SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Development of Learning Media in Science Based-Solar: An Analysis Using the Many-Facet Rasch Model

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ABSTRACT

This study addresses the urgent need to improve science education, particularly in renewable energy, by developing and evaluating solar cell-based learning media. As sustainable practices and environmental awareness gain importance, equipping students with relevant knowledge and skills is essential. This research aims to assess the effectiveness of solar cell-based media in enhancing science learning and engagement, using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model. The study involved three experts and 60 undergraduate students: 33 from a private university in Jakarta, Indonesia, and 27 from a university in Mindanao, the Philippines. Experts in science and media, with 15-20 years of teaching experience, evaluated the media. Students, aged 17 to 25 years, with a gender ratio of 20% male and 80% female, participated. The Many-Facet Rasch Model analysis confirmed the media's reliability. Expert assessments aligned with the Rasch model's prescribed ranges, and inter-rater agreement was substantial. Results show the media's usability, deemed 'good' by experts, and positive student responses, suggesting its potential to enhance science learning and engagement. Further research is necessary for continuous improvement.

Keywords:

Development; Learning media; Many facet; Rasch model; Science education solar-cell

1. Introduction

Access to quality education remains a formidable challenge in many developing countries, particularly across Southeast Asia. Despite concerted efforts to address this issue, disparities in educational access and quality persist, posing significant barriers to equitable learning opportunities. To tackle these challenges, various strategies have been explored, with a notable emphasis on leveraging technology in educational media [1]. Research indicates that interactive

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https://doi.org/10.37934/araset.59.1.2337

media learning can substantially enhance the quality of education and augment students' problem-solving abilities, fostering a more engaging and effective learning environment [2]. Against the backdrop of Industry 4.0, characterized by rapid technological advancements, integrating these innovations into educational methodologies has become increasingly imperative, especially in higher education. This shift aims to equip students with the requisite scientific literacy and critical thinking skills necessary to grapple with pressing global issues such as renewable energy, climate change, and environmental sustainability. By cultivating a holistic approach to education, universities aim to empower students to engage meaningfully with complex societal challenges while honing their communication skills and fostering a deeper understanding of scientific concepts. Consequently, embracing technology-enhanced learning methodologies is pivotal in preparing students to navigate the complexities of the modern world and contribute meaningfully to society.

Scientific literacy is indispensable in empowering individuals to understand, evaluate, and apply scientific concepts in everyday scenarios, forming the cornerstone of 21st-century learning competencies. As fundamental pillars of education, literacy skills are essential for providing students with the tools necessary to confront contemporary challenges effectively. Thus, educational methodologies that facilitate the application of knowledge in real-world contexts are imperative [3]. Despite the potential benefits of incorporating learning materials addressing current social science issues to bolster scientific literacy, research suggests that such initiatives are scarce [4]. This study endeavours to bridge this gap by developing and implementing learning media centred on contemporary social science topics, particularly renewable energy, utilizing solar cells as an energy source within science education platforms. The objective is to ascertain whether the integration of solar cell-based science learning media can positively impact students' scientific literacy skills. Through this investigation, insights will be gleaned into the efficacy of utilizing innovative approaches to enhance scientific literacy and prepare students for active engagement with pressing societal issues in the modern world [5].

Numerous studies have focused on enhancing scientific literacy skills [6-9] through technology-based learning media. These initiatives predominantly employ virtual platforms, including Learning Management Systems (LMS), digital worksheets, and Augmented Reality (AR)-based E-books[10-12]. However, a critical observation reveals that existing technology-based media lack integration with contemporary social science issues, presenting a significant gap in science education. Despite the digital nature of these resources, the absence of alignment with current societal challenges diminishes their effectiveness in fostering holistic scientific literacy. Consequently, there is a pressing need for the development of concrete learning media that seamlessly integrate current social science issues into science education frameworks. By bridging this gap, educators can cultivate a more dynamic and relevant learning experience that empowers students to engage critically with real-world problems while strengthening their scientific understanding. Through the incorporation of pertinent social science topics, such as renewable energy and climate change, into technology-based learning media, educational initiatives can better equip learners with the knowledge and skills needed to navigate complex global issues and contribute meaningfully to society.

Previous research often relies on a raw score approach for analysis, potentially leading to biased results [13]. To mitigate this issue and ensure the validity and accuracy of the products being evaluated, a more objective validation method is essential. In this study, validation procedures incorporate many-facet analysis and stacking model analysis, offering a comprehensive assessment framework. Raw validation data, along with data from media trials, undergo transformation into Logit form. This transformation enables each research subject's performance to be evaluated based on the probability level associated with the given item questions. By adopting this approach, the assessment focuses on integrated abilities rather than solely on raw data, aligning evaluations with the difficulty level of the questions posed. Consequently, the validation process becomes more robust and reliable, offering insights into the effectiveness and suitability of the learning media being examined. Moreover, by employing a systematic and objective validation method, potential biases inherent in traditional analysis approaches are minimized, enhancing the credibility and validity of the study's findings. Overall, this comprehensive validation approach ensures that the assessments accurately reflect the performance of individuals, thereby providing valuable insights into the efficacy of solar cell-based science learning media in enhancing students' scientific literacy and engagement.

2. Methodology

The solar cell-based learning media was developed using the ADDIE model, a structured approach widely utilized in instructional design. The development procedure, adapted from the ADDIE framework [27,28], encompasses several distinct phases. Firstly, the Analysis phase aims to identify issues, need analysis, and conduct task analysis. This phase involves initial and final studies, analysis of student materials, and review of relevant literature in the International Journal of Science Learning Media. Subsequently, the Design phase is dedicated to crafting the solar cell learning media blueprint. This involves conceptualizing and creating the design elements of the learning media. Following this, the Development phase is focused on actualizing the design into tangible products. This phase includes developing the solar cell learning media, expert validation, and iterative revisions based on Phase I and small group trials, leading to Phase II revisions. The Implementation phase involves deploying the developed solar cell learning media to gauge student responses in educational settings. Lastly, the Evaluation phase encompasses assessments by experts at each stage of development to enhance the product's quality and effectiveness.

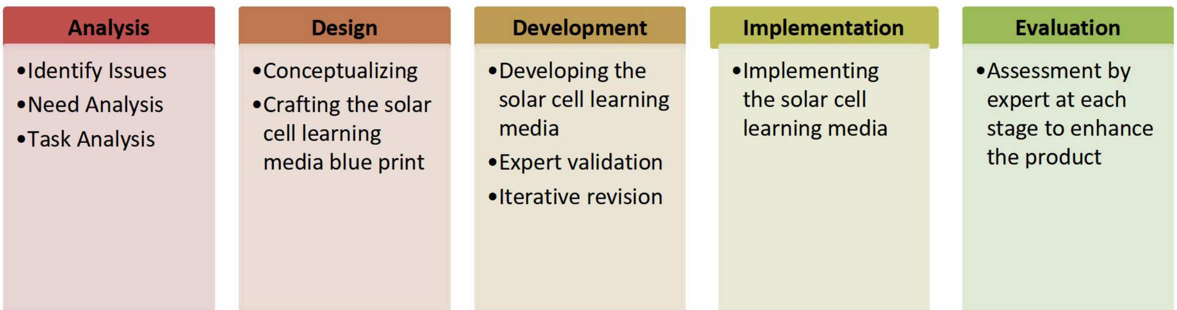

Fig. 1. Procedure Research

This research involved three experts and 60 undergraduate students, with 33 from a private university in Jakarta, Indonesia, and 27 from a university in Mindanao, the Philippines. The experts involved are specialists in science and media, with teaching experience of 15-20 years. Meanwhile, the participating students are pursuing science courses, with an age range of 17 to 25 years and a gender ratio of 20% male and 80% female. Sampling was done purposively from November 2023 to March 2024. All respondents willingly participated in this research in accordance with research ethics codes. Expert respondents filled out validation sheets, while students filled out questionnaires about their responses to using solar cell-based science learning media through the Google Form link [21,22].

In this study, students reported their learning experiences during science lectures utilizing solar cell-based media. The primary objective is to comprehend the development of solar cell-based science learning media and students' responses during the learning process. Student respondents required 20-30 minutes to complete their questionnaires, while experts needed 30-45 minutes. The questionnaire consisted of 60 statements assessed by three experts based on four criteria, each rated on a scale of 1-4 (Not Clear-Very Clear): Scientific Compatibility between media and science (KI), Compatibility with science curriculum material (KK), Clarity of Media (KM) and Clarity of media usage instructions (KP).

Expert assessments were clustered into four groups: Cluster 1 (very good): logit value > 3.03; Cluster 2 (Good): 3.03 > logit value > 0.00; Cluster 3 (fair): 0.00 > logit value > -3.03 and Cluster 4 (poor): logit value < -3.03. Additionally, 60 students responded to the 60 statements using a Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree). Subsequently, a fit statistical analysis of values (Outfit MNSQ, Outfit ZSTD, and PT Mean Corr) was conducted on the data. Limited trials based on statistical calculations involved criteria where the question could be accepted if at least one criterion was met. Here are the criteria:

i. The Outfit MNSQ value is accepted within a range lower than 1.5.
ii. The Outfit ZSTD value is accepted within the -2.0 < ZSTD < +2.0 range.
iii. The PT Mean Corr value is accepted when < 0.85.

Furthermore, the validation results of the research data from the expert team were analysed using the Facet 3.71.3 program, employing a multiple-rater Rasch assessment model [23-26]. Conversely, the results from the student questionnaires were analysed utilizing a subject ability approach and item difficulty level, employing the Rasch model and Winstep version 3.73 program [22,23,26]. The Rasch model continuously assesses respondents' answers concerning the difficulty level of questions, yielding Logit values from two perspectives: from the respondent's side (person) and the items answered correctly (item). The Logit formulas for both perspectives are illustrated in Figure 2:

$$\text{Person Logit}: \Psi[p] = \ln[p/(1-p)]$$

$$\text{Butir Logit}: \Psi[p-\text{value}] = \ln[p-\text{value}/(1-p-\text{value})]$$

Fig. 2. Logit Person Value and Question Item

The Logit values obtained from respondents and test items serve as a crucial reference for understanding the relationship between respondents' abilities and the test items they answered, as they share the same Logit units. Ultimately, these values enable us to conclude the quality of the items and the respondents' abilities to answer them following the treatment.

3. Results

3.1 Analysis

During the analysis phase, a needs analysis was conducted using observation sheets and questionnaires at the beginning of the study. The questionnaire consisted of 9 questions with a Likert scale of 1-5, and the results are displayed in Table 1. Observations were made during science lectures, and information was obtained indicating that lectures still needed improvement in the use of media, especially concrete media related to current social science issues such as renewable energy. Additionally, based on questionnaire data, it was found that students experienced difficulties in learning science concepts without media, and students needed help in addressing current social science issues using their scientific knowledge [29,30].

Table 1
Results of the needs analysis questionnaire

Question	%				
	1	2	3	4	5
The material delivered through conventional learning media is easy to understand.	30	55	8.3	6.7	0
Today's conventional learning media helps me understand renewable energy issues more deeply.	31.7	48.3	20	0	0
I feel actively involved during the learning process using media	35	35	30	0	0
Today's conventional learning media improve my ability to apply scientific concepts in everyday life.	21.7	50	23.3	5	0
After using this learning medium, I can identify relevant scientific information from various sources.	25	38.3	26.7	5	5
I can better evaluate the accuracy of scientific information.	11.7	23.3	33.3	30	1.7
I feel more confident in applying scientific knowledge to solve real problems.	23.3	31.7	18.3	15	11.7
I needed a learning medium that could help me communicate about scientific issues with others.	0	0	53.3	23.3	23.3
Learning media that are in accordance with the latest science issues can increase knowledge of science concepts.	0	6.7	33.3	36.7	23.3

3.2 Design

A design for solar cell-based science learning media was developed at the design stage. The specifications for tools, materials, instruments, and teaching methods employed during media utilization were outlined at this stage. The design of the learning media is shown in Figure 3.

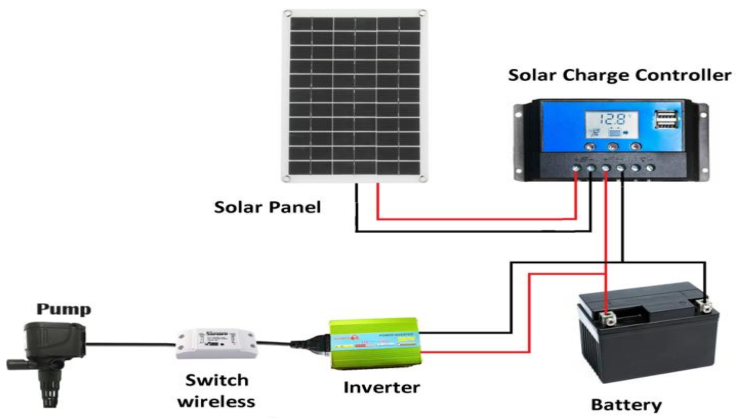

Fig. 3. The Design of Learning Media

3.3 Development

The media and its usage method were developed during the development stage, as shown in Figure 4, and learning media specification showed in Table 2.

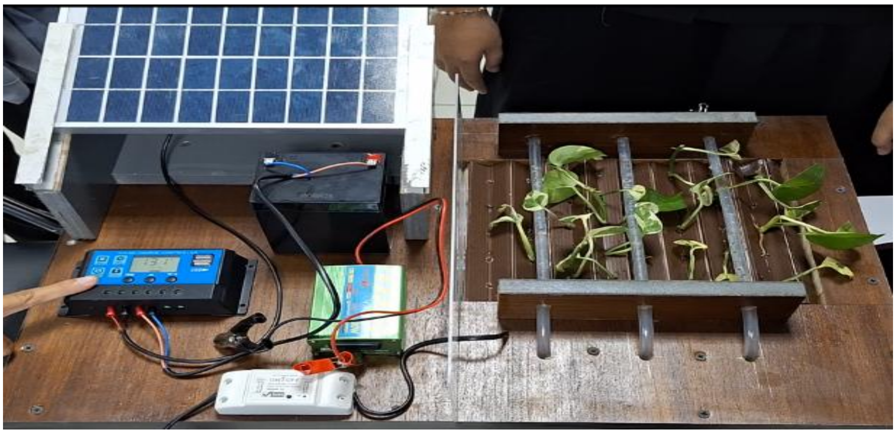

Fig. 4. Working Principle of the Media

Table 2
Learning media specification

Panel Surya	Solar Charge Controller	Inverter
Type: Monocrystalline Capacity: 300 watts per panel Efficiency: 19% Dimensions: 1680 x 1000 x 35 mm	Type: MPPT (Maximum Power Point Tracking) Maximum capacity: 30 Operating stretch: 12V/24V DC automatic Display: LCD to monitor charging status	Type: Pure Sine (Pure Sine Wave) Capacity: 1000 watt Input voltage: 12V DC output stretch: 220V AC Free feature: Overload protection, low battery alarm
Battery/Accu	Switch Wireless	
Type: Deep Cycle AGM Capacity: 200 Ah Voltage: 12V DCU battery nuts: Up to 5 years Dimensions: 522 x 240 x 219 mm	Technology: Wi-Fi 2.4 GHz Compatibility: Can connect with smart home devices Operating distance: Up to 50 meters Features: Can be integrated with mobile apps for remote control	

After the media is developed, validation is carried out with experts. Initially, validation is conducted on questions based on assessments by three expert validators in media and science. The data is processed using the Facet Rasch model program, generating the Validator Measurement Report. This report indicates the validators' assessments' quality, consistency, and diversity. The validation results are displayed in Table 3.

Table 3
Validator Assessment Results

Validator Code (Expert)	Measure	Standard error	Outfit MNSQ	Outfit ZSTD	PT Mean Corr
V 1	-4,07	0,09	0,95	-0,2	0,65
V 2	-4,25	0,09	0,75	-1,6	0,54
V 3	-3,75	0,10	1,02	0,1	0,73

Based on the data from the Validator Measurement Report, the assessments by the three validators indicate that all expert values for each assessment aspect align with the Rasch model's prescribed ranges (MNSQ 0.5-1.5; ZSTD -2.0 – 2.0; PT Mean Corr 0.4 - 0.85). No deviations were observed in the validators' media assessments, confirming the media validation's reliability. Following the validators' approval of the media's quality, the subsequent step involves evaluating the quality based on the validators' questionnaire responses using the Facet program. These responses will be grouped according to the output of the multi-rater analysis using the Rasch model facets. The distribution of media quality can be visualized through the Wright map, which illustrates the classification of media quality based on logit values. The data results of the Wright map analysis of media quality based on the questionnaire items by the validators are provided in Figure 5.

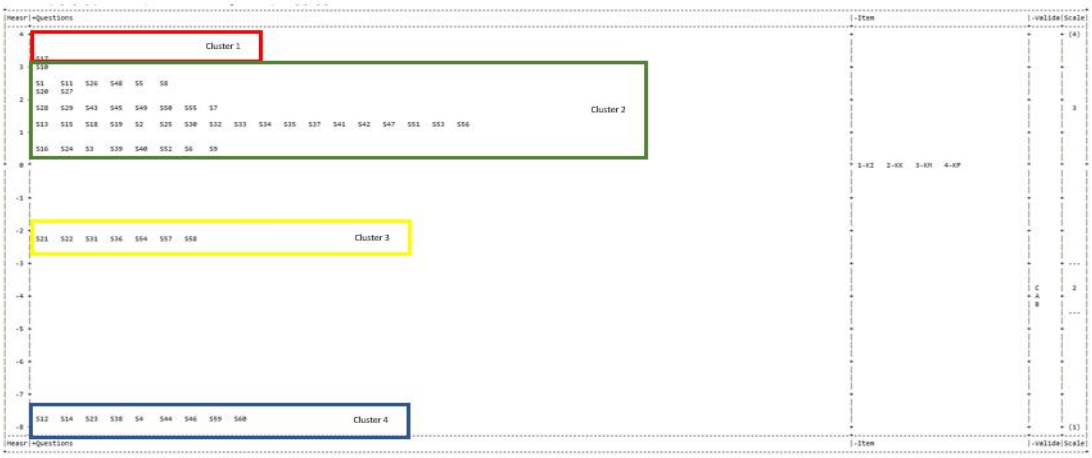

Fig. 5. Wright Map Result of Media Quality Analysis by Validators

Based on the Wright map data, the sequence of questions is organized according to their measure or logit values. Questions with higher logit values are positioned higher, while those with lower logit values are placed lower. The validation results from the validators indicate that the best questionnaire item regarding media alignment with the curriculum is question number 17, which falls into cluster 1. Additionally, 43 questionnaire items are categorized into Cluster 2, 7 into Cluster 3, and 9 into Cluster 4. These four clusters are grouped into four categories: very good, good, fair, and poor, based on the mean value of the assessment results, which is 0.00, with a standard deviation of 3.03. The grouping of the questions is shown in Figure 6.

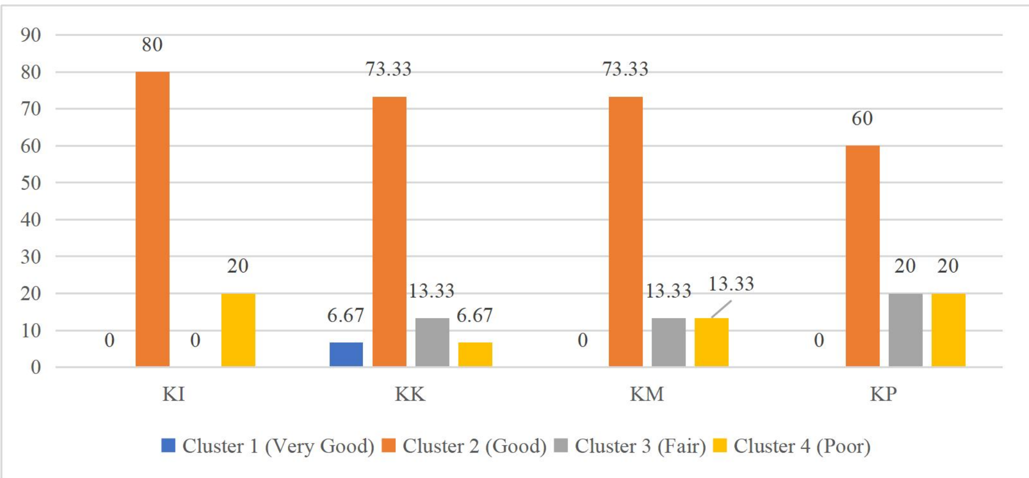

Fig. 6. Validation Results of Solar Cell-Based Media

Based on the grouping chart of the questionnaire validation results, it is evident that overall, solar cell-based learning media falls into the "good" category. Further analysis reveals that for the scientific suitability category (KI), 80% are considered "good," while 20% are categorized as "poor." In terms of curriculum suitability (KK), 6.67% are classified as "very good," 73.33% as "good," 13.33% as "fair," and 6.67% as "poor." Regarding media suitability (KM), 73.33% are rated as "good," 13.33% as "fair," and 13.33% as "poor." Finally, for media instruction suitability (KP), 60%

are deemed "good," 20% "fair," and 20% "poor".

The multi-rater facet testing also offers insights into the quality of the questions, facilitating categorization. Summarizing the data from the multi-rater facet test results on content validation from the perspective of validator and question quality yields the following findings. The data are presented in Table 4.

Table 4
Media validation results

	Validator	Question
Sum	3	60
Infit MNSQ	0.98	0.89
Outfit MNSQ	0.9	0.9
Separation	1.99	2.44
Strata	2.98	3.58
Chi-square	14.5**	8055.5**
Inter-Rater Agreement	71.10%	
Exact Agreement		
Expected Agreement	75.10%	

3.4 Implementation

The limited trial phase involved a research pilot wherein the media was administered to 60 students, followed by their completion of a prepared questionnaire. The testing process was executed gradually until stable results were attained, and with 60 respondents, the data achieved stability. Subsequently, upon gathering student responses to the 60 questionnaire items, the researcher analysed the responses using fit statistical analysis employing the Rasch model. The outcomes of this analysis are presented in Table 5.

Table 5
Results of Limited Trial of the Media

Number	Measure	Out MNSQ	Out ZSTD	PT Mean Corr	Number	Measure	Out MNSQ	Out ZSTD	PT Mean Corr
1	-0.27	0.8829	-0.5991	0.3651	31	0.89	0.9841	-0.169	0.2996
2	-0.27	13.076	15.913	-0.0334	32	0.3	0.8906	-0.9891	0.4246
3	0.6	0.9105	-10.291	0.3803	33	0.15	11.026	0.8211	0.1872
4	0.38	0.8626	-13.491	0.4513	34	0.15	0.8497	-11.992	0.4223
5	0.07	12.756	18.913	-0.0485	35	1.18	0.988	-0.099	0.3116
6	-0.46	0.9141	-0.3491	0.2968	36	0.67	0.8985	-12.291	0.4321
7	1.26	10.821	0.8411	0.1776	37	-0.01	11.546	10.512	0.0941
8	0.96	10.048	0.091	0.2785	38	0.45	0.9041	-0.9891	0.3919
9	0.75	0.9498	-0.5991	0.3496	39	-0.56	10.089	0.111	0.193
10	0.96	0.9334	-0.8091	0.3882	40	-0.27	0.7591	-13.692	0.4749
11	0.67	14.468	47.314	-0.3371	41	-0.09	11.649	10.412	0.0762
12	-0.48	11.344	0.6811	0.0361	42	-0.18	12.909	16.213	-0.0491
13	-0.18	0.9174	-0.4391	0.2996	43	0.67	0.9649	0.399	0.3205
14	-0.01	0.9836	-0.059	0.2634	44	-0.66	0.8924	-0.3691	0.3719
15	0.38	13.348	29.513	-0.1469	45	-0.66	10.006	0.081	0.2595
16	0.82	12.407	28.212	-0.0694	46	0.23	10.292	0.281	0.2347
17	0.45	0.8791	-12.591	0.4092	47	0.6	10.967	11.011	0.1435
18	0.75	0.9925	-0.069	0.2761	48	-0.27	0.8577	-0.7591	0.427
19	0.6	13.478	36.313	-0.1833	49	-0.56	0.7561	-10.892	0.4326
20	-0.56	0.7784	-0.9792	0.3902	50	0.23	10.598	0.5311	0.1867
21	0.07	0.9532	-0.299	0.3016	51	-0.46	0.9703	-0.069	0.2941
22	-0.89	0.7691	-0.7792	0.3497	52	0.67	14.819	50.515	-0.3766

23	-0.42	0.8132	-0.8692	0.3575	53	-0.01	13.139	19.813	-0.0973
24	-0.18	0.9183	-0.4391	0.306	54	0.45	14.479	40.814	-0.3017
25	-0.18	12.881	16.113	0.0102	55	0.96	0.8867	-14.091	0.4564
26	0.07	12.567	17.713	0.0128	56	1.04	12.435	27.012	-0.0759
27	1.49	10.345	0.321	0.2493	57	1.04	0.8904	-13.191	0.4559
28	0.53	0.9476	-0.5491	0.3125	58	-0.66	0.8079	-0.7492	0.3671
29	-0.01	0.8957	-0.6791	0.3936	59	-1.17	0.766	-0.6292	0.3113
30	0.45	10.147	0.181	0.2531	60	0.67	12.027	23.012	-0.0303

Table 6 presented the summary of the fit statistic values for the limited trial questionnaire assessment.

Table 6
Summary of Fit Statistic Results for Limited Trial Testing

	Infit		Outfit		Reliability
	MNSQ	*ZSTD*	*MNSQ*	*ZSTD*	
Person (N=60)	1	0,1	0,98	0,0	0,86
Item (N=60)	1	0,1	0,98	0,0	0,81

4. Discussion

The results, displayed in the Table 1, highlight key aspects of conventional learning media in terms of comprehensibility, engagement, and application of scientific concepts. For the statement "The material delivered through conventional learning media is easy to understand," 85% of respondents disagreed. Similarly, 80% disagreed that conventional learning media help them understand renewable energy issues more deeply. Regarding active involvement during the learning process, 70% disagreed or strongly disagreed. Additionally, 71.7% felt that conventional learning media did not improve their ability to apply scientific concepts in everyday life.

In terms of identifying relevant scientific information, 38.3% disagreed that the learning media helped. Evaluating the accuracy of scientific information showed more mixed results, with 33.3% neutral and 30% agreeing. Confidence in applying scientific knowledge to solve real problems had 31.7% disagreeing, while a significant portion, 53.3%, indicated a need for learning media to help communicate scientific issues with others. Finally, 60% believed that learning media aligned with the latest science issues could enhance their knowledge of scientific concepts.

The survey results suggest that while conventional learning media are generally found lacking by respondents in areas such as comprehensibility, engagement, and practical application of scientific concepts, there is a strong need for modern learning media that improve understanding, active involvement, and the ability to apply and communicate scientific knowledge effectively [31-33].

In response to this needs analysis, this research developed learning media focused on current issues, specifically solar panels. These media are designed to promote sustainable practices and environmental awareness [34-37]. Solar cells capture sunlight and convert it into electrical energy through the photovoltaic process, wherein sunlight photons stimulate electron flow within the solar cells. The resulting electric current is then collected and transmitted through cables for utilization as power. A solar charge controller oversees the flow of electricity from the solar panel to the battery, ensuring safe and efficient charging while preventing overcharging or undercharging. Meanwhile, an inverter transforms the direct current (DC) electricity from the solar panel into alternating current (AC) electricity suitable for standard electrical devices, adjusting the voltage accordingly. The battery stores the energy produced by the solar panel, charging during sunny periods and supplying power when sunlight is unavailable, thereby ensuring a continuous power supply [17]. Additionally, a wireless switch enables remote control over the electricity flow from other devices connected to the system via a Wi-Fi network, simplifying power management without requiring physical interaction with switches or cables.

Following the design phase, the media were developed using modern educational technologies to ensure accessibility and ease of use for students. The developed media underwent a rigorous validation process involving experts in science education and media, who provided feedback to refine and enhance the effectiveness of the learning tools. This iterative process ensured that the final product not only met educational standards but also effectively engaged students in learning about renewable energy and its applications. The validation results regarding content mastery and multiple representation skills are derived from three validators' assessment of 60 questionnaire items. All validators unanimously agree that the evaluated media meets these criteria, as indicated by the MNSQ values. Moreover, the strata and separation values demonstrate a well-distributed range of responses among validators, showcasing varied perspectives. Furthermore, the Inter-Rater agreement values indicate substantial alignment, with Exact agreements among validator responses reaching 71.1%, while Expected Agreements based on the system stand at 75.1%. This suggests a minimal disparity between validator diversity in assessment results and the system's expectations. In conclusion, based on the validation results conducted by the three validators, it is affirmed that the solar cell-assisted science learning media is suitable for science education. The results of this analysis are in accordance with previous research that has used the Many Facet Rasch Model method to evaluate validation results and validator agreement [22,31,32].

Analysing the validation results offers profound insights into the quality and suitability of solar cell-based learning media for science education. Firstly, in terms of Scientific Suitability (KI), where 80% of the criteria are rated as "good," the learning media is deemed effective in supporting the scientific aspect of the curriculum, indicating its alignment with expected scientific standards. Secondly, Curriculum Suitability (KK) indicates a comprehensive understanding of media alignment with the existing curriculum, although the percentages of "sufficient" and "poor" highlight areas for improvement. Thirdly, Media Suitability (KM) demonstrates "good" values with potential for enhancement in certain media aspects. Fourthly, Media Instruction Suitability (KP) underscores the media's capacity to facilitate effective instruction, with a need for further refinement in design and media usage aspects. Additionally, Content Validation affirms the questionnaire's questions as valid and meeting evaluation needs. Moreover, Inter-Rater Consistency reflects high agreement among raters, reinforcing confidence in the evaluation results [22,40,41]. Overall, the validation results advocate for the utilization of solar cell-based learning media in science education; however, enhancements in curriculum and media instruction suitability can augment its effectiveness. With these insights, developers can implement necessary improvements to enhance the quality and efficacy of the learning media.

The implications drawn from the validation analysis results hold significant weight within science education. The favourable ratings of solar cell-based learning media underscore their potential to augment the efficacy of science learning. With the integration of high-quality media, there's an anticipation for improved comprehension among students, fostering a more interactive and engaging learning environment. Moreover, insights regarding curriculum suitability present avenues for refining or adapting the curriculum to align with the utilized learning media. This adaptation can facilitate the development of a more pertinent curriculum tailored to students' requirements and technological advancements in learning. Areas requiring enhancement in media design, such as media suitability and instructional aspects, underscore the importance of bolstering support for effective learning. By refining graphic design, navigation, and interactivity within learning media, learning experiences can be further enriched. The substantial consensus among raters further validates the evaluation of this learning media, providing a robust foundation for decision-making regarding its integration into science education. With an understanding of these implications, education stakeholders can undertake concrete measures to elevate the quality and efficacy of solar cell-based learning media. These measures may encompass curriculum refinements, the development of more interactive learning media, and the enhancement of teacher training in utilizing learning technology [2,42,43].

The data analysis reveals a predominant trend of highly favourable responses among students towards the integration of solar cell-based learning media within science education. Findings from the student satisfaction survey consistently indicate elevated levels of approval towards the utilization of this media. Students acknowledge its value in enhancing their comprehension of scientific concepts through engaging and accessible means. This enthusiastic reception underscores students' openness to innovative learning approaches and technology, signifying that solar cell-based learning media effectively cater to their learning needs and expectations, thereby enhancing their overall learning experiences . Consequently, the analysis affirms that the adoption of this learning media represents an effective and apt measure towards augmenting the quality of science education within academic settings.

Students' positive responses to solar cell-based learning media carry significant implications for the efficacy and efficiency of science education. Their favourable reception suggests that this media effectively delivers subject matter in an engaging and comprehensible manner, thereby enhancing motivation, alleviating boredom, and reinforcing understanding of scientific concepts and literacy [44,45]. Moreover, this positive feedback can catalyse advancements in educational technology, foster innovation in science education, and broaden the integration of learning media within educational curricula. Ultimately, the implications of students' positive responses extend to enhancing the quality and pertinence of science education, equipping students with the skills and knowledge needed to navigate the complexities and addressing learning difficulties [46].

Based on the validation outcomes of the media and the encouraging feedback from students regarding solar cell-based learning media, several assessments can be undertaken to gauge the efficacy of this learning media in enhancing students' comprehension and involvement in science education [40-42]. Furthermore, assessments can be conducted iteratively to refine and improve the content and functionalities of the learning media. Insights gleaned from student feedback and validation outcomes can offer guidance on areas requiring enhancement or further development to augment the effectiveness of the learning media.

The development of solar cell-based learning media presents several advantages, particularly in the context of two countries, Indonesia and the Philippines. Firstly, both nations are grappling with the challenge of improving science education, especially in the domain of renewable energy [51-53]. Solar cell-based media offer a practical solution to integrate cutting-edge technology with educational curricula, thereby fostering a deeper understanding of renewable energy concepts among students. Secondly, these countries boast abundant sunlight, making solar energy accessible. Leveraging this natural resource for educational purposes enhances the curriculum's relevance and promotes environmental awareness and sustainability. Thirdly, the collaboration between Indonesia and the Philippines in this research endeavour facilitates knowledge exchange and mutual learning. By sharing insights and best practices, both nations can accelerate their efforts in enhancing science education and addressing common challenges in curriculum development and technology integration [54].

Despite the advantages, several limitations should be acknowledged in this research. Firstly, the study primarily focuses on developing and evaluating solar cell-based learning media, potentially overlooking other critical aspects of science education. Secondly, the research sample is limited to specific universities in Jakarta, Indonesia, and Mindanao, the Philippines, which may not fully represent the diverse educational landscape of both countries [55,56]. The study's timeframe may also restrict the long-term assessment of the media's effectiveness and sustainability.

From a global standpoint, this research contributes to advancing science education and promoting sustainability practices, environmental awareness and renewable energy literacy. By showcasing the efficacy of solar cell-based learning media, the study offers a scalable solution that can be adopted by educational institutions worldwide [50]. Moreover, the collaborative nature of the research underscores the importance of international partnerships in addressing global challenges, such as climate change and sustainable development [57,58]. The findings of this research can inform policymakers, educators, and stakeholders about the potential of integrating renewable energy technology into educational curricula, thereby empowering future generations to become environmentally conscious global citizens.

5. Conclusions

Based on the research findings, it is evident that solar cell-based learning media has undergone thorough validation across various dimensions, including scientific suitability, alignment with the curriculum, media quality, and instructional effectiveness. The analysis outcomes consistently rate the learning media as "good" and deem it appropriate for integration into science education. Moreover, students' favourable responses further corroborate the successful implementation of this media. This underscores its potential to enhance the efficacy of science learning and inspire the refinement of curricula and the enhancement of learning media design and features. Moving forward, additional evaluation is imperative to gauge the specific impact of this media on students' learning outcomes and to refine and enhance its quality based on student feedback continually. Consequently, this research makes significant strides in advancing the development and adoption of innovative learning media within science education, thereby contributing positively to the educational landscape.

Acknowledgement
This research was supported by the LEMLITBANG Universitas Muhammadiyah Prof. DR. HAMKA Indonesia, under Grant No. 030/F.03.07/2024 and Mindanao State University.

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