in students' understanding is not due to chance, but is a result of the implemented learning intervention. This improvement demonstrates that the students developed a better understanding of renewable energy concepts. Therefore, the results confirm a clear increase in students' cognitive knowledge following the completion of the educational activities on renewable energy topics. The bar chart comparing pre-test and post-test results is shown in Figure 7.

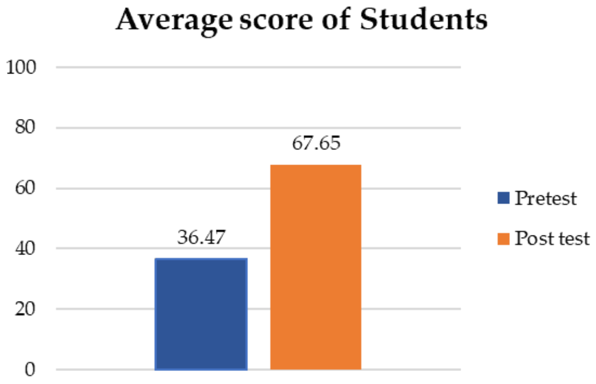

Figure 7. Pretest and Posttest Score of Students

Although there was a significant improvement in students' knowledge, the average post-test score of 67.64 indicates that their understanding has not yet reached the desired ideal threshold (for example, a minimum score of 75 or higher). This result suggests that there is still room for improvement that should be the main focus in future educational implementations. This gap is most likely due to the limited duration of the practicum sessions, especially when students were learning more complex materials such as series and parallel circuits, which require more time for exploration and repetition. Therefore, the main recommendation for future activities is to conduct follow-up sessions for reinforcement. While the current program provided general understanding, the follow-up sessions should focus on more specific or advanced topics, supported by extended practice time and simpler supplementary modules for difficult concepts [29]. This will ensure that students' understanding reaches a more optimal standard of knowledge.

In addition to cognitive evaluation, qualitative feedback was also collected through surveys from three respondent groups students, university students, and teachers. The satisfaction survey results indicate positive responses from participants. The survey used a Likert scale (1–4), where higher scores indicate stronger agreement. In general, the survey results showed very high ratings, with all measured aspects scoring above 3.0, indicating good participant satisfaction. The Learning Aspect emerged as the clear highlight, with the highest scores from university students (around 3.8) and teachers (around 3.9), confirming the strong effectiveness of the modules and methods used. However, there was a noticeable difference in the Ease-of-Use assessment: students (around 3.3) and teachers (around 3.5) rated this aspect quite high, while university students gave the lowest score (around 3.1).

The inclusion of university students as respondents refers to their role as facilitators during the intervention. Their feedback was included to provide additional perspectives on the usability and instructional design of the SolarPuz-Kit. This suggests that the system or platform used may be less intuitive for higher-education users. Meanwhile, the student group showed the most consistent ratings, with the highest scores given to the aspects of Usefulness and Sustainability of the activity. The survey results are illustrated in Figure 8.

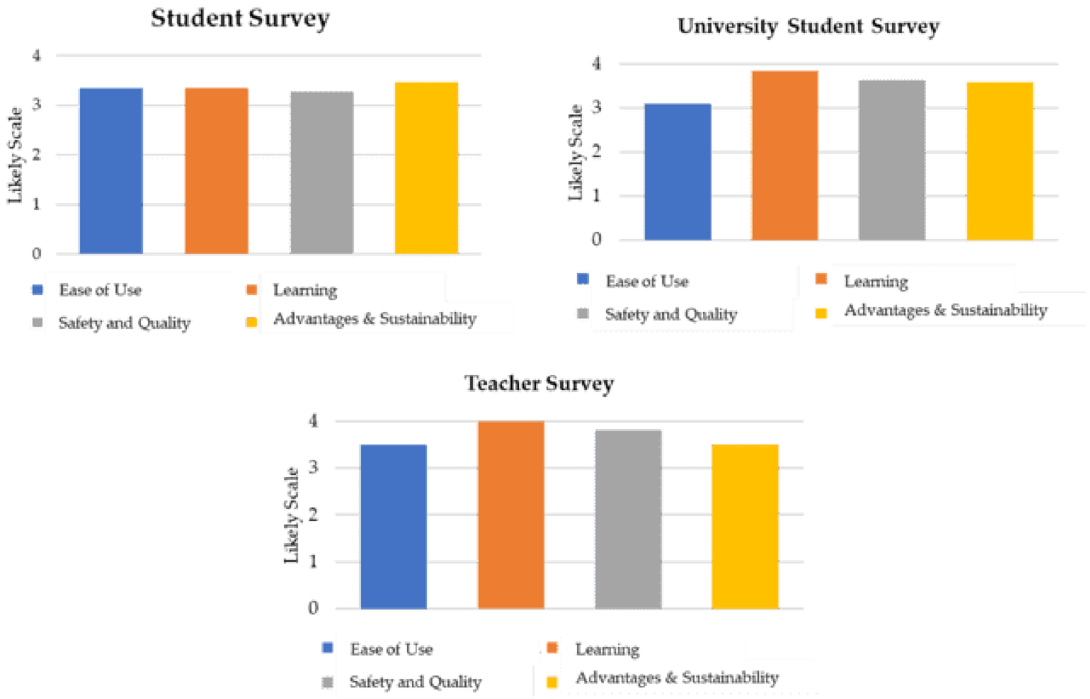

Figure 8. Survey Result

Despite the significant improvement observed, this study has several limitations. The intervention was conducted in a single day, which may primarily capture short-term cognitive gains rather than long-term retention [30]. Additionally, the absence of a control group limits the ability to compare the effectiveness of this method with other instructional approaches. However, short-duration interventions are commonly used in experiential learning contexts to measure immediate learning outcomes. Future studies are recommended to include longitudinal designs and control groups to further validate the effectiveness of the SolarPuz-Kit. Overall, the findings demonstrate that the SolarPuz-Kit is an effective technology-based learning tool that enhances renewable energy literacy through experiential and interactive learning approaches.

4. Conclusion

This study demonstrates that the SolarPuz-Kit, as a technology-based educational intervention, is effective in improving students' understanding of renewable energy concepts. The findings show a significant increase in students' knowledge scores from an average of 36.47 before the intervention to 67.64 after, with an improvement of 85% supported by statistical analysis ($p < 0.05$) and a large effect size. This result directly addresses the research objective of evaluating the effectiveness of a hands-on, game-based learning tool in renewable energy education. From a theoretical perspective, this study contributes to the integration of experiential learning, constructivist learning, and game-based learning approaches, demonstrating how active and interactive learning environments can enhance conceptual understanding. From a practical perspective, the SolarPuz-Kit provides an innovative and applicable instructional tool for renewable energy education, particularly in remote and island contexts. However, this study has several limitations, including the short duration of the intervention (one-day implementation), the absence of a control group, and the relatively limited sample size. These factors may affect the generalizability of the findings.

Therefore, future research is recommended to conduct longitudinal studies with larger sample sizes and controlled experimental designs to further validate the effectiveness of the SolarPuz-Kit and explore its long-term impact on student learning outcomes. Overall, this study highlights the potential of interactive, technology-enhanced learning media in supporting sustainable energy education and fostering students' awareness of renewable energy.

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