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Needs Analysis of an E-Module Integrated with Deep Learning, ESD, and Local Wisdom Approaches Assisted by Canva AI to Facilitate Students' Creative Thinking Skills

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ABSTRACT

The development of students' creative thinking skills in physics learning has not been optimally supported by the teaching materials used in schools, particularly in renewable energy topics. Creative thinking plays an important role in supporting Education for Sustainable Development (ESD) by enabling students to generate innovative solutions to sustainability-related problems. This study aims to analyze the need for developing a Deep Learning-based e-module integrated with ESD, local wisdom, and Canva AI to facilitate students' creative thinking skills in physics learning. This research employed a Research and Development (R&D) approach using the Four-D (4D) model consisting of the Define, Design, Develop, and Disseminate stages; however, this study was limited to the Develop stage. Data were collected through creative thinking skills tests, student needs analysis questionnaires, ESD questionnaires, and teacher interviews involving 30 tenth-grade students. The data were analyzed using descriptive quantitative techniques. The preliminary findings revealed that students' creative thinking skills were categorized as low, with an average score of 40.75%, while the originality indicator obtained the lowest score. In contrast, students demonstrated a very high level of readiness for digital learning. These findings indicate the need to develop a Deep Learning-based e-module integrated with ESD, local wisdom, and Canva AI to provide meaningful, contextual, and interactive physics learning that facilitates students' creative thinking skills.

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INTRODUCTION

Sustainable development has become one of the world's major priorities in addressing increasingly complex environmental, social, and economic challenges. In response to these challenges, the United Nations established the Sustainable Development Goals (SDGs), which recognize education as a key driver for equipping learners with the knowledge, skills, values, and attitudes necessary to contribute to sustainable development (United Nations, 2015;

UNESCO, 2020). In line with this agenda, UNESCO, through the *Education for Sustainable Development: Towards Achieving the SDGs (ESD for 2030)* framework, emphasizes that education should not only focus on academic achievement but also foster learners' ability to make informed decisions and adopt sustainable lifestyles (UNESCO, 2020; Leicht et al., 2018). Therefore, learning should be designed to connect scientific concepts with authentic real-world problems and encourage students to develop innovative solutions to sustainability challenges (Leicht et al., 2018; Redman & Wiek, 2021).

Education for Sustainable Development (ESD) is an educational approach that integrates the principles of sustainable development into teaching and learning processes to equip learners with the knowledge, skills, values, and attitudes needed to contribute to a more sustainable future (UNESCO, 2020; Leicht et al., 2018). Beyond promoting conceptual understanding, ESD encourages students to critically examine environmental, social, and economic issues from multiple perspectives and make informed and responsible decisions (UNESCO, 2020; Leicht et al., 2018). The effective implementation of ESD requires active, collaborative, and contextual pedagogical approaches that foster sustainability competencies through meaningful learning experiences (Lozano et al., 2023; Scharenberg et al., 2021). Furthermore, Redman and Wiek (2021) argue that achieving the goals of ESD depends on learners' mastery of sustainability competencies supported by higher-order thinking skills, including creative thinking. Therefore, ESD-oriented learning should provide opportunities for students to construct knowledge, connect scientific concepts with real-world situations, and generate innovative solutions to complex sustainability challenges in practice (Redman & Wiek, 2021; Lozano et al., 2023).

In line with the implementation of Education for Sustainable Development (ESD), the Deep Learning approach has gained increasing attention as a learning approach that emphasizes meaningful learning through students' active engagement in authentic inquiry, reflection, collaboration, and problem-solving activities (Fullan et al., 2020). This approach encourages students to connect their prior knowledge with new learning experiences, enabling them to construct deep conceptual understanding and transfer their learning to authentic contexts (Fullan et al., 2020). The integration of Deep Learning with ESD is expected to create more meaningful learning experiences while supporting the development of sustainability competencies through contextual and learner-centered instruction (Lozano et al., 2023; Redman & Wiek, 2021). Sarasdewi (2025) reported that the implementation of Deep Learning through renewable energy projects increased students' engagement, strengthened conceptual understanding, and enhanced critical, creative, and collaborative thinking skills. Similarly, O'Toole et al. (2026) found that project-based learning combined with reflective practices in sustainability education effectively fostered students' creative thinking through authentic learning experiences. Therefore, integrating ESD with the Deep Learning approach has the potential to strengthen students' conceptual understanding while preparing them to address complex sustainability challenges through creative and responsible problem-solving (Redman & Wiek, 2021; O'Toole et al., 2026).

Among the various competencies required in the 21st century, creative thinking skills are recognized as one of the essential competencies for addressing increasingly complex sustainability challenges. These skills enable students to generate multiple ideas, examine problems from different perspectives, develop innovative solutions, and adapt to rapidly changing environmental, social, and technological conditions (Redman & Wiek, 2021; UNESCO, 2020). Creative thinking consists of four main indicators, namely fluency, flexibility, originality, and elaboration, which collectively reflect students' ability to produce diverse, novel, and well-developed ideas (Munandar, 2012; Nurdayanti et al., 2020). The development of these indicators is an important objective of science education because it not only strengthens students' conceptual understanding but also equips them with the capacity to respond creatively and responsibly to sustainability-related problems in real-world contexts (UNESCO, 2020; Lozano et al., 2023).

The development of creative thinking skills is one of the primary objectives of physics education because physics learning is not merely intended to help students master scientific concepts but also to cultivate scientific reasoning, inquiry skills, and problem-solving abilities that are essential for addressing real-world challenges (OECD, 2024; Redman & Wiek, 2021). Through physics learning, students are expected to observe natural phenomena, analyze problems based on scientific evidence, and apply scientific concepts to solve contextual problems encountered in everyday life (OECD, 2024). Therefore, physics instruction should provide meaningful learning experiences that emphasize inquiry, collaboration, reflection, authentic problem-solving, and active student participation to foster creative thinking while strengthening students' conceptual understanding (Fullan et al, 2020; Lozano et al., 2023). Such learning experiences are also aligned with the goals of Education for Sustainable Development, which encourage students to apply scientific knowledge creatively and responsibly in responding to sustainability challenges in real-world contexts (UNESCO, 2020; Redman & Wiek, 2021).

One of the physics topics that is highly relevant to the implementation of ESD is renewable energy. This topic is closely associated with global efforts to reduce dependence on fossil fuels and promote the transition toward cleaner and more sustainable energy sources in achieving the Sustainable Development Goals (United Nations, 2015; UNESCO, 2020). Learning about renewable energy not only enables students to understand scientific concepts but also provides opportunities to analyze environmental, social, and economic issues from multiple perspectives and develop innovative solutions to real-world sustainability challenges (Kioupi & Voulvoulis, 2019; Lozano et al., 2023). Therefore, renewable energy serves as an appropriate learning context for fostering sustainability awareness while simultaneously promoting students’ creative thinking skills through meaningful and contextual learning experiences (Redman & Wiek, 2021; UNESCO, 2020).

Despite its potential, the development of students' creative thinking skills in physics learning remains a significant challenge. Classroom instruction is still predominantly focused on concept acquisition through memorization and routine problem-solving, providing limited opportunities for students to explore ideas, generate alternative solutions, and solve authentic contextual problems (OECD, 2024; Nugroho et al., 2025). In addition, the integration of local wisdom into physics learning has not been optimized, even though local wisdom offers authentic and contextual learning experiences that enable students to relate physics concepts to their surrounding environment and everyday life. Previous studies have shown that ethnoscience-based physics teaching materials can improve students' conceptual understanding, thinking skills, and engagement by connecting scientific concepts with local culture and community practices (Fianti & Neratania, 2024; Pieter & Risamasu, 2024). Therefore, integrating local wisdom with Education for Sustainable Development (ESD) and the Deep Learning approach is expected to create meaningful, contextual, and student-centered learning experiences while fostering students' creative thinking skills (Fullan et al, 2020; Lozano et al., 2023).

The results of the needs analysis conducted at SMA Negeri 1 2×11 Kayu Tanam revealed that students' creative thinking skills in renewable energy topics were still relatively low. The average achievement of creative thinking skills was only 40.75%, with all four indicators fluency, flexibility, originality, and elaboration classified in the very low category. Among these indicators, originality obtained the lowest percentage, indicating that students still experienced difficulties in generating novel ideas and proposing alternative solutions to renewable energy-related problems. These findings suggest that the current physics learning practices have not yet provided sufficient opportunities for students to develop creative thinking skills through meaningful, inquiry-based, and contextual learning experiences, which are essential for fostering higher-order thinking and sustainability competencies (OECD, 2024; Lozano et al., 2023).

These findings were further supported by interviews with physics teachers and the analysis of students' needs questionnaires. The results indicated that classroom learning was still dominated by the use of printed teaching materials that primarily focused on concept explanation and routine exercises, without systematically integrating the principles of ESD, the Deep Learning approach, and local wisdom into the learning process. Furthermore, the utilization of digital learning media remained limited, although most students demonstrated a high level of readiness to use technology in learning. Consequently, the existing teaching materials have not been able to provide meaningful, authentic, and student-centered learning experiences that actively engage students in inquiry, collaboration, reflection, and problem-solving, thereby limiting the development of students' creative thinking skills (Fullan et al, 2020; Fianti & Neratania, 2024; Lozano et al., 2023).

Based on these challenges, the development of digital e-modules has emerged as a promising alternative for supporting more meaningful and contextual learning. Compared with printed teaching materials, e-modules can integrate various multimedia elements, such as text, images, videos, animations, and interactive assessments into a single learning medium, thereby facilitating students' understanding of abstract physics concepts and encouraging active learning (Fianti & Neratania, 2024). Furthermore, Canva AI provides opportunities to develop visually engaging, interactive, and accessible digital teaching materials that can enhance students' motivation and engagement during the learning process (Puluhulawa et al., 2024). These advantages indicate that digital e-modules supported by Canva AI have considerable potential to improve the quality of physics learning by creating more meaningful and student-centered learning experiences.

However, previous studies have generally examined the implementation of ESD, Deep Learning, local wisdom, and digital technology separately. Studies on ESD based renewable energy e-modules have mainly focused on improving sustainability awareness (Ta Saqina, 2024), while project-based learning research has emphasized the development of creative thinking and communication skills (Rahmayani & Asrizal, 2024). Other studies have independently integrated local wisdom into physics learning (Fitonia, 2024; Mardiyah, 2025) or explored the use of Canva AI in digital learning media development (Puluhulawa et al., 2024). Despite these contributions, few studies have integrated these components into a comprehensive learning design. Therefore, there is still a need to develop a digital e-module that integrates ESD, the Deep Learning approach, local wisdom, and Canva AI into a single learning design to facilitate students' creative thinking skills in renewable energy learning.

Based on these research gaps, this study proposes the development of a physics e-module that integrates the Deep Learning approach, ESD, local wisdom, and Canva AI within a single digital learning resource for renewable energy learning. Unlike previous studies that have generally investigated these components independently or in partial combinations (Ta Saqina, 2024; Rahmayani & Asrizal, 2024; Fitonia, 2024; Mardiyah, 2025; Puluhulawa et al., 2024), this study combines all four components into a unified instructional design. The proposed integration is designed to facilitate students' creative thinking skills through meaningful, contextual, technology-enhanced, and student-centered learning experiences (Fullan et al, 2020; Lozano et al., 2023). In addition, it is expected to strengthen students' conceptual understanding of renewable energy while encouraging them to generate innovative solutions to sustainability-related challenges by connecting scientific concepts with authentic local contexts.

Accordingly, this study aims to analyze the needs for developing the proposed e-module, determine its validity, and evaluate its practicality. The findings are expected to contribute to the development of innovative digital physics teaching materials that promote students' creative thinking skills. Furthermore, the developed e-module is expected to support the implementation of Education for Sustainable Development through the integration of the Deep Learning approach, local wisdom, and artificial intelligence-assisted learning media. Ultimately, this study is expected to provide an alternative instructional resource for enhancing the quality of renewable energy learning in senior high school physics.

METHODS

This study employed the Research and Development (R&D) method, which is widely used to systematically develop and evaluate educational products (Sugiyono, 2023). The development process adopted the Four-D (4-D) model proposed by Thiagarajan et al. (1974), consisting of four stages: Define, Design, Develop, and Disseminate. However, this study was limited to the Develop stage because the primary objective was to produce and evaluate the validity and practicality of the developed e-module within the scope of this research. The product developed was a physics e-module integrating the Deep Learning approach, Education for Sustainable Development (ESD), local wisdom, and Canva AI on renewable energy materials to facilitate students' creative thinking skills.

The study was conducted during the 2025/2026 academic year at SMA Negeri 1 2×11 Kayu Tanam, West Sumatra, Indonesia. The research subjects consisted of three university lecturers from the Department of Physics Education serving as expert validators, two physics teachers, and thirty tenth-grade students from Class X, who were selected using purposive sampling based on the requirements of the product development process. The three expert validators and two physics teachers were involved in assessing the validity of the developed e-module, while the thirty students participated in the practicality testing to evaluate the usability and implementation of the e-module during the learning process. The involvement of these participants was intended to obtain comprehensive feedback regarding the quality, feasibility, and practicality of the developed e-module before its wider implementation.

The Define stage includes front-end analysis, student analysis, concept analysis, task analysis, and the formulation of learning objectives. The Design stage is done by designing the structure and format of the e-module, selecting appropriate learning media, and developing an initial prototype using Canva AI. The Develop stage includes expert validation, product revision, and practicality testing. The product validation was carried out by three lecturers of physics education experts at Padang State University. Furthermore, the practicality test involved one physics teacher and class X students to determine the level of ease of use, attractiveness, and practicality of the developed e-module.

Research data were collected through several instruments, including teacher interviews, student needs analysis questionnaires, Education for Sustainable Development (ESD) questionnaires, creative thinking skills tests, expert validation sheets, and practicality questionnaires. The use of multiple instruments was intended to obtain comprehensive data regarding students’ needs, the feasibility of the product, and the effectiveness of its implementation. Creative thinking skills were measured based on four indicators, namely fluency, flexibility, originality, and elaboration, which reflect students’ ability to generate ideas, view problems from different perspectives, produce unique responses, and expand ideas in detail. The data were analyzed using quantitative descriptive analysis techniques. The percentage of students’ creative thinking skills was calculated using the formula proposed by Purwanto (2010), while product validity and practicality data were analyzed using a percentage technique based on assessment criteria according to Sugiyono, (2023). The categories of students’ creative thinking skills are presented in Table 1.

Table 1. Categories of Students' Creative Thinking Skills

Percentage %	Category
86-100	Excellent
76-85	Good
60-75	Enough
55-59	Less
≤54	Less Than Once

Source: (Purwanto, 2010)

Based on the categories in Table 1, the percentage of creative thinking skills of 86–100% is categorized as Very Good, 76–85% is categorized as Good, 60–75% is categorized as Adequate, 55–59% is categorized as Poor, and ≤54% is categorized as Very Poor. The percentage of students' creative thinking skills is calculated using Equation (1).

$$NP = \frac{R}{SM} x\ 100\%$$

Description:
NP = the percentage value of students' creative thinking skills
R = the raw score obtained by the student
SM = ideal maximum score

RESULTS AND DISCUSSION

Results

The first stage of the Four-D (4-D) development model is the Define stage, which aims to identify and define the instructional requirements that serve as the basis for developing the proposed learning product (Thiagarajan et al., 1974). This stage consists of five analytical activities, namely front-end analysis, learner analysis, task analysis, concept analysis, and specification of instructional objectives. The findings obtained from these analyses were used to determine the learning needs, instructional content, learning activities, and instructional design of the developed physics e-module. The results of each analysis are presented in the following sections. The Define stage also provides an empirical basis for ensuring that the developed e-module aligns with students' characteristics, learning needs, and the demands of sustainability-oriented physics learning. Furthermore, the results of this stage serve as a reference for designing instructional components that can facilitate students' creative thinking skills in renewable energy learning.

Learning Problem Analysis

The first analysis, namely the front-end analysis, was conducted to identify the fundamental problems encountered in physics learning on renewable energy materials as the basis for developing the proposed e-module. This analysis focuses on identifying instructional problems, evaluating existing instructional resources, and determining the necessity of developing new learning materials (Thiagarajan et al., 1974). Therefore, it included the identification of students' creative thinking skills, interviews with physics teachers, and an evaluation of the teaching materials currently used in the learning process. The results of the initial creative thinking skills test conducted on 30 students of Class X E1 at SMA Negeri 1 2×11 Kayu Tanam are presented in Figure 1.

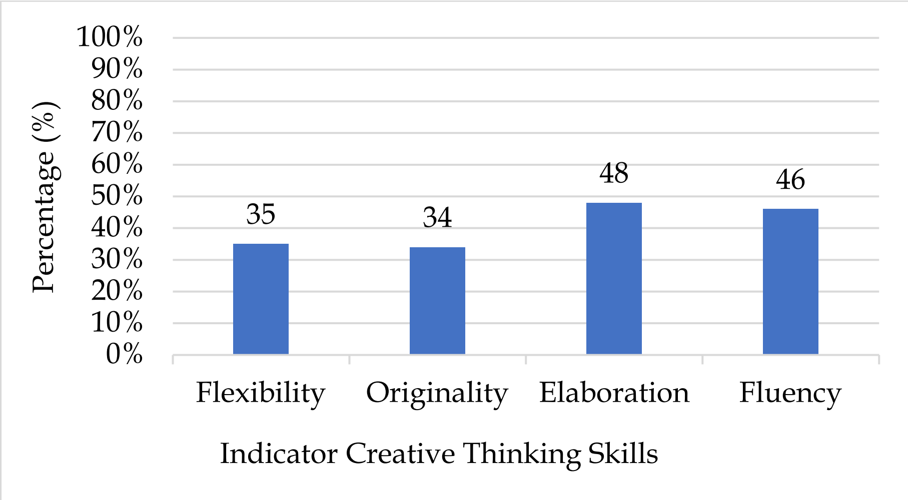

Figure 1. Students' Creative Thinking Skills Analysis

Based on the data presented in Figure 1, the average level of students' creative thinking skills was 40.75%, which falls into the very low category. Among the four indicators, originality obtained the lowest percentage (34%), whereas elaboration achieved the highest percentage (48%). These findings indicate that students experienced difficulties in generating original ideas, proposing alternative solutions, and elaborating their ideas when solving renewable energy-related problems, suggesting that current physics instruction has not adequately supported the development of higher-order thinking skills through meaningful and contextual learning experiences. Similar findings were reported by Nugroho et al. (2025), who emphasized that student-centered and contextual learning environments are essential for fostering higher-order thinking skills. Likewise, Utamirohmahsari et al. (2025) and Redman & Wiek (2021) argued that integrating sustainability issues into learning can effectively enhance students' creative thinking, problem-solving, and decision-making competencies in sustainability-oriented learning.

The quantitative findings were reinforced by interviews with physics teachers, which revealed that classroom instruction remains dominated by concept explanation, memorization, and procedural problem-solving. As a result, students have limited opportunities to engage in inquiry, collaboration, reflection, and authentic problem-solving activities or to connect physics concepts with sustainability issues and real-life contexts. These learning conditions are inconsistent with the principles of ESD, which emphasize meaningful, contextual, and learner-centered learning experiences to develop sustainability competencies, higher-order thinking skills, and responsible decision-making (UNESCO, 2020; Redman & Wiek, 2021; Lozano et al., 2023). Therefore, the front-end analysis indicates the need for an innovative learning resource that integrates the Deep Learning approach, ESD, local wisdom, and Canva AI to support students' creative thinking and provide more meaningful and contextual learning experiences.

Student Needs Analysis

The second finding of this study was obtained from the student needs analysis conducted during the Define stage. This analysis aimed to identify students' perceptions of the existing physics learning conditions (PLC), the availability of teaching materials (ATM), learning styles (LGS), digital learning readiness (DLR), and the need for developing an e-module on renewable energy (NDE). Understanding these aspects is essential to ensure that the developed e-module addresses students' learning needs and supports the implementation of meaningful, student-centered learning. The results of the student needs analysis are presented in Figure 2.

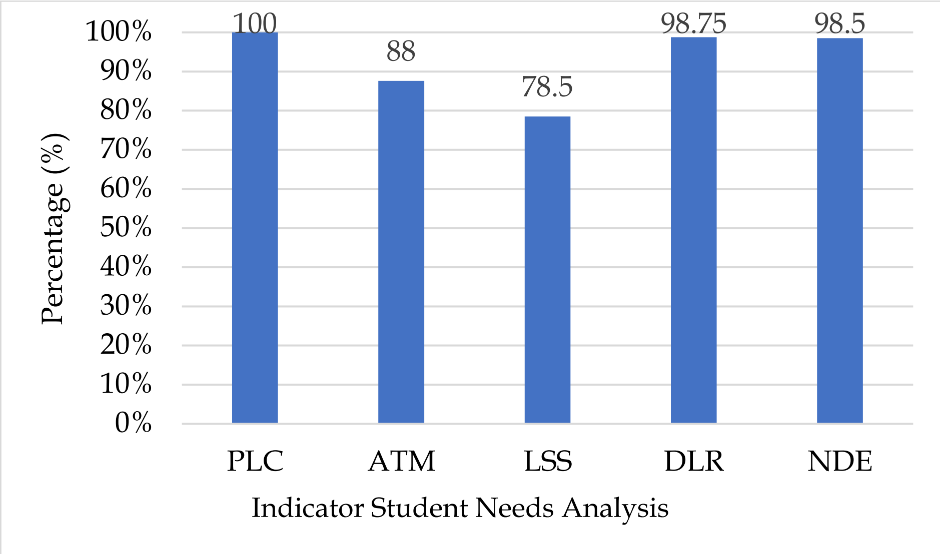

Figure 2. Results of the Student Needs Analysis

Based on Figure 2, the overall score of the student needs analysis reached 92.67%, indicating a very high level of need for improving the current learning resources. The highest percentage was obtained in the physics learning conditions (100%), followed by digital learning readiness (98.75%) and the need for e-module development (98.50%), suggesting that students are familiar with digital learning and strongly support the development of interactive teaching materials. Meanwhile, the availability of teaching materials obtained a score of 87.67%, indicating that although teaching materials are available, they have not fully accommodated students' learning needs. In addition, the learning style aspect received the lowest percentage (78.50%), suggesting that the current learning process has not optimally facilitated diverse learning preferences. These findings indicate the need to develop a physics e-module integrating the Deep Learning approach, Education for Sustainable Development (ESD), local wisdom, and Canva AI to provide more meaningful, interactive, and student-centered learning experiences while facilitating students' creative thinking skills.

Teaching Material Analysis

The third finding of this study was obtained from the analysis of the instructional materials used in renewable energy learning at SMA Negeri 1 2×11 Kayu Tanam. This analysis was conducted to evaluate the quality of the existing teaching materials based on seven aspects, namely self-instructional (SI), self-contained (SC), stand-alone (SA), user-friendly (UF), visual and multimedia (VM), adaptive (AD), and contextual (CT). The evaluation compared the ideal characteristics of instructional materials with the actual conditions of the teaching materials currently used in the classroom. The purpose of this analysis was to identify the strengths and limitations of the existing teaching materials as the basis for developing the proposed physics e-module. In addition, the analysis examined the extent to which the existing teaching materials were able to facilitate independent learning, present comprehensive and relevant content, integrate visual elements effectively, and connect renewable energy concepts with real-world issues related to sustainable development. Identifying these strengths and limitations is essential to ensure that the developed e-module addresses the shortcomings of the existing materials while incorporating appropriate instructional features to better support students' creative thinking skills and understanding of Education for Sustainable Development (ESD). The results of the instructional material analysis are presented in Figure 3

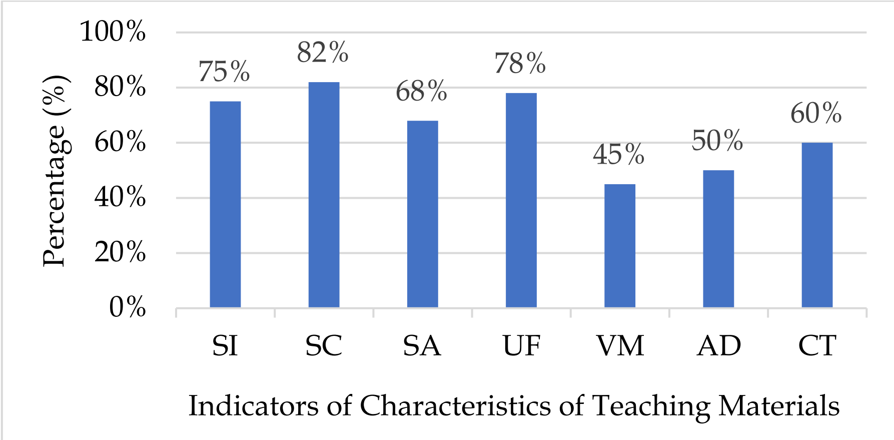

Figure 3. Results of the Context Analysis of Teaching Material

Based on Figure 3, the analysis of the existing instructional materials indicates that the self-contained aspect obtained the highest score (82%), followed by the user-friendly (78%) and self-instructional (75%) aspects. These findings indicate that the module provides relatively complete learning content, clear learning activities, and sufficient guidance to support students' learning. However, the visual and multimedia aspect received the lowest score (45%), while the adaptive aspect achieved only 50%. This indicates that the module is still dominated by printed text and static images and has not integrated interactive multimedia, such as videos, animations, or embedded digital features. In addition, although the module includes inquiry activities, PhET simulations, and project-based tasks, it has not systematically integrated the principles of Education for Sustainable Development (ESD), local wisdom, or technology-enhanced learning. Therefore, the development of a physics e-module integrating the Deep Learning approach, ESD, local wisdom, and Canva AI is necessary to provide more interactive, contextual, and meaningful learning experiences while facilitating students' creative thinking skills.

In addition to evaluating the general characteristics of the existing teaching materials, this study also analyzed the extent to which the principles of the Deep Learning approach have been integrated into the instructional materials. This analysis was conducted based on the three core principles of Deep Learning, namely Meaningful Learning, Mindful Learning, and Joyful Learning. The purpose of this analysis was to identify whether the existing teaching materials have supported meaningful, reflective, and enjoyable learning experiences. The results of the analysis are presented in Figure 4.

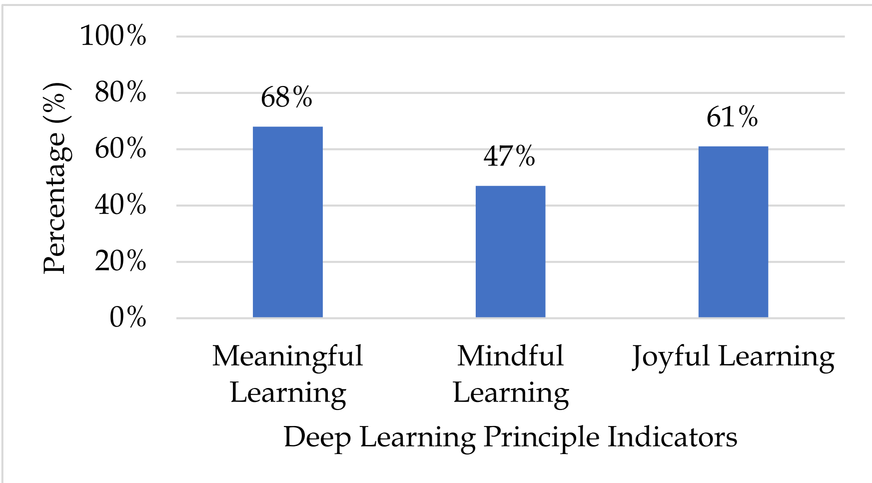

Figure 4. Deep Learning Principles Analysis

Based on Figure 4, the analysis of the integration of Deep Learning principles in the existing teaching materials indicates that Meaningful Learning obtained the highest percentage (68%), followed by Joyful Learning (61%), whereas Mindful Learning received the lowest percentage (47%). These findings indicate that the teaching materials have partially supported meaningful learning by relating renewable energy concepts to real-life situations and providing inquiry- and project-based learning activities. However, opportunities for students to engage in reflective thinking, self-evaluation, and metacognitive learning remain limited. Furthermore, although the teaching materials include learning activities that encourage student participation, they are still dominated by text-based explanations and have not systematically integrated interactive digital media, local wisdom, or reflective learning activities. Consequently, the existing teaching materials have not fully implemented the principles of Deep Learning. Therefore, the development of a physics e-module integrating the Deep Learning approach, Education for Sustainable Development (ESD), local wisdom, and Canva AI is necessary to provide more meaningful, reflective, interactive, and student-centered learning experiences while facilitating students' creative thinking skills.

Analysis Of Learning Objectives

The learning objectives analysis was conducted to evaluate the quality of the learning objectives developed for the Renewable Energy topic. Well-formulated learning objectives are essential for ensuring alignment among learning outcomes, instructional activities, teaching materials, and assessment. Therefore, this analysis examined the completeness of the learning objectives based on the Audience, Behavior, Condition, and Degree (ABCD) framework to determine whether the objectives had been formulated clearly, measurably, and consistently with the expected competencies. The results of the analysis are presented in Figure 5.

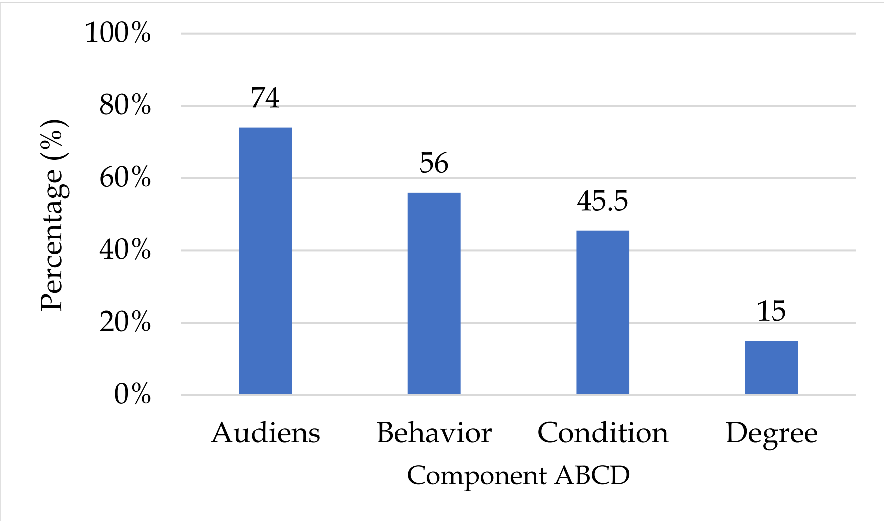

Figure 5. Analysis of Learning Objectives Based on the ABCD Components

Figure 5 shows that the completeness of the learning objectives based on the ABCD framework varies across the four components. The Audience component obtained the highest percentage (74%), indicating that most learning objectives clearly specify the intended learners. The Behavior component reached 56%, suggesting that the expected learning behaviors were identified in several objectives, although they were not consistently formulated using observable and measurable action verbs. Meanwhile, the Condition component achieved only 45.5%, indicating that the circumstances or learning situations under which students were expected to demonstrate the intended behaviors were often omitted. The lowest percentage was found in the Degree component (15%), demonstrating that most learning objectives did not clearly define the expected level of performance or mastery. As a result, the learning objectives have not yet fully met the ABCD criteria, which may reduce the clarity of instructional planning, learning implementation, and assessment. Therefore, the learning objectives should be refined by incorporating all ABCD components systematically to ensure that they are specific, measurable, and aligned with the intended competencies in renewable energy learning.

The fourth stage of the Four-D (4D) development model is the Disseminate stage, which aims to distribute and implement the developed product on a wider scale. According to (Thiagarajan et al., 1974), this stage involves the dissemination of validated instructional materials to a broader educational context to determine their effectiveness in diverse settings. However, in this study, the Disseminate stage was not carried out due to time limitations and the scope of the research, which was restricted to the Develop stage. Therefore, the evaluation of the e-module was limited to expert validation and small-scale trials.

Discussion

This study produced five main findings during the Define stage of the Four-D development model, including the analysis of students' creative thinking skills, student needs, existing teaching materials, the integration of Deep Learning principles in teaching materials, and learning objectives. Collectively, these findings indicate that the current physics learning process has not yet fully supported meaningful, reflective, contextual, and sustainability-oriented learning. These conditions highlight the need for innovative teaching materials that integrate the Deep Learning approach, Education for Sustainable Development (ESD), local wisdom, and digital technology to facilitate students' creative thinking skills and sustainability competencies (Fullan et al., 2020; UNESCO, 2020; Lozano et al., 2023).

The first finding revealed that students' creative thinking skills were still categorized as very low, particularly in the originality indicator. This result indicates that students experience difficulties in generating original ideas, proposing alternative solutions, and elaborating their ideas when solving renewable energy-related problems. Such conditions suggest that existing learning practices have not provided sufficient opportunities for students to engage in higher-order thinking through authentic and contextual learning experiences. These findings are consistent with previous studies reporting that student-centered and contextual learning environments play an important role in fostering creative thinking and problem-solving abilities (Nugroho et al., 2025; Utamirohmahsari et al., 2025). Likewise, interactive digital teaching materials have been shown to improve students' creative thinking by providing opportunities for exploration, collaboration, and independent knowledge construction (Akmala, 2025; (Mubarok et al., 2022).

The second finding, obtained from the student needs analysis, showed that students expected more interactive, technology-supported, and contextual learning resources. Although students demonstrated relatively good digital learning readiness, they perceived that the current learning conditions and available teaching materials have not fully supported meaningful and student-centered learning. This finding suggests that digital teaching materials should not only function as learning resources but also facilitate active engagement, collaboration, and independent learning. Previous studies similarly reported that innovative digital teaching materials improve learning engagement, motivation, and higher-order thinking skills (Akyuna et al., 2025; Ta Saqina, 2024).

The third and fourth findings demonstrated that the existing teaching materials have not systematically integrated the principles of the Deep Learning approach. Although the materials provide contextual examples, inquiry activities, project assignments, and PhET simulations, opportunities for reflective learning, metacognitive thinking, and enjoyable learning experiences remain limited. These findings indicate that meaningful learning should be accompanied by reflective and enjoyable learning experiences to promote creativity and lifelong learning. This interpretation is consistent with Fullan et al. (2020), who described Deep Learning as the integration of meaningful, mindful, and joyful learning experiences. Similar findings were also reported by (Nurazizah et al. 2025), who found that implementing the Deep Learning approach enhances meaningful learning and students' creative thinking. Furthermore, integrating contextual issues and local wisdom into science learning has been shown to improve conceptual understanding and learning relevance (Panis et al., 2023; Azizah & Wulandari, 2024).

The final finding showed that the existing learning objectives have not fully fulfilled the Audience, Behavior, Condition, and Degree (ABCD) framework, particularly in the Condition and Degree components. Incomplete learning objectives may reduce the alignment among learning outcomes, instructional activities, teaching materials, and assessment. Well-formulated learning objectives are essential because they provide a clear direction for instructional planning and competency-based assessment (Fullan et al., 2020; Redman & Wiek, 2021). Therefore, revising the learning objectives based on the complete ABCD framework is necessary to support meaningful and competency-oriented learning.

Overall, the findings of this study demonstrate that developing the proposed physics e-module is necessary not only to improve students' creative thinking skills but also to align student needs, teaching materials, Deep Learning principles, and learning objectives within a single instructional design. The novelty of this study lies in integrating the Deep Learning approach, Education for Sustainable Development (ESD), local wisdom, and Canva AI into a physics e-module to create meaningful, contextual, reflective, and technology-enhanced learning experiences. This integrated approach is consistent with previous studies emphasizing that sustainability-oriented, project-based, and reflective learning effectively develops students' creative thinking and problem-solving skills (O'Toole et al., 2026; Redman & Wiek, 2021; UNESCO, 2020).

CONCLUSION

Based on the findings obtained during the Define stage of the Four-D development model, this study concludes that students' creative thinking skills in renewable energy learning are still at a very low level, particularly in the originality indicator. The analysis of student needs further revealed that although students demonstrate high readiness for digital learning, the current learning process and available teaching materials have not yet supported meaningful, contextual, and student-centered learning experiences. In addition, the analysis of existing teaching materials showed that the implementation of Deep Learning principles remains suboptimal, particularly in facilitating reflective, mindful, and joyful learning. The analysis of learning objectives also indicated that several objectives have not fully met the ABCD framework, especially the Condition and Degree components, resulting in less optimal alignment between learning objectives, learning activities, teaching materials, and assessment. These findings demonstrate a clear gap between the current learning conditions and the competencies expected in renewable energy learning. Therefore, the development of a physics e-module integrating the Deep Learning approach, Education for Sustainable Development (ESD), local wisdom, and Canva AI is considered necessary to address these gaps. The proposed e-module is expected to provide meaningful, contextual, technology-enhanced learning experiences while facilitating the development of students' creative thinking skills and sustainability competencies.

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