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Feasibility of ESD-Based Teaching Materials Using EDP in Senior High School Physics on Alternative Energy and Environmental Issues

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Abstract: Twenty-first-century education requires critical, creative, and solution-oriented thinking skills to address global issues such as environmental problems and the energy crisis. One approach that supports these skills is Education for Sustainable Development (ESD) integrated with the Engineering Design Process (EDP). This study aims to develop and evaluate the feasibility of ESD-EDP–based teaching materials on the topic of alternative energy in senior high school physics learning. This research is a type of Research and Development (R&D) using the ADDIE model, limited to the Analyze, Design, and Development stages. The Analyze stage included learning outcomes and student needs analysis, the Design stage produced the instructional framework, and the Development stage resulted in teaching materials validated by two subject matter experts, two media experts, and evaluated through the responses of 23 tenth-grade students. Validation results indicated very high feasibility with scores of 94% (content), 93% (presentation), 84% (language), and 92% (graphic design). Student responses averaged 88%, categorized as very good. Thus, ESD-EDP–based teaching materials are considered highly valid and feasible for senior high school physics learning on alternative energy topics.
Keywords: Teaching Materials; Education for Sustainable Development; Engineering Design Process; Alternative energy; Senior High School

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Introduction

Environmental issues and energy crises are global challenges that require urgent attention, particularly through education. In this context, Education for Sustainable Development (ESD) plays a crucial role in equipping students with the knowledge, attitudes, and skills necessary to make responsible decisions for environmental sustainability. Physics, as a subject that addresses natural phenomena and energy concepts, provides a strategic platform to introduce ESD, especially through topics like alternative energy sources that are directly linked to sustainable living (UNESCO, 2020).

The integration of sustainability into school curricula is no longer optional but essential. As global environmental challenges such as climate change, depletion of fossil fuels, and pollution intensify, education must prepare learners to think critically, solve complex problems, and take informed action. ESD, as promoted by UNESCO (2020), emphasizes the importance of equipping students with the values and skills needed to become active contributors to a more sustainable future. In science education, particularly in physics, incorporating ESD enables students not only to understand scientific principles but also to apply them in solving real-life environmental problems (Tilbury, 2011).

The topic of alternative energy is especially relevant for high school physics, as it connects fundamental physics concepts (such as energy transformation, power, and systems) to pressing global issues. However, the way these topics are taught often remains theoretical and disconnected from the students' lived experiences. Traditional didactic methods rarely provide opportunities for students to engage in design thinking or environmental decision-making. This disconnect can reduce students' motivation and limit the development of 21st-century skills such as creativity, collaboration, and sustainability literacy (Bybee, 2013).

Several recent studies have attempted to incorporate ESD into science education through the development of teaching materials and digital modules. Badiah et al. (2024) developed ESD-based digital teaching materials on renewable energy that were found to be highly feasible, valid, and effective in promoting students' critical thinking. Hanifah et al. (2025) demonstrated that ESD-integrated e-modules significantly improved students' scientific literacy on low-carbon energy topics. Meanwhile, Putri et al. (2025) successfully implemented SDGs-integrated physics modules to enhance students' environmental literacy and awareness. These studies underline the importance and potential of ESD-based learning tools in improving both cognitive and affective domains in science education.

However, most of the existing teaching materials developed under ESD frameworks tend to use conventional or general learning models. Few studies have explored the use of the Engineering Design Process (EDP), a structured, iterative model widely used in STEM education as a pedagogical approach in developing ESD-based physics materials. The EDP model emphasizes problem-solving, creativity, and iterative thinking, making it a promising fit for ESD, especially when teaching complex issues like renewable energy, where real-world application and student-driven design are essential (Cunningham & Kelly, 2017). When applied to ESD contexts, EDP not only deepens scientific understanding but also promotes student agency and real-world application. For example, students can design and evaluate small-scale models of renewable energy systems (like solar cookers or wind turbines) to explore energy efficiency and environmental impacts (Cunningham, 2018). This kind of learning fosters both conceptual mastery and a sense of environmental responsibility.

Despite the compatibility between ESD and EDP, there is a lack of research that explicitly combines these two frameworks in the development of teaching materials for high school physics. Prior studies have validated ESD-based materials (Badiah et al., 2024; Hanifah et al., 2025), but few have utilized the engineering design process as the underlying instructional model. Therefore, integrating ESD with EDP represents a significant pedagogical innovation that bridges theory with action and content with context.

Accordingly, this study aims to develop teaching materials for senior high school physics that integrate Education for Sustainable Development (ESD) with the Engineering Design Process (EDP), focusing on the topic of alternative energy. The specific objectives are (1) to analyze the process of developing ESD-based teaching materials using the EDP model on alternative energy topics, (2) to evaluate the content and construct validity of the materials through expert judgment, and (3) to assess students' responses toward the teaching materials in terms of relevance, engagement, and usability. This research seeks to contribute to the development of sustainable physics education by fostering design thinking and environmental literacy simultaneously.

Method

This study employs a Research and Development (R&D) approach. The purpose of this research is to develop or improve an educational product. The research design follows the ADDIE model, which consists of five stages: Analyze, Design, Development, Implementation, and Evaluation. This study aims to produce teaching materials that are valid for use in the classroom and to assess students' responses after using teaching materials based on ESD integrated with the EDP model on the topic of alternative energy. The scope of this research was restricted to the Development stage of the ADDIE model. In the Analyze stage, the researcher identified learning objectives and examined common problems in teaching alternative energy through classroom observations and literature review to explore student needs, teacher challenges, and relevant theoretical frameworks. In the Design stage, the researcher developed teaching materials based on ESD principles and the EDP model, including components such as the cover, table of contents, concept map, learning outcomes, and a validation instrument assessing content, language, presentation, and graphic design. In the Development stage, the materials were created in line with the national curriculum, then validated by 3 validators, which consisted of two lecturers and one physics teacher using BSNP (2008) instruments covering content and media validation. After being declared valid, student responses were collected through questionnaires focusing on interest, content clarity, and language use to evaluate their perceptions of the developed materials, which involved 20 students (Kohar, 2022).

The data analysis technique in this study was designed to determine the feasibility of the developed teaching materials and to assess whether they met the established validity criteria. Validation was carried out by two physics lecturers and one high school physics teacher from Bunga Bangsa Islamic Senior High School, Samarinda. These validators provided assessments for each component included in the validation instrument. The validity evaluation focused on four aspects: presentation, content, language, and graphics (Manurung, et al., 2021; Mislia, 2018). The data obtained from the validation sheets were then analyzed using Equation 1, where $\bar{x}$ represents the average score obtained, while $\sum x$ denotes the total score achieved, and n refers to the number of items included in the assessment sheet.

$$\bar{x} = \frac{\sum x}{n} \tag{1}$$

To convert the average score into a qualitative value, a five-point scale based on the assessment aspects (Widoyoko, 2011) was used, as shown in Table 1. In this table, $\bar{x}$ represents the empirical score obtained from the validation results. The empirical score is calculated by summing the scores given by the validators for each component of the instrument and dividing it by the total number of assessment items. Furthermore, the mean score ($\overline{x_i}$) is determined using the formula $\frac{1}{2}$ (ideal maximum score + ideal minimum score), which represents the midpoint between the highest and lowest possible scores and serves as a reference value. The ideal standard deviation (sb_i) is calculated using the formula $\frac{1}{6}$(ideal maximum score - ideal minimum score), which indicates the distribution range of the ideal scores by dividing the score difference into six categories. The values of x and sb_i are then used to determine the validity category of the teaching materials, whether they are classified as very valid, valid, quite valid, less valid, or invalid, as presented in Table 1.

Table 1. Validity Criteria

Range	Category
$\overline{\overline{x}}\text{i} + 1{,}8\, xSb_i < x$	Very Valid
$\overline{\overline{x}}\text{i} + 0{,}6 \times Sb_i < x \leq \overline{x}_\text{i} + 1{,}8 \times Sb_i$	Valid
$\overline{x}\text{i} - 0{,}6 \times Sb_i < x \leq \overline{x}_\text{i} + 0{,}6 \times Sb_i$	Quite Valid
$\overline{x}\text{i} - 1{,}8 \times Sb_i < x \leq \overline{x}_\text{i} - 0{,}6 \times Sb_i$	Less Valid
$x \leq \overline{x}_\text{i} - 1{,}8 \times Sb_i$	Invalid

Equation 2 was used to calculate the validity in the form of a percentage. This equation helps the researcher measure how well the teaching materials meet the predetermined criteria. The validity calculation results then provide a clear overview of the quality of the developed teaching materials.

$$Validity\ percentage = \frac{total\ score\ obtained}{maxmum\ possible\ score} \times 100\ \% \quad (2)$$

The results of the data analysis were classified based on the validity percentage using the criteria proposed by Widoyoko (2011). This classification helps to provide a clearer understanding of the level of validity of the developed teaching materials. According to the criteria, teaching materials are categorized as Very Valid if the validity percentage is between 81%–100%, Valid for 61%–80%, Moderately Valid for 41%–60%, Less Valid for 21%–40%, and Not Valid if the validity percentage is below 21%, as presented in Table 2.

Table 2. Validity Criteria Based on Percentage.

Range	Category
81 %≤ *Validity percentage* ≤ 100 %	Very Valid
61 %≤ *Validity percentage* < 81 %	Valid
41 %≤ *Validity percentage* < 61%	Moderately Valid
21 %≤ *Validity percentage* < 41%	Less Valid
< 21%	Not Valid

To obtain data regarding students' responses to the learning process, the researcher used a student response questionnaire. In this instrument, students were asked to provide scores for each statement based on a Likert scale ranging from 1 to 5, where a score of 1 indicates "Strongly Disagree," 2 indicates "Disagree," 3 indicates "Neutral," 4 indicates "Agree," and 5 indicates "Strongly Agree." The collected scores were then analyzed by calculating the percentage of the total score obtained using the formula presented in Equation (3). This equation was employed to assess student responses by comparing the total score achieved with the maximum possible score, thereby showing the relative level of student acceptance of the teaching materials. After the calculation, the results were interpreted based on the response criteria outlined in Table 3.

$$responses\ percentage = \frac{total\ score\ obtained}{maxmum\ possible\ score} \times 100\ \% \quad (3)$$

Table 3. Student Response Criteria

Range	Category
Response percentage ≤ 20	Very Good
20 < *Response percentage* ≤ 40	Good
40 < *Response percentage* ≤ 60	Fair
60 < *Response percentage* ≤ 80	Poor
80 < *Response percentage* ≤ 100	Very Poor

Results and Discussion

Result

To achieve research objectives, the development of ESD-EDP-based teaching materials followed the ADDIE model, which in this study was limited to three stages: Analyze, Design, and Development. Each stage provided a systematic foundation for ensuring that the teaching materials were relevant, valid, and aligned with the goals of sustainable physics education. The discussion of each stage is presented as follows.

1. Analyze Stage

Before developing the teaching materials, the author first analyzed problems frequently encountered in learning about alternative energy. The analysis was carried out through classroom observations and a literature review to identify challenges faced by teachers, student difficulties, as well as the learning needs required for more effective instruction. Based on the results of this analysis, several findings were categorized into three main aspects, namely the problems encountered in learning, students' needs to address these problems, and the proposed solutions through the development of ESD-EDP-based teaching materials. A summary of the analysis results is presented in Table 4.

Table 4. Analysis of Problems, Students' Needs, and Proposed Solution.

No	Identified Problems	Students' Needs	Solutions
1	Lack of integration of sustainability values in science learning	Materials containing environmental awareness, social responsibility, and sustainability consciousness	Alternative energy material aligns with ESD principles as it promotes understanding of the sustainable use of natural resources.
2	Learning is still monotonous and teacher-centered	Active, engaging, and student-involved learning	ESD provides exploratory, participatory, and contextual activities.
3	Alternative energy material is delivered in a theoretical and abstract manner.	Explanations that are concrete and related to daily life	ESD connects the material with local issues and students' surrounding environment.
4	Students are less encouraged to think critically and creatively	Challenges to solve problems and create solutions	Teaching materials include student worksheets (LKPD) using the EDP model to train real problem-solving skills.
5	Low student awareness of environmental and sustainability issues	Values of environmental care and social responsibility	ESD fosters environmental awareness through sustainability-based and reflective activities in teaching materials

2. Design Stage

At this stage, the researcher formulated learning objectives referring to the Phase E learning outcomes in the Merdeka Curriculum for senior high school physics. Instruments were also designed, including expert validation sheets, student response questionnaires, practice exercises, and student worksheets (LKPD). The teaching materials were designed using UNESCO's standard paper size (15.5 x 23 cm), 1.5 line spacing, and Cambria font. Visual design elements such as cover, layout, infographics, and content were created using Canva. The materials were systematically structured, consisting of book instructions, an introduction

to ESD and EDP, a concept map, main content, and worksheets. The stages of teaching material design are presented in Figure 1.

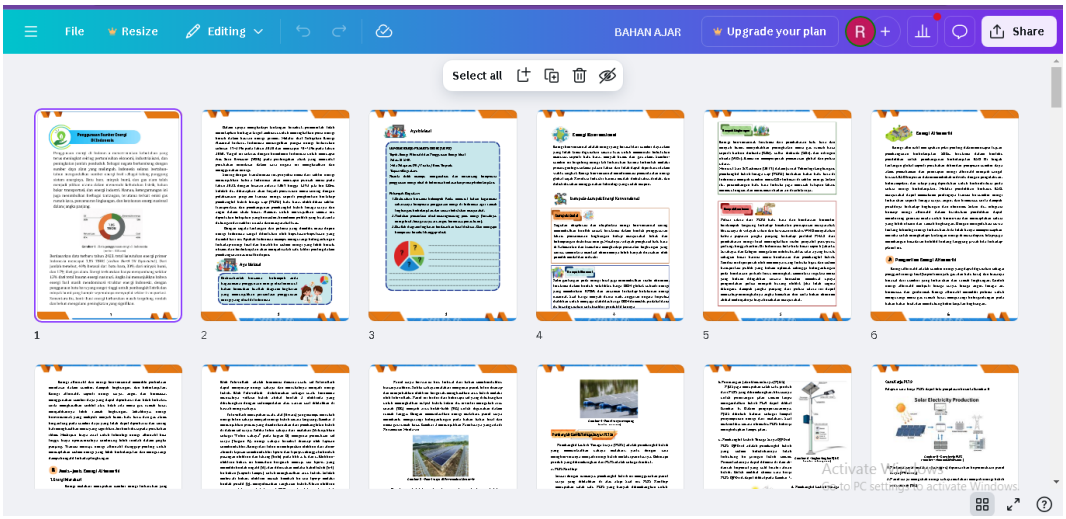

Figure 1. The Process of Designing Teaching Materials

3. Development Stage

In the development stage, the conceptual design was transformed into a complete set of teaching materials focused on alternative energy, using the EDP model within the ESD framework. Once the development was complete, the product underwent a validation process by experts in content and media to evaluate its material quality and presentation. The results of this stage served as a foundation for determining the feasibility and effectiveness of the developed teaching materials (Manurung, et al., 2021; Mislia, 2018).

To assess the validity of the developed ESD-based teaching materials on alternative energy, the researcher conducted expert validation involving both content and media aspects. The content validity was evaluated using a questionnaire consisting of 23 Likert-scale items, covering two main aspects: content (accuracy, relevance to learning outcomes, and up-to-dateness) and presentation (clarity, learning support, coherence, and instructional flow). Meanwhile, the media validity was assessed using 28 items, focusing on language (clarity, communicativeness, interactivity, age-appropriateness, and grammar) and graphics (layout size, cover design, and content design) (Tarigan, 2009). The product was validated by content and media experts, and the results are presented in Table 5.

Table 5. Teaching Material Validity Result

Aspect	Validity Percentage	Category
Materials Validity		
Content	94 %	Very Valid
Presentation	93 %	Very Valid
MediaValidity		
Language	84 %	Very Valid
Graphics	92 %	Very Valid

To evaluate student responses to the ESD-based teaching materials on the topic of alternative energy, a questionnaire consisting of 20 Likert-scale items was administered. The scoring ranged from 1 (strongly disagree) to 5 (strongly agree), with a minimum possible score of 20 and a maximum of 100. The questionnaire assessed

three aspects: interest, content, and language. Based on the analysis, the results showed high levels of student agreement across all aspects. The interest aspect scored 88%, content scored 87%, and language scored 90%, with an average percentage of 88%, placing the overall student response in the "Very Good" category. These findings indicate that the developed teaching materials were well-received and considered engaging, relevant, and easy to understand by the students.

Table 6. Student Response Percentage

Aspect	Response Percentage	Category
Interest	88 %	Very Good
Content	87 %	Very Good
Language	90 %	Very Good
Average	88 %	Very Good

The ESD-based teaching materials on the topic of alternative energy for senior high school (SMA/MA) obtained a validity score in the "very valid" category with a value of 90.75%, and student responses were in the "very good" category with a value of 88%. However, the developed teaching materials still received comments and suggestions from the validators as an evaluation for improvement to make the materials better. Several revisions and recommendations from the content experts and media experts can be seen in Table 7.

Table 7. Comments and Suggestions

Comments and Suggestions	Revisions Made
Revise typographical errors found in the foreword section.	Typographical errors in the foreword have been corrected.
Provide clear and measurable statements of learning objectives.	Learning objectives have been added and formulated in a measurable manner.
Simplify and restructure the Student Worksheet (LK) so that it fits within a single page.	The Student Worksheet has been revised and reformatted to fit on one page.
Include a comprehensive explanation of the stages of the Engineering Design Process (EDP).	A complete explanation of the EDP stages has been incorporated.
Add relevant arguments or conclusions related to Education for Sustainable Development (ESD) in the section on impacts.	Relevant conclusions regarding the presented impacts have been added to the teaching materials.
Ensure that foreign terms, particularly English terminology, are written in italicized format.	Foreign terms have been corrected and italicized accordingly.

After thoroughly reviewing the suggestions provided by the validators and making the necessary revisions based on their feedback, the development of this teaching material has been completed. All recommended aspects have been addressed, resulting in a more systematic, communicative, and pedagogically appropriate teaching resource. Consequently, this teaching material is considered feasible for use in instructional activities, as it effectively supports the achievement of learning objectives. The final version of the developed and refined teaching material can be seen in Figure 2. Furthermore, the presence of this teaching

material is expected to provide students with a more meaningful and engaging learning experience.

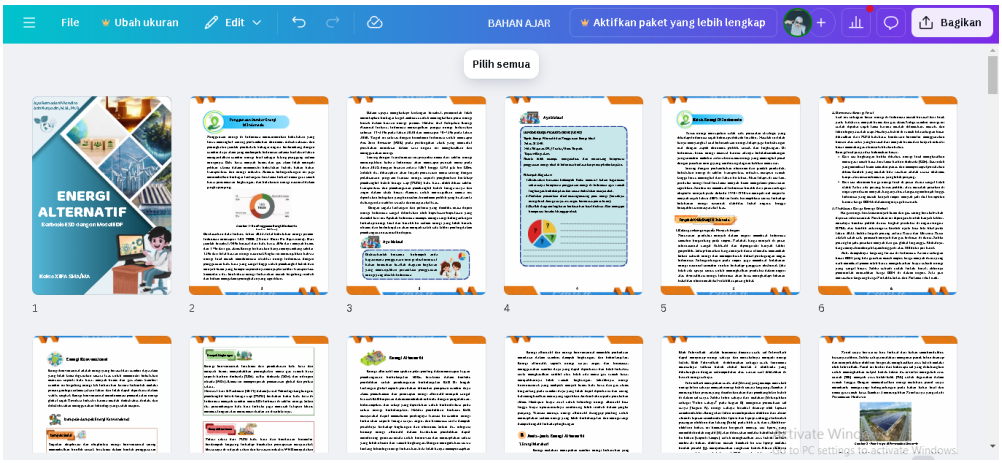

Figure 2 Final Version of the Developed Teaching Material

Discussion

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five main stages; however, the research was conducted only until the third stage, namely Analyze, Design, and Develop. At the Analyze stage, In the Analyze stage, the researcher conducted a needs assessment of classroom learning and evaluated its alignment with the Merdeka Curriculum. The analysis involved collecting information on learning outcomes and elements of the Natural Sciences subject, particularly alternative energy, which served as the foundation for designing teaching materials integrated with the Education for Sustainable Development (ESD) approach and the Engineering Design Process (EDP) model. The results indicated that previous learning was still conventional and lacked contextualization, making it difficult for students to comprehend alternative energy concepts. Students also had limited opportunities to develop critical and creative thinking and were not yet fully aware of environmental and sustainability issues. These findings are consistent with Putri, et al. (2025), who found that existing teaching materials did not meet students' needs for independent and interactive learning because they were primarily in print format. The study emphasized the need for innovative, interactive e-modules tailored to students' needs (Putri et al., 2025).

Based on the needs analysis, the researcher proceeded to the Design stage, developing ESD-based teaching materials with the EDP model aligned with the Merdeka Curriculum. The design included essential components such as the cover, table of contents, concept maps, learning outcomes, learning objectives, and Student Worksheets (LKPD). Special attention was given to language, material presentation, and graphics to ensure the materials were understandable, engaging, and age-appropriate for students (Tarigan, 2009). This approach aligns with the findings of Anggraini, et al. (2025), who developed ESD-oriented e-modules on palm oil waste processing into alternative energy to enhance students' scientific literacy. Their research demonstrated that e-modules designed with a focus on content clarity, interactivity, and visual appeal effectively improved students' understanding and skills in alternative energy topics (Anggraini et al., 2025).

The result of the development stage was a teaching material product that had been structured according to the applicable learning outcomes (CP) and included a questionnaire to measure the validity and responses of the research subjects (Sugihartini & Yudiana, 2018). At this stage, ESD-based teaching materials with the EDP model were prepared and organized into three parts: 1) the front section, which included the cover page, preface, table of contents, list of figures, user guide, concept map, science learning outcomes, learning objectives, and

introduction to ESD and EDP; 2) the main section, which contained alternative energy materials, example problems, science facts, LKPD using the EDP model, self-assessment questions, and summaries; and 3) the final section, which included a glossary, answer keys, and references.

The developed teaching materials were validated by two expert lecturers—one media expert and one content expert—and one science teacher. The validation instrument consisted of four aspects: content, presentation, language, and graphics. The content aspect aimed to assess the novelty and necessity of the materials. The presentation aspect evaluated the clarity and quality of the material delivery. The language aspect assessed readability and appropriateness for students, while the graphics aspect examined layout and illustrations.

The content aspect achieved a validity percentage of 94%, categorized as very valid, indicating that the ESD-based teaching materials could support the achievement of science learning outcomes in accordance with the Merdeka Curriculum. The presentation aspect scored 93% (very valid), showing that the material components and presentation quality were appropriate. The language aspect obtained 84% (very valid), indicating that the language was readable and suitable for the students' level. The graphics aspect scored 92% (very valid), reflecting neatness, illustration quality, and layout effectiveness. The overall validity from the expert evaluation was 90.75%, classifying the ESD-based teaching materials on alternative energy as very valid and ready for use.

After the teaching materials were declared valid, the next step was to assess students' responses. Students first read the ESD-based materials and then completed a questionnaire consisting of three aspects: attractiveness, content, and language. The attractiveness aspect evaluated whether colors, illustrations, and layout enhanced material comprehension. The content aspect measured the relevance and effectiveness of the materials in supporting understanding and motivation. The language aspect assessed whether the language was simple and easily understood according to the students' level (Kohar, 2022).

Students' responses showed that the attractiveness aspect scored 88% (very good), indicating that students found the materials engaging due to appealing colors, illustrations, and layout. The content aspect scored 87% (very good), showing that the materials supported science learning in a systematic manner and encouraged students' motivation. The language aspect scored 90% (very good), indicating that the language was appropriate and easy to understand for eleventh-grade students. Overall, the average student response was 88%, categorized as very good.

In conclusion, the ESD-based teaching materials on alternative energy were validated and received positive feedback from eleventh-grade students at SMA Bunga Bangsa Samarinda. The teaching materials have strengths due to their systematic and integrative approach, combining scientific, social, economic, and environmental aspects through the ESD concept and EDP model. This approach allows students not only to understand the material theoretically but also to apply it in real-life contexts, developing critical and innovative skills. Additionally, the book provides a comprehensive range of alternative energy sources with explanations of their mechanisms and impacts, enriching students' knowledge. However, the materials may be complex for high school students, requiring intensive teacher guidance. Furthermore, since the approach is both theoretical and project-oriented, supporting facilities and additional teacher training may be necessary for optimal implementation. These findings are in line with previous studies that have also highlighted the potential of ESD-based materials to integrate multiple dimensions of learning For instance, Setyowati et al. (2023) developed science teaching materials using a PjBL- STEM model combined with an ESD approach on environmental pollution topics showing that such integration enhances students' critical thinking and environmental awareness Similarly, Septyani et al. (2022) applied the EDP model in STEM learning on the topic of global warming and found that it effectively improved students' conceptual understanding and engagement in sustainability-related

issues). These studies support the argument that a systematic and integrative approach, such as the one adopted in this research, can enrich students' learning experiences while also presenting challenges in terms of implementation that require adequate teacher preparation and institutional support.

Conclusion

Based on the research objectives, it can be concluded that the development process of ESD-based teaching materials with the EDP model on alternative energy topics was carried out through three main stages of the ADDIE model, namely Analyze, Design, and Development. At the Analyze stage, a needs assessment was conducted to examine the learning requirements and their alignment with the Merdeka Curriculum; at the Design stage, a structured draft of the teaching materials was produced along with validation instruments; and at the Development stage, the draft was transformed into a complete product, validated by experts, and tested through student responses. The validation conducted by two expert lecturers and one science teacher yielded an average validity score of 90.75%, categorized as very valid, indicating that the teaching materials are feasible for use. Furthermore, student response testing resulted in an average score of 88%, categorized as very good, suggesting that the materials were perceived as engaging, easy to understand, and supportive of students' learning motivation. Overall, these teaching materials demonstrate significant strengths as they are systematically and integratively designed by combining scientific, social, economic, and environmental dimensions through the ESD approach and the EDP model, thereby encouraging students to think critically and innovatively as well as to connect the content with real-world contexts. Nevertheless, certain limitations remain, particularly the complexity of the materials, which may require intensive guidance, along with the need for supporting facilities and additional teacher training to ensure optimal implementation.

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