



STEAM-SDGs-Based Physics Learning Design on Renewable Energy Material to Improve Students' Literacy and Numeracy Skills

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Abstract: This study aims to design and evaluate a physics learning module based on the STEAM-SDGs approach on renewable energy material to improve students' literacy and numeracy skills. The background of this study is the low literacy achievements of Indonesian students in reading, mathematics, and science in international assessments such as PISA. To address this challenge, the development of innovative, contextually relevant teaching materials aligned with the United Nations' Sustainable Development Goals (SDGs) is necessary. This study employs the Research and Development (R&D) method, utilizing the ADDIE development model, which encompasses the stages of analysis, design, development, implementation, and evaluation. The developed product was validated by experts, tested in the classroom, and analyzed for its practicality and effectiveness. The results demonstrate that the developed teaching materials are valid, practical, and effective in enhancing students' understanding of renewable energy, while also significantly improving their literacy and numeracy skills. This research contributes to science education by integrating an interdisciplinary STEAM-based approach and sustainability-oriented content relevant to real-life contexts.

Keywords: literacy; numeracy; physics learning; renewable energy; STEAM-SDGs

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INTRODUCTION

Education in the 21st century requires students to have cognitive competencies, critical thinking skills, problem-solving skills, and an understanding of global challenges (Khoiri, Ristanto, et al., 2023; Khoiri, Roshayanti, et al., 2023; Syahril, 2024). Fauzi and Fadilah (2024), Hardianto et al. (2024), and Herawan (2021) stated that literacy and numeracy are fundamental skills needed to navigate an increasingly complex, data-driven society. The results of the Program for International Student Assessment (PISA) in 2018 and 2022 indicate that Indonesian students continue to rank at the bottom in reading, mathematics, and science (OECD, 2019, 2024). This indicates a serious problem with the quality of education in Indonesia. These weaknesses hinder the development of scientific reasoning, problem-solving, and sound decision-making skills—all of which are crucial for active participation in sustainable development initiatives (Ifriyia et al., 2022; Mu'minah, 2021; Sholeh et al., 2024).

The Indonesian government's long-term development plan (RPJPN 2025–2045), as outlined in Law Number 59 of 2024, emphasizes the importance of quality education as the primary foundation for achieving the Sustainable Development Goals (Kementerian PPN/Bappenas, 2020). Of the 17 goals, Goals 4 (Quality Education), 7 (Clean and Affordable Energy), and 13 (Addressing Climate Change) are highly relevant to science education (Khusniati & Yamtinah, 2024). Physics, as a subject, plays a crucial role in this regard due to its interdisciplinary nature and its significant potential for linking scientific concepts to real-world applications, particularly those related to energy use and environmental sustainability (Vioresa et al., 2023).

In practice, this enormous potential highlights that physics learning in schools remains dominated by abstract content and conventional learning methods (Ajibudiarta et al., 2025). This approach often fails to engage students actively and lacks contextual learning, resulting in boredom and difficulty understanding concepts (Nuzula & Jatmiko, 2023; Ifriyia et al., 2022). Teachers also often lack the tools or knowledge to effectively integrate global issues, such as climate change and renewable energy, into classroom learning (Ajibudiarta et al., 2025). Current learning designs do not explicitly aim to improve students' literacy and numeracy skills through science learning (Herawan, 2021; Sandrawati et al., 2023). Innovation in curriculum design is necessary to enable students to learn physics in a contextual, engaging, and relevant manner that addresses real-world problems.

One pedagogical approach that can be used as an alternative solution to existing problems is the STEAM-SDGs (Science, Technology, Engineering, Arts, and Mathematics - Sustainable Development Goals), which encourages interdisciplinary, inquiry-based, and project-oriented learning (Ajibudiarta et al., 2025; Jeong & González-Gómez, 2024; Permanasari et al., 2021). STEAM learning emphasizes not only mastery of material but

also the development of creativity, collaboration, and critical thinking skills (Hayat et al., 2024; Mulyani, 2019; Sumarni et al., 2022). The integration of STEAM with the SDGs enables students to apply their knowledge to address complex and authentic problems, such as the global energy crisis and environmental degradation. This model encourages students to explore renewable energy technologies, evaluate their environmental impact, and consider the ethical, social, and economic dimensions involved.

Several studies have demonstrated the effectiveness of STEAM-based approaches in improving science learning outcomes. Hayat et al. (2024) and Muntamah et al. (2023) found that integrating SDGs into STEAM projects improved students' creative thinking and problem-solving skills. Similarly, Wahyuni et al. (2023) demonstrated that STEAM-based learning improved students' understanding of physics concepts and their awareness of sustainability issues. Most of these studies are limited in scope and have not explicitly addressed the contribution of this approach to improving students' literacy and numeracy, particularly in physics topics related to energy (Ajibudiarta et al., 2025; Relmasira et al., 2023).

Furthermore, research on integrating STEAM and the SDGs into physics learning in the Indonesian context remains very limited (Awwalina et al., 2025). Several initiatives have incorporated the SDGs as learning themes, but few have developed comprehensive, validated learning designs that systematically and measurably link STEAM activities to the SDGs (Ayu et al., 2024; Hidayanthi et al., 2024; Meda, 2022; Mulyani, 2019). This creates a research gap, particularly in developing learning designs that not only teach physics content but also enhance basic skills such as reading graphs, calculating energy use, analyzing data, and evaluating real-world problems from a scientific perspective (Ajibudiarta et al., 2025; Sumarni et al., 2022).

Based on preliminary studies, including classroom observations and interviews with high school physics teachers and students, most educators have not yet implemented STEAM principles or contextual learning strategies related to the SDGs (Ajibudiarta et al., 2025). Many students consider physics a complex and abstract subject, perceiving it as irrelevant to daily life or future challenges (Aini et al., 2024; Meda, 2022; Sriwahyuni et al., 2019; Ulfa et al., 2024). Meanwhile, teachers expressed difficulty in designing learning that goes beyond textbooks and integrates interdisciplinary projects or social issues such as renewable energy (Nurhidayat & Asikin, 2021; Putra & Ellianawati, 2024; Ulfa et al., 2024). These findings underscore the importance of systematic learning design, incorporating a STEAM-SDGs approach, and offering structured support to enhance literacy and numeracy through physics education (Ajibudiarta et al., 2025).

To address these challenges, this study aims to develop a physics learning design based on the STEAM-SDGs approach for renewable energy. This topic is highly relevant to SDGs 7 and 13, which focus on clean energy and climate action, respectively. By integrating these themes into the learning process, students are expected to gain a deeper understanding of the role of science in addressing global problems and develop a sense of responsibility for environmental sustainability (Hartati & Hariyono, 2020; Holdinga et al., 2025; Kiswanda et al., 2021; Matitaputty et al., 2022). Furthermore, this learning design incorporates activities that support literacy skills (e.g., reading scientific texts, interpreting data, and evaluating arguments) and numeracy skills (e.g., analyzing energy consumption data, calculating efficiency, and modeling physical systems).

The model development followed the ADDIE framework—Analysis, Design, Development, Implementation, and Evaluation—to ensure a structured and systematic process (Sugiyono, 2023). The learning design included inquiry and project elements tailored to the cognitive and contextual needs of high school students in Indonesia. The teaching materials were validated by experts and piloted in the classroom to assess their practicality and effectiveness. The study also included pretests and posttests to measure improvements in student literacy and numeracy, supplemented by qualitative data through student interviews and teacher feedback.

This research aims to address the gap in contextual physics learning by developing a STEAM-SDGs-based learning design that strengthens basic skills. This model not only aligns with national education policies and curriculum reforms but also supports the development of critical, solution-oriented students to address global sustainability challenges. It is hoped that this model will become a practical, scalable innovation that can be implemented across various educational contexts to improve the quality of science education and student competencies.

METHODS

This study employs a research and development (R&D) approach, utilizing the ADDIE development model, which consists of five sequential stages: Analysis, Design, Development, Implementation, and Evaluation (Figure 1). This study aims to develop a valid, practical, and effective physics learning design based on the STEAM-SDGs framework, with a focus on renewable energy topics, to enhance students' literacy and numeracy skills.

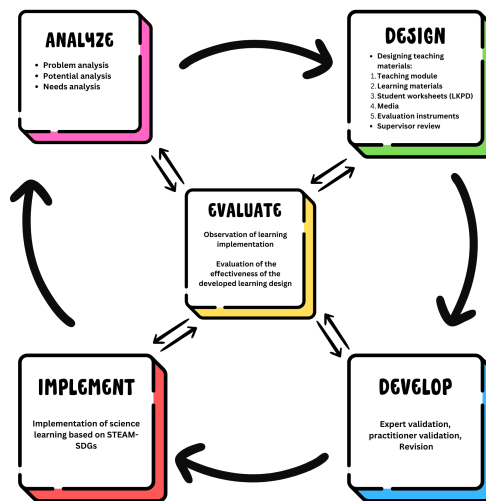


Figure 1. ADDIE Development Model

The research was conducted at SMA Negeri 1 Grobogan, involving 10th-grade students from two parallel classes: one class served as the experimental group and the other as the control group, each consisting of 30 students. Learning activities in the experimental class were designed using inquiry-based and project-based learning strategies within the STEAM-SDGs context, whereas the control class followed conventional learning methods. In the analysis stage, a needs assessment was conducted through teacher interviews, student questionnaires, and a curriculum review to identify learning gaps and opportunities to integrate the STEAM approach and SDG content into the physics curriculum. The design phase involved developing learning tools, including lesson plans, student worksheets, teacher guides, and project modules, that emphasized renewable energy concepts aligned with SDG 7 (Affordable and Clean Energy) and SDG 13 (Addressing Climate Change). These materials included interdisciplinary tasks such as science experiments, data analysis, artistic representation, and mathematical reasoning.

During the development stage, the design was validated by two subject experts and one learning media expert using a structured validation sheet. The experts' input was used to revise and refine the learning design. Next, during the implementation stage, the learning design was implemented in the experimental class for four meetings. Material and instructions were delivered through digital and print media, including solar and wind energy science kits, multimeters, and printed project modules. Observations were conducted to assess practicality, while pretests and posttests were administered to both groups to assess effectiveness. The evaluation phase included analysis of expert validation data, observation sheets, student and teacher questionnaire responses, and test results. Scientific literacy skills were measured through students' ability to interpret scientific information, explain phenomena, and evaluate evidence. Numeracy skills were measured through the ability to interpret graphs, perform calculations, and apply mathematical concepts in real-world energy contexts.

Data were analyzed using both quantitative and qualitative techniques. Expert validation scores were converted into percentages and categorized as "very valid," "valid," "moderately valid," or "invalid." Practicality data from the observation sheets were analyzed descriptively and interpreted using a Likert scale. Effectiveness was measured by comparing pretest and posttest scores using SPSS version 26 software. Normality tests (Shapiro–Wilk), homogeneity tests (Levene's test), and significance tests (independent-samples t-test) were conducted at the 0.05 significance level. The model was considered effective if students in the experimental group demonstrated significant improvements in literacy and numeracy skills compared with those in the control group. This procedure ensured that the developed learning design was not only theoretically sound but also practically feasible and empirically validated.

RESULT AND DISCUSSION

The developed STEAM-SDGs-based physics learning design was evaluated based on three main aspects: validity, practicality, and effectiveness. The validation process for the products developed in this study was conducted by two experts with competencies in education and learning tool development. Validation aimed to assess the appropriateness of the content, the suitability of the construction, and the usability of each product before implementation in the learning process. The validated products included the Learning Objective Flow, Learning Modules, Teacher Teaching Materials, Student Learning Materials/Student Worksheets, and Literacy and Numeracy Skill Test Instruments, with scores presented in [Table 1](#).

Table 1. Recapitulation of Expert Validation Data

Product	Score	Maximum Score	Percentage	Validity Level	Decision
Learning Objective Flow	38.5	40	96%	Very Valid	Valid to use without revision
Learning Modules	70	74	95%	Very Valid	Valid to use without revision
Teacher Teaching Materials	102	104	98%	Very Valid	Valid to use without revision
Student Learning Materials/Student Worksheets	54	56	96%	Very Valid	Valid to use without revision
Instrument Test Literacy and Numeracy Skill Test Instruments	54.5	56	97%	Very Valid	Valid to use without revision
Average Score	64	66	97%	Very Valid	Valid to use without revision

Validation results indicated that all products were categorized as Very Valid based on the percentage of scores achieved relative to the maximum score. Learning Objective Flow scored 38.5 out of 40, equivalent to 96%, indicating that the formulation of learning objectives aligns with curriculum principles and supports expected learning outcomes. Learning Modules scored 70 out of 74 (95%), indicating that the content, learning strategies, and assessments align with the principles of project-based learning and the STEAM-SDGs approach.

Teacher Teaching Material scored 102 out of 104 (98%), indicating that the materials met the requirements for completeness, readability, and suitability to student characteristics and the physics learning context. Meanwhile, Student Learning Material scored 54 out of 56 (96%), indicating that the worksheets were effective in guiding students in exploring physics concepts and strengthening their literacy and numeracy skills. The Literacy and Numeracy Skill Test instrument received a score of 54.5 out of 56 (97%), indicating that it is valid in both content and construction and suitable for measuring literacy and numeracy skills in the context of project-based physics learning. Overall, the average score across all products was 64 out of 66, corresponding to a 97% average. This confirms that all products are in the Very Valid category and can be used without revision. This high validity ensures that the developed products are of high quality, supporting the achievement of learning objectives, particularly in improving students' literacy and numeracy skills through a contextual approach integrated with sustainability principles.

After validation by experts, the developed learning tools were tested for practicality by educational practitioners, namely, physics teachers with direct classroom experience. This practicality test aimed to assess the extent to which the learning tools could be implemented effectively, efficiently, and appropriately in real-world conditions. Five product types were tested: Learning Objective Flow, Learning Modules, Teacher Teaching Materials, Student Learning Materials/Student Worksheets, and Literacy and Numeracy Skill Test Instruments. The assessment results showed that all components received a "Very Practical" category, with an average practicality percentage of 94%. In detail, Learning Objective Flow scored 37.17 out of a maximum score of 40 (93%), Learning Module scored 67.83 out of 74 (92%), the Teacher Teaching Materials scored 100.50 out of 104 (97%), the Student Worksheet scored 52.50 out of 56 (94%), and Literacy and Numeracy Skill Test Instruments scored 53.17 out of 56 (95%). The overall data are presented in [Table 2](#).

Table 2. Recapitulation of Practitioner Validation Data

Product	Score	Maximum Score	Percentage	Practicality Level	Decision
Learning Objective Flow	37.17	40	93%	Very Practical	Practical to use without revision
Learning Modules	67.83	74	92%	Very Practical	Practical to use without revision
Teacher Teaching Materials	100.50	104	97%	Very Practical	Practical to use without revision
Student Learning Materials/Student Worksheets	52.50	56	94%	Very Practical	Practical to use without revision
Instrument Test Literacy and Numeracy Skill Test Instruments	53.17	56	95%	Very Practical	Practical to use without revision
Average Score	62.23	66	94%	Very Practical	Practical to use without revision

These results indicate that the learning tools are not only valid in substance and structure but also practical for classroom use. Practitioners noted that the learning flow was easy to understand, the project modules were well-structured, and the project-based learning activities and numeracy literacy could be implemented flexibly according to student characteristics. All components were assessed as meeting the principles of efficient time use, clear instructions, and alignment with the Merdeka Curriculum. Furthermore, practitioners assessed that the STEAM approach integrated with the SDGs, particularly SDGs 7 (Affordable and Clean Energy) and 13 (Addressing Climate Change), could provide contextual meaning to physics learning. The association with real-world problem-based projects not only increased student engagement in learning but also strengthened the development of 21st-century competencies such as collaboration, scientific communication, critical thinking, and creativity. With such a high level of practicality, the resulting learning tool can be considered suitable for classroom use without the need for revisions to content, strategy, or technical implementation. This strengthens the tool's position as a relevant, contextual learning aid, with a direct impact on improving student literacy and numeracy through sustainable, renewable energy material.

The model's effectiveness was tested through a posttest comparison of literacy and numeracy skills between the experimental and control groups. Statistical analysis using an independent sample t-test revealed a significant improvement ($p < 0.05$) in both domains for the experimental group, whereas the control group showed only a marginal improvement. Students who participated in STEAM-SDGs-based learning demonstrated stronger abilities to interpret scientific information, explain energy phenomena, and evaluate the sustainability of various energy sources. In the numeracy aspect, students were able to perform data-based calculations, compare energy outputs, and estimate efficiency and environmental impact. These skills are crucial, not only for mastering physics but also for actively participating in sustainable development, as evidenced by the scores from the experimental and control classes presented in Figure 2.

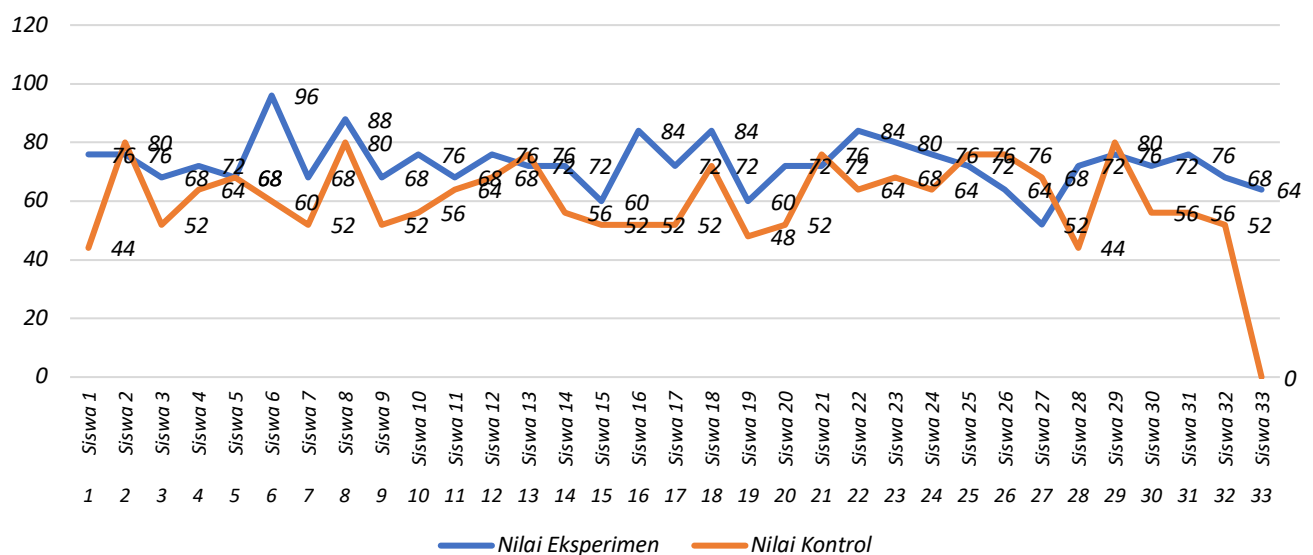


Figure 2. Summary of Literacy and Numeracy Test Results of Experimental and Control Classes

The Mann-Whitney U test was conducted to determine whether there was a significant difference in learning outcomes between students in the experimental and control classes. This test was chosen because the data in one of the groups (the control class) was not normally distributed; thus, parametric testing could not be used. The test results are presented in Figure 3.

Mann-Whitney Test

		Ranks		
	Kelas	N	Mean Rank	Sum of Ranks
Hasil Belajar	Kelas Eksperimen	33	41.42	1367.00
	Kelas Kontrol	32	24.31	778.00
	Total	65		

Test Statistics^a

Hasil Belajar	
Mann-Whitney U	250.000
Wilcoxon W	778.000
Z	-3.677
Asymp. Sig. (2-tailed)	<.001

a. Grouping Variable: Kelas

Figure 3. Results of the Mann-Whitney U Test

Based on the results of the Mann-Whitney U test, a significance value of $p < 0.001$ was obtained. Because the significance value is less than 0.05, it can be concluded that there is a statistically significant difference in student learning outcomes between the experimental and control classes. The results of this study confirm that developing a STEAM-SDGs-based physics learning design on renewable energy significantly improves students' literacy and numeracy skills. The three main aspects analyzed—validity, practicality, and effectiveness—indicate that the developed learning tool is highly suitable for implementation in secondary school science education. First, expert validation results indicate that all components of the learning tool have a very high level of validity (97%). This indicates that the design is appropriate in terms of content, construction, and language to the demands of the curriculum and the needs of 21st-century learning. Experts also highlighted the successful integration of the Sustainable Development Goals (SDGs), particularly SDGs 7 and 13, into contextual and meaningful project-based activities. These findings align with those of [Hayat et al. \(2024\)](#) and [Khoiri, Roshayanti, et al. \(2023\)](#), who emphasized the importance of interdisciplinary learning for fostering conceptual understanding and critical thinking skills.

Furthermore, the practicality aspect assessed by practitioners achieved an average percentage of 94%, reinforcing previous findings that the developed tools were not only theoretically feasible but also easy to implement in real-life learning. Teachers assessed that the learning activity flow was easy to follow, work instructions were clear, and project activities provided space for student collaboration and exploration. These findings align with those of [Darwanto et al. \(2021\)](#), [Muntamah et al. \(2023\)](#) and [Wahyuni et al. \(2023\)](#), who have emphasized the importance of contextual and project-based teaching materials in increasing student engagement and the relevance of science materials to real-life applications.

In terms of effectiveness, the learning design was statistically proven to improve students' literacy and numeracy skills compared to the control group. This improvement reflects not only mastery of physics content but also skills in interpreting data, thinking analytically, and making decisions based on scientific arguments. These results support [Fauzi and Fadilah \(2024\)](#) and [Syahril \(2024\)](#), who stated that literacy and numeracy can be significantly improved through learning designs that emphasize interdisciplinary connections, scientific inquiry, and real-world contexts. Moreover, integrating artistic elements into the STEAM approach—such as visualizing energy processes and designing scientific communication—demonstrates that physics learning need not be confined to abstract formulas and theories. Instead, by integrating aesthetics and data, students can express their understanding creatively and reflectively. This also enriches learning from both affective and cognitive perspectives.

Overall, the STEAM-SDGs-based physics learning design developed in this research has successfully addressed the need for science education that focuses not only on cognitive achievement but also on the development of higher-order thinking skills, awareness of global issues, and readiness for a sustainable future. The model's primary contribution lies in unifying academic, pedagogical, and sustainability dimensions within a single, operational, and proven-effective framework. Unlike previous studies that mainly focused on students' conceptual understanding, creativity, or problem-solving, this research explicitly demonstrates how a STEAM-SDGs-based physics learning design can significantly enhance both literacy and numeracy skills. This dual emphasis provides a new contribution to science education by linking sustainability-oriented content with measurable improvements in fundamental competencies.

CONCLUSION

This research successfully developed a STEAM-SDGs-based physics learning design for renewable energy materials, which was proven to be valid, practical, and effective in improving students' literacy and numeracy skills. The validation results, as assessed by experts, showed that all components of the learning device—including the Learning Objective Flow, Learning Modules, Teacher and Student Materials, and Test Instruments—were categorized as "Very Valid" with an average score of 97%. Practicality tests by practitioners showed that the developed device was easy to implement and relevant to the classroom context, with an average practicality percentage of 94%. The effectiveness of this learning design was evident in the significant increase in literacy and numeracy skills among students who participated in STEAM-SDGs learning, compared to those in conventional learning. The integration of project-based and inquiry-based learning, linked to the Sustainable Development Goals (SDGs), directly strengthens the connection between physics concepts and global issues, such as clean energy and climate change. Thus, the developed learning design can serve as an innovative alternative for interdisciplinary, contextual physics learning, oriented toward strengthening 21st-century skills. This design not only supports improved academic learning outcomes but also fosters students' awareness and responsibility for sustainability, in line with national and global education policy directions.

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