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Design and Development of Solbag: An Innovative and Sustainable Learning Bag by Integration of Renewable Energy Technology

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Abstract

Background: Indonesia, as an equatorial country, has a large solar energy potential. The great intensity of solar radiation throughout the year makes solar panel technology an alternative source of electricity, particularly in rural locations that are not yet connected to the conventional grid.
Aims: The aim of this research is to develop a prototype study bag that can utilize solar energy to charge portable electronic devices such as study lamps, using a simple electronic circuit but with stable power output. This integration of renewable energy technology can support educational activities based on environmental sustainability principles, particularly in remote areas.
Methods: The research method includes the design, manufacturing and testing stages of the prototype, including empirical validity testing and theoretical validity testing by a team of experts.
Result: The test results meet the theoretical validity interpretation criteria with a percentage of 93.67%, which is included in the very valid category, with a percentage of agreement value of 91.57%, which indicates the conformity of the assessment among the validators. In the empirical validity assessment, the Solbag system is able to provide an average stable voltage of 3.865 V. In addition, user analysis shows that Solbag is considered practical, functional, and contributes to increasing student awareness of the use of renewable energy.
Conclusion: The solbag system fits within the optimal range based on prototypes and comparable goods related to portable solar study lamps, and possesses the ability to serve as an eco-friendly lighting solution for students in rural areas with limited energy access.

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1. Introduction

The use of renewable energy has become a crucial component of sustainable national development, particularly in developing countries like Indonesia. In recent decades, increasing energy demand has placed pressure on non-renewable fossil fuels and negatively impacted the environment (Lukma *et al.,* 2024). Therefore, renewable energy development has become a government priority, outlined in various national policies, with a target of 23% renewable energy utilization by 2025 (Adzikri *et al.,* 2025). This aligns with global efforts to reduce carbon emissions and mitigate climate change through the use of clean, environmentally friendly energy (Institute for Essential Services Reform, 2024).

Indonesia, as a country located on the equator, has enormous renewable energy potential, particularly solar energy. The abundant solar radiation potential opens up significant opportunities for utilizing solar panel technology as an alternative electricity source, particularly in remote areas that still struggle to access conventional electricity grids (Niwanda *et al.,* 2025). Geographical constraints and limited infrastructure development create an increasingly urgent need for independent energy solutions to improve the quality of life for communities in these areas.

As technology advances, the use of solar panels in portable bags is increasingly relevant and innovative for meeting the electricity needs of students in areas without conventional electricity. Research on bag designs with solar panels and rechargeable batteries demonstrates the efficient utilization of solar energy and the ability to meet the needs of mobile and environmentally friendly electronic devices (Ariawan *et al.,* 2025). The implementation of photovoltaic systems in portable products is also supported by research on charging bag technology, which can absorb sunlight and convert it into electricity, thus serving as an adaptive electricity solution in the education sector (Hartanti & Amilian, 2025). The integration of these devices not only supports broader access to learning but also encourages awareness and active participation in the use of clean, renewable energy.

Despite Indonesia's abundant solar energy potential and widespread implementation of solar panels at the household and public sector levels (Leksono, 2024), innovation studies are still dominated by the application of stationary solar panel systems for household-scale electrification, public facilities, and energy-independent villages (Taufiq & Putra, 2021; Wahyuni *et al.,* 2020; Mahfud & Alif, 2025; Rahmawati et al., 2022). Studies on portable devices such as solar panel bags have been limited to outdoor and recreational activities, while the development and evaluation of portable solar panel-based devices for student learning in remote areas with limited electricity (Birrulwalidaini & Chalik, 2024). Empirical literature on the actual effectiveness, device durability, energy efficiency, and impact on student learning quality with the use of these portable media is also very limited in both national and international publications (White Analyst, 2025).

In the context of education, providing portable electrical energy is crucial to support student learning activities, especially in areas with limited electricity supply. The innovation of a solar panel-based bag, a device that can provide portable electricity and lighting, represents an adaptive and applicable technological alternative (Putri & Wulandari, 2025). This bag is designed to harness solar energy through integrated photovoltaic panels, directly powering lamps and electronic devices (Birrulwalidaini & Chalik, 2024).

However, research focusing on the concept of combining mini photovoltaic technology with educational functions, particularly for learning activities in remote areas, has never been conducted. Therefore, research using an empirical approach is necessary. *The novelty lies in the empirical development and evaluation of a solar panel–integrated portable bag for students in remote areas, integrating mini photovoltaic technology with educational applications.*

The purpose of this study is to develop and test the effectiveness of a solar panel bag (solbag) as an innovative renewable energy solution that students can utilize in their daily learning activities. This study also aims to support the practical implementation of renewable technology at the community level while encouraging the sustainable use of solar energy (Wahyuni *et al.,* 2020). This approach is expected to positively contribute to accelerating the energy transition and supporting Indonesia's sustainable development agenda.

2. Methods

The research was conducted in the electronics laboratory of the Faculty of Engineering and Informatics, Balitar Islamic University from April to September 2025. This research is a type of design research that aims to design and develop a solar panel-based study bag, with the method used is Research and Development (R&D), which is a method used to develop a specific tool model based on the research process (Tuanany et al., 2024). The R&D method consists of four stages: definition, design, development, and evaluation (Rahman & Raharjo, 2023). The first stage, namely the definition stage, is carried out by conducting literature studies, data collection and needs analysis, and formulating research problems and research objectives. The second stage, namely the design stage, is carried out by designing the concept of a panel-based study bag based on the needs and objectives of the research. The third stage, namely the development stage, is carried out by making a prototype of the teaching aid that has been designed and conducting trials on the prototype. The fourth stage, namely the evaluation stage, is carried out by evaluating the quality and effectiveness of the prototype teaching aid that has been made (Rahman & Raharjo, 2023). The sample will be determined using simple random sampling. Simple random sampling is a technique for randomly selecting members of a population, regardless of the strata within the population (Firmansyah & Dede, 2022).

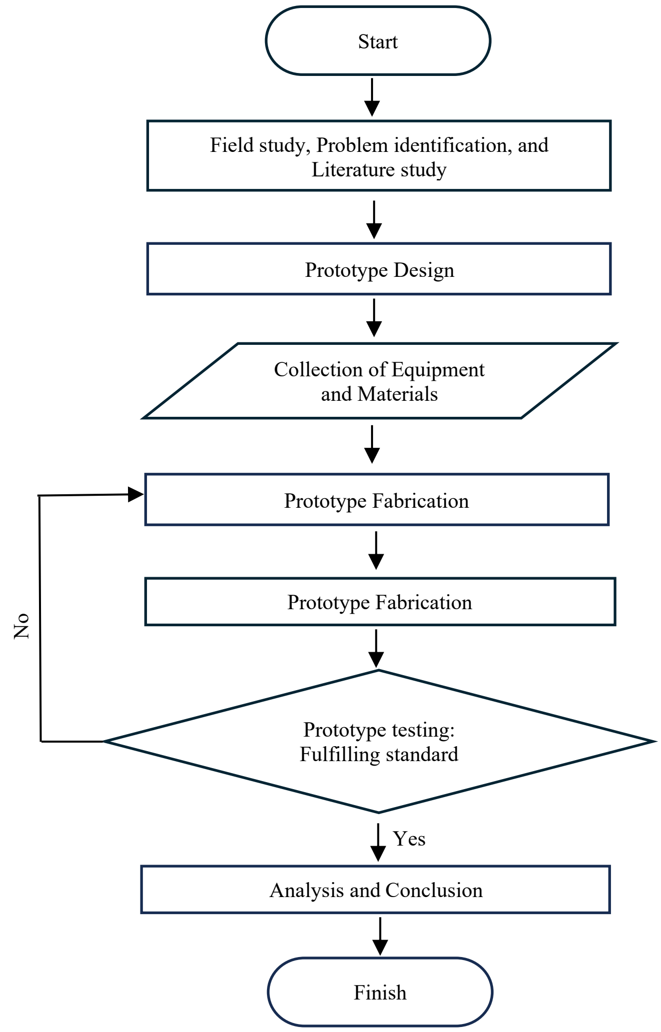

Figure 1. Research Flowchart

Based on the flowchart in Figure 1, the research began with the initial stage, which was determining the research focus to develop a solar-powered study bag as an environmentally friendly learning medium. At this stage, the researchers formulated the main objective, namely to design a Solbag (solar bag) capable of integrating solar panels as an alternative energy source for the user's learning needs. The next stage was a field study, problem identification, and literature review. The researchers conducted observations in educational settings to identify the energy needs of portable learning devices and the obstacles experienced by students when electricity access is limited. Then, they reviewed literature related to portable solar panel technology, functional bag design, and the concept of sustainable learning. The findings from the field and literature review were used as the basis for formulating the Solbag's functional specifications, such as required power capacity, bag ergonomics, and safety standards for use. The observation targets were students and teachers from two schools in Blitar Regency: SDN Gembongan 2 Ponggok and SDN Bence 4 Garum, with a total of 15 teachers and 125 students as respondents. The next step was to design a Solbag prototype, including the mechanical design of the bag, the placement of the solar panel module on the bag's surface, and the design of the charging and energy storage circuit. During the tool and material gathering stage, researchers selected and prepared components that met specifications, such as the type of solar panel, energy storage battery, charging control module, strong yet lightweight fabric or bag material, and other supporting accessories to ensure user comfort and safety.

The prototyping stage involved assembling all components into an initial version of the Solbag, integrating the solar panel's electrical system with the bag's structure to ensure comfort. The completed prototype then entered the prototype testing stage, where researchers tested the solar panel's ability to charge the battery, the stability of the power output for charging devices, the durability of the bag's material, and user comfort when using the Solbag for daily learning activities both indoors and outdoors. Test results were then evaluated at the "Does the test result meet the criteria?" stage. If the Solbag's performance was deemed not to meet the established criteria, such as insufficient power or an ergonomically unsuitable design, the prototype was revised and returned to the manufacturing stage until the desired performance was achieved. If the test results are "yes" or meet the criteria for energy efficiency, comfort, and safety, the research proceeds to the analysis and conclusion phase, which involves analyzing performance test data and user responses to assess the feasibility of integrating renewable energy technology into the Solbag and formulating conclusions and suggestions for further development. The research series is declared complete once a functional, innovative, and sustainable Solbag prototype is obtained, meeting the research objectives.

The teaching aid instrument was validated by three expert lecturers: a solar energy content/technical expert, a product design expert, and an ergonomics expert (Fitriyah *et al.,* 2021; Desryanto *et al.,* 2024). Following the validation process, the data were analyzed using construct validity and content validity, with the research limited to the development stage. The data analysis technique used a validity test sheet with scoring based on a Likert scale, as presented in Table 1.

Table 1. Likert Scale

Evaluation categories	Code	Score
Very Good	VG	5
Good	B	4
Fairly Good	FG	3
Poor	P	2
Very Poor	VP	1

According to Puspitasari (2021), validity testing is carried out using a descriptive method, namely by calculating the scores given by all validators using a certain formula Puspitasari (2021), namely:

$$p = \frac{s}{n} x100\%$$

Description:
p = percentage of assessment
s = score obtained
n = highest number of scores

As a reference for interpreting the validation results scores, please see table 2.

Table 2. Interpretation of validation result scores.

Percentage score (P)	Interpretation categories
$0\% \leq P \leq 20\%$	Very Invalid
$21\% \leq P \leq 40\%$	Less Valid
$41\% \leq P \leq 60\%$	Moderately Valid
$61\% \leq P \leq 80\%$	Valid
$81\% \leq P \leq 100\%$	Highly Valid

Based on the category references in Table 2, a teaching aid is declared valid if the validation percentage reaches at least 41%. After the percentage value is obtained, the validation data is then further analyzed to determine the level of agreement between the validator assessments by calculating the percentage agreement using a predetermined formula, namely:

$$percentage\ of\ agreement = \left(1 - \frac{A - B}{A + B}\right) 100\%$$

Description:
A: Highest frequency
B: Lowest frequency

The results of the calculations using this formula indicate the level of reliability of the validation process, with the criterion of acceptance being achieved if the obtained score reaches at least 75%. According to Borich (1994), a learning device assessment instrument is considered suitable for use if its assessment percentage score is at or above 75% (Nyoman *et al.,* 2022).

The following are the components used in the construction of the solar panel–based learning bag prototype:

1. TP4056 charging module (1 unit)
2. 5 V, 3.5 W solar panel (1 unit)
3. 18650 cylindrical lithium-ion rechargeable battery (1 unit)
4. 1N4007 diode (1 unit)
5. Push on/off switch (1 unit)
6. 5 mm LED (1 unit)

The TP4056 module functions to charge and protect the 18650 lithium-ion battery so that the charging process from the solar panel takes place safely and under control. The 5 V 3.5 W solar panel converts sunlight energy into DC electricity which is then stored in the battery as a source of energy for the study bag. The 1N4007 diode is used to prevent backflow from the battery to the panel, while the on/off push switch regulates the flow of electricity from the battery to the load. The 5 mm LED becomes the main load in the form of a study lamp that lights up using the energy stored in the battery.

3. Results and Discussion

3.1 Design and Development of Solar Panel-Based Study Bags

The 5V 3.5W solar panel captures sunlight and converts it into a direct voltage of approximately 5V, which is the primary input for the battery charging circuit. This electrical energy forms the basis of the Solbag's renewable power supply. A 1N4007 diode is then placed on the positive path from the solar panel to the charging module to prevent backflow from the battery to the panel when there is no light. This ensures the battery remains safe and does not experience reverse discharge through the panel. The TP4056 module receives voltage from the solar panel (via the diode) and regulates the safe charging of the lithium-ion battery with constant current and voltage modes. The TP4056 is also typically equipped with an internal LED indicator to indicate the charging process and full battery condition. An 18650 lithium-ion battery serves as an energy storage medium charged by the TP4056, allowing solar energy to be utilized at any time even in the absence of sunlight. This battery will later become the primary power source for powering loads such as indicator lights or charging small devices. A push on/off switch is placed on the battery output path to connect or disconnect the power supply to the load. Users can manually turn the system on or off for more efficient energy use. A 5mm LED serves as a visual indicator that the output system is active or as a simple battery load simulation. When the switch is pressed and the circuit is connected, the LED illuminates, indicating that the energy from the battery, charged by the solar panel, is being properly distributed. For circuit installation, see Figure 2.

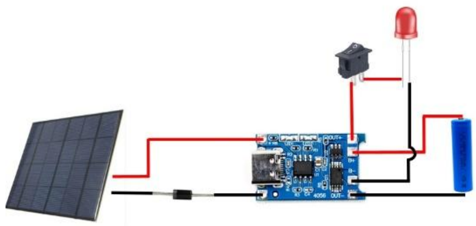

Figure 2. Circuit Installation.

The physical form of the prototype can be seen in Figure 3.

Figure 3. Solbag Prototype lights off condition (left), lights on condition (right).

3.2 Theoretical Validity

The theoretical validity test was conducted by three expert lecturers. The test results can be seen in table 3.

Table 3. Results of theoretical validity test.

		Validator		
		Expert A	Expert B	Expert C
Evaluation	Construct Validity	48	46	48
	Content Validity	48	45	46
Total		96	91	94
Average		93.67 (Highly Valid)		
Percentage		96%	91%	94%
Average		93.67% (Highly Valid)		

Based on Table 3, the Solbag is declared to meet the theoretical validity interpretation criteria with a percentage of 93.67%, which is included in the very valid category. Meanwhile, the results of the reliability test through the calculation of the percentage of agreement showed a value of 91.57%, indicating a concordance of assessments among the validators. Details of these results can be seen in Figure 4.

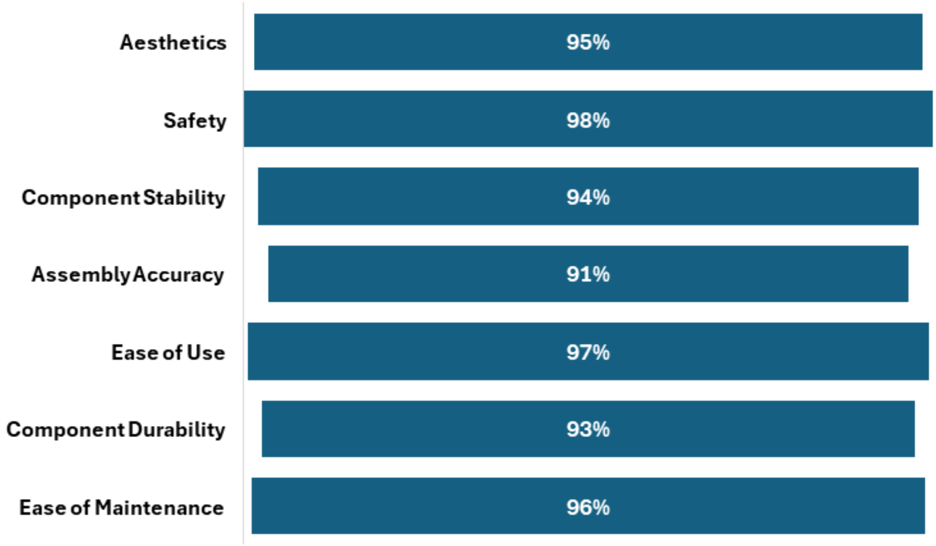

Figure 4. Theoretical validity diagram.

Theoretical validity assessment covers several aspects, including aesthetics, safety, component stability, assembly accuracy, ease of use, component durability, and ease of maintenance. The accuracy of the material and its relationship to energy conversion are considered very good, because the application of solar panels on the Solbag provides students with direct experience in the use of renewable energy, in accordance with the findings of solar cell-based educational teaching aids that are also valid for use in science learning (Delima & Mayub, 2023). Ease of use and maintenance is accommodated by a portable, adaptive design that can be used independently by students, as also suggested by research on renewable energy-based Energy Teaching Kits that emphasize the simplicity and flexibility of the tool (Yuniahastuti *et al.,* 2025). Storage of components and teaching aids is facilitated by the integration of components in a single package, inspired by the results of research on the development of miniature power plant teaching aids that emphasize unit completeness and storage effectiveness (Lima *et al.,* 2023). The stability and safety of the teaching aids during use are guaranteed through material selection and electrical system protection, as in the validation results of other renewable energy teaching aids that have received a "very good" score for safety and stability aspects. Aesthetic assessment is strengthened through innovative bag designs that are attractive and support students' learning motivation, in line with the need for learning media that are in accordance with the curriculum and support a fun learning experience (Ristianti *et al.,* 2024).

3.3 Empirical Validity

In the empirical validity phase, the Solbag was tested and physically analyzed. The panel was fully charged, as indicated by the battery indicator, under direct sunlight (not covered by clouds). The lamp was turned on continuously. Data was taken 10 times, every 5 minutes. The lamp was then left on until the light was very dim. Detailed test results can be seen in Table 4.

Table 4. Test results of empirical validity

Panel Voltage (V)	Time	Battery Voltage (V)	Switch Status	Lamp Voltage (V)	Lamp Condition
5.035	16.00	4.108	Off	0	Off
		3.986	On	3.902	Brightly lit
		3.938		3.873	Brightly lit
		3.949		3.870	Brightly lit
		3.920		3.806	Brightly lit
		3.913		3.818	Brightly lit
		3.895		3.834	Brightly lit
		3.895		3.832	Brightly lit
		3.888		3.817	Brightly lit
		3.873		3.798	Brightly lit
	20.00	2.671			Very dimly lit

The test results show that in the first 10 tests (data taken every 5 minutes), the lamp was brightly lit, with a fairly stable lamp voltage, where the average voltage was 3.865 V.

The empirical test results show that the solbag is able to light the LED lamp brightly and stably during the first 10 measurements (±50 minutes), with an average voltage of 3.865 V which fluctuates slightly so that it meets the criteria for good physical performance for short-term study lighting. This pattern is in line with the design of an off-grid solar panel system for student study lights, where the LED lights remain bright in the initial stage before a gradual decrease in brightness occurs (Ramadhanti, 2019; Sharma *et al.,* 2019). A 3.7 V Li ion battery has a full voltage of around 4.2 V and is considered to be discharged in the range of 3.0–3.4 V, while its "normal" working voltage is around 3.6–3.8 V as an average value during the discharge process. The measured stable voltage of 3.865 V indicates that the battery is in the upper-middle working zone (not yet 100% full, but still far from the lower safe limit), so it is technically reasonable for the Solbag system to stabilize at this value under light or moderate loads (Kadafi *et al.,* 2023).

Many commercially available portable solar-powered study lamps also use low-voltage batteries of around 3–4 V and are designed to last for a few hours under bright conditions, so the Solbag's operating voltage is within the normal and effective range for energy-efficient LED study lamps. Another solar backpack study reported a solar backpack system with a 20 Wp panel and a 12 V–7.2 Ah battery to supply 5 V USB and 12 V outputs, tested for hiking and portable off-grid use. Another study of a solar-powered backpack for students reported a study lamp's lighting capacity of approximately 1.5–5 hours after charging via a built-in panel. If the Solbag uses a 5 V–3.5 W panel and a single 18650 cell, its performance is more suited to being categorized as a low-power system for LED lighting and charging low-power devices, rather than for heavy-duty devices like laptops. This positions the Solbag comparable to educational solar backpacks that focus on study lamps and charging lightweight devices (Wijaya *et al.,* 2025).

This is also supported by similar research on solar panel-based light bags, namely the Solar Scholar Bag development research which states that solar bags with thin-film modules and internal batteries are tested through repeated charge and discharge cycles to ensure voltage stability and energy supply resilience for portable devices, with LED indicators showing charge status and power availability (Oli & Poudel, 2025; Lukma *et al.,* 2023). This approach is similar to the solbag which uses a battery indicator to indicate full condition before the test, then maintains the operating voltage in the low range (around 3–4 V) commonly used in modern solar-powered light systems and portable devices (Gouder & Lotsch, 2023; Chowdhury & Kaiser, 2021). Typical 18650 Li-ion cells have a capacity of around 2,000–3,000 mAh at 3.7 V, equivalent to approximately 7–11 Wh of energy. If Solbag turns on a study LED of around 1 W, then theoretically the duration of the light can be 7–10 hours in full battery condition, while solar backpack research states the test duration is around 1.5–5 hours of lighting depending on the design and efficiency of the lamp. This means that technically one 18650 battery is sufficient for night study activities several hours per day, but the actual duration still depends on the efficiency of the LED, the daily panel charging level, and system losses so it is important to directly test the Solbag's light time in the field (Wijaya *et al.,* 2025).

4. Conclusion

Based on the results of the empirical validity test, it can be concluded that the solbag has reliable electrical performance as a portable solar-based study lighting tool. The solar panel-battery-LED system is able to maintain a bright light condition with a relatively stable average voltage of 3.865 V for at least 10 initial measurements (approximately 50 minutes) after full charging under direct sunlight exposure, thus meeting the short-term lighting needs for study activities. The results of this study indicate that the design of a small-power solar panel, low-voltage battery, and low-power LED is able to provide a stable power supply. Thus, the performance of the solbag can be stated to be within the appropriate range of prototypes and similar products in the realm of portable solar-powered study lights, and has the potential to be implemented as an environmentally friendly lighting solution for students in areas with limited access to electrical energy.

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