Validity and Reliability of ESD Based E-Module to Enhance Students' Scientific Literacy on Low Carbon Energy Topic

Wafa Hanifah*, Diana Rochintaniawati, Rika Rafikah Agustin
Faculty of Science and Mathematics Education, Universitas Pendidikan Indonesia, Indonesia
wafahanifahz@upi.edu*; diana_rochintaniawati@upi.edu; rikarafikah@upi.edu
*Corresponding author

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ABSTRACT

Nowadays, science learning aims to help students to critically evaluate information and solve real-world problems. Therefore, integrating scientific literacy into learning is needed to enable students distinguish between credible and misleading information. This study aims to describes the validity and reliability of an Education for Sustainable Development (ESD) based e-module used to enhance students' scientific literacy. The validity of the developed e-module is reviewed by two experts evaluating the content feasibility, ESD suitability, scientific literacy, visual feasibility, and language feasibility. The reliability of the e-module is reviewed by 3 practitioners and through readability test by 12 students. This study employed the ADDIE method. The data collection was carried out using the textbook validation method, incorporating e-module validation sheet and readability test as assessment instruments. The validity is measured using the Aiken's V scale and the reliability is evaluated using Likert scale. Based on data analysis, the results of validity reviewed by experts indicates that the content feasibility is 3,78, the ESD suitability is 3.75, the scientific literacy is 3,93, visual feasibility is 3,75, and language feasibility is 3,94 which are categorized as very valid. The reliability yielded a score of 95% which are very reliable. The readability test yielded a score of 90,78%. This suggest that the e-module developed is a valid and reliable product instructional research.

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Introduction

Scientific literacy stands as a fundamental competency for the 21st century, enabling individuals to critically analyze, interpret, and apply scientific knowledge in real-world context (OECD, 2019; Fives et al., 2014; Allchin, 2014). It forms the basis for informed decision-making and supports lifelong learning in increasingly complex societies (Herawati & Istiana, 2021; Nurramadhani & Pursitasari, 2021). As defined before, the ability of scientific literacy is essential in effective educational practice. It underpins the capacity of students to question, synthesize, and apply scientific concepts in dynamic environments. Such proficiency empowers learners to navigate contemporary societal challenges and contribute meaningfully to public discourse (Hanson, 2022; Rahmawati et al., 2023).

Global assessments like the Program for International Student Assessment reveal that only 12% of 15-year-olds demonstrate advance competency in applying scientific knowledge to sustainability challenges. This finding indicates a critical deficit in scientific literacy at an international level. The gap in competency further highlights the need for transformative educational interventions.

Education for sustainable development (ESD) has emerged as a critical transformative mechanism, equipping learners with competencies to reconceptualize energy systems through low-carbon transitions (Ramadhanti & Nuryadin, 2024; Yuliawati et al., 2024). fosters interdisciplinary approaches that enable students to become “systems thinker” capable of addressing energy-climate nexuses (OECD, 2019). Such an approach is essential for integrating sustainability into educational frameworks.

Despite its potential, current science curricula inadequately address low-carbon energy literacy, with only 46,6% of primary school textbooks containing sufficient coverage of emission reduction concepts (Hudha et al., 2021; Nurramadhani et al., 2024). This shortfall compromises students’ ability to fully understand and engage with the principles of sustainable energy. Consequently, learners are left with fragmented knowledge that hinders the development of a comprehensive sustainability mindset.

The integration of digital learning tools into ESD frameworks shows considerable promise, with meta-analyses indicating that e-modules improve STEM concept retention compared to traditional pedagogical approaches. Digital tools offer dynamic, interactive, and adaptive learning experiences that traditional materials often lack, supporting the development of both technical and analytical skills in learners (Allison & Goldston, 2018; Puspitasari et al., 2020).

The integration of digital learning tools into ESD frameworks shows considerable promise, as they can enhance student engagement and personalize learning experiences (El-Hanafi & Stephen, 2024). Nevertheless, existing digital resources frequently neglect three essential dimensions of energy transitions: 1) techno-economic analyses of renewable energy, 2) behavioral aspects of consumption patterns, and 3) policy-science interfaces governing decarbonization pathways (Lv & Qin, 2016; Polzin & Sanders, 2019).

However, existing digital resources frequently neglect essential dimensions of energy transitions, such as integrating concepts of SDGs into STEM lessons and promoting hands-on activities (Habibaturrohmah et al., 2023). This narrow focus creates a disconnect between problem recognition and the formulation of systematic solutions. A content analysis reveals that a significant portion of platforms focus narrowly on environmental impacts rather than systematic solutions, further exacerbating this issue (Hudha et al., 2021). Institutional barriers further compound these challenges, with many educators facing challenges in integrating education for sustainable development (ESD) into science. Addressing these barriers is critical for transforming science education to meet contemporary demands (Herawati & Istiana, 2021).

The traditional pedagogical approach, which often emphasizes rote memorization over critical inquiry, has contributed to the persistent gap in scientific literacy. Students frequently struggle to transfer theoretical knowledge into practical problem-solving scenarios. This reliance on passive learning models calls for a shift toward more active and student-centered teaching strategies that prioritize experiential learning and critical thinking (OECD, 2023).

In response to these challenges, Education for Sustainable Development offers a comprehensive framework that integrates environmental, social, and economic dimensions into the curriculum. ESD-based approaches encourage interdisciplinary problem-solving and foster sustainable practices among learners. This transformative model is essential for equipping students with the skills necessary to tackle complex global issues, thereby bridging the gap between theoretical knowledge and practical application.

Integrating ESD principles with scientific literacy creates a robust educational paradigm that transcends traditional content delivery. This integration not only emphasizes the application of scientific knowledge within real-world sustainability contexts but also fosters critical thinking and interdisciplinary collaboration (Herawati & Istiana, 2021). Through such an approach, learners are better prepared to address environmental challenges by connecting scientific theory with systemic solutions (Shabrina et al., 2024).

Low-carbon energy education is a vital component of this integrated approach, as it directly addresses the urgent need for sustainable energy solutions. Understanding low-carbon energy systems requires a dual focus on both technical proficiency and the socioeconomic implications of energy use (Kioupi & Voulvoulis, 2022; Nurramadhani et al., 2022). By combining these elements, educational interventions can provide learners with the comprehensive skill set needed to drive effective energy transitions and support global sustainability efforts.

Digital e-modules, designed within an ESD framework, offer an innovative solution to the shortcomings of traditional instructional materials. These interactive tools facilitate scenario-based decision simulations, applied carbon footprint analyses, and energy system modeling, thereby promoting active engagement and deeper understanding (Rosanti et al., 2024). Moreover, electronic media can make the learning process more interesting, can be used anywhere and anytime and can improve the quality of learning (Saqina, 2024).

The novelty of this study is the implementation of low-carbon energy concept in e-module based education sustainable development (ESD) which led to sustainable development in education. The implication and significancy of this study for the practical, this e-module could be used at school for students to enhance their comprehension for sustainability. Thus, this study aims to address these critical educational gaps by developing an e-module based on education for sustainable development (ESD) focused on low-carbon energy as teaching resources to increase scientific literacy among high school students that is both valid and practical.

Method

The type of research in this study is research and development (R&D). R&D is a developmental research method used to develop and evaluate a certain product (Dick et al., 2015). This development research employs Dick and Carry's ADDIE model, which encompasses the stages of analysis, design, development, implementation, and evaluation as shown in Figure 1 (Dick et al., 2015). The ADDIE model is chosen in this study with a notion that it has clear and easy-to-understand stages. According to Cheung (2016) explained in his research that the ADDIE model is easy to implement and flexible for any curriculum focused on knowledge, skills, or attitude. Additionally, it helps instructors design curricula in a structured and systematic way.

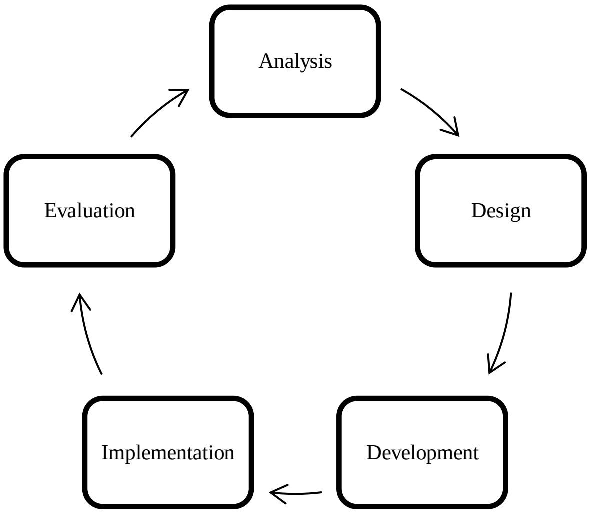

Figure 1. The flow of development method in ADDIE

The analysis stage was done by analyzing the National Curriculum regarding the topic chosen, analyzing the needs of learners and teachers, and analyzing the scientific literacy skills and ESD to be integrated in the e-module. Analyzing the needs of teachers and students was obtained through a questionnaire distributed via Google Forms to science teachers and junior high students. The design stage involves identifying the content materials to be included in the e-module and creating an initial draft of the e-module. This is intended to ensure that the e-module can be developed more efficiently and in line with the desired needs. This research specifically describing the development stage where the product is developed and then reviewed by expert, practitioners, and students before the implementation stage to make sure the product is feasible to be used in broader purpose.

The validity data collection was carried out through a review and validation method by experts and practitioners. Validation by experts and practitioners was carried out using e-module validation sheet as instrument based on its content feasibility, ESD suitability, suitability of scientific literacy skill with content of the e-module, visual feasibility, and language feasibility. The e-module's eligibility will be reviewed by two expert lecturers in the field of science content and three science teachers as practitioners. The validation sheet used Likert scale ranged from 1 to 4, where 1 means not acceptable and 4 very acceptable. An e-module is considered as valid if yields the minimum score of 2.6.

The data analysis technique to determine validity of the e-module is carried out quantitatively. The data collected from the validity questionnaires were then subjected to analysis using the formula below. The value of the validity is then categorized into several levels of validity level which adapted from Riduwan (2013) as shown on Table 1.

Table 1. Validity Scores Category

Average Score	**Category**
1.00 – 1.75	Less Valid
1.76 – 2.50	Quite Valid
2.60 – 3.25	Valid
3.26 – 4.00	Very Valid

The reliability of the e-module was carried out through a practicality sheet by three science teachers and readability test by 12 students. Practicality sheet consists of the attractiveness, content, language, and usage of the e-module in the form of questionnaire using Likert scale from 1 to 4. The readability test consists of 40 multiple choices questions regarding the main idea of each paragraph in the e-module.

The readability test conducted by 12 students where they determine the main idea of 40 paragraphs included in the e-module. The readability score is obtained by calculating the average number of students who are able to identify the main idea from 40 paragraphs. Readability score of 75% or higher indicates that the e-module is reliable and suitable for use.

The reliability of the e-module is carried out using the Borich method. The Borich method, commonly referred to as the Percentage Agreement (PA), is a straightforward approach to assess reliability (Dhillon, 2007). PA measures the level of agreement or consistency between evaluators in assigning scores. The reliability score is calculated using a specific formula. An instrument is deemed reliable if its PA value is 75% or higher (Liani et al., 2022; Verawati et al., 2022). If the PA value falls below 75%, further refinement and validation by observers are recommended to ensure clarity and approval.

Results and Discussion

The development of the ESD-based e-module on low-carbon energy topic to enhance students' scientific literacy was guided by findings from the analysis conducted in the earlier stages. Based on the analysis of teachers' and students' needs questionnaire, revealed that while 100% of teachers acknowledged the richness of science topics in Education for Sustainable Development (ESD) values, 76,7% reported as lack of understanding of how to effectively integrate these values into their teaching practices. Low-carbon energy, as a science teaching topic, aligns closely with Sustainable Development Goals (SDGs) 7 – affordable and clean energy- and serves as an ideal framework for integrating ESD principles. This topic not only emphasizes content knowledge but also encourages behavioral changes in students' daily lives, fostering meaningful learning experiences. The findings underscore the need to equip teachers with practical tools that bridge the gap between theoretical ESD principles and their application in classrooms, ultimately promoting scientifically literate and sustainability-conscious learners.

Furthermore, the questionnaire discovers the potential benefits of electronic teaching materials in schools. Although such materials are highly advantageous, their utilization remains suboptimal due to the limited availability of resources that integrate ESD principles with scientific literacy skills, particularly on low-carbon energy topics. An e-module offers significant advantages by providing diverse formats such as videos, animations and audio content that capture students' attention more effectively than traditional paper-based modules. This interactivity not only makes learning more engaging but also reduces monotony in the classroom environment. The developed e-module aims to address these gaps by offering an innovative and interactive approach to teaching low-carbon energy within an ESD framework.

The design stage was done by focusing on material selection and structural framework design for the e-module. This stage resulted in the production of an e-module draft, which encompasses a syllabus, scientific content, practical worksheets, and post-chapter evaluation questions. Following the design stage, the development stage commenced, during which the draft was transformed into a functional e-module. The visual representation of the developed e-module is illustrated in Figure 2. This iterative process ensured that e-module's content and structure aligned with the intended educational objectives while maintaining scientific rigor and pedagogical effectiveness.

Figure 2. The display of e-module
(a) The cover of the e-module (b) The table of contents where students can find the parts they want to read (c) The practical worksheet (d) The post evaluation in every chapters

Figure 2 illustrates the key components of the developed e-module. Panel (a) displays the cover page which includes the title and author information. Panel (b) presents an interactive table of content, facilitating efficient navigation through the e-module's materials. This feature allows users to access specific sections directly by clicking on the relevant chapter titles. Panel (c) depicts the science practical worksheet, which incorporates instructional videos to guide students through experimental procedures. Additionally, this section highlights the alignment of practical work with relevant Sustainable Development Goals (SDGs), promoting contextual understanding. Panel (d) showcases the post-chapter evaluation, which comprises scientific literacy-oriented questions pertaining to the chapter's content. This structure ensures a comprehensive and interactive learning experience, integrating theoretical knowledge, practical skills, and assessment components within the e-module.

This e-module has been reviewed by two lecturers and three practitioner who are experts in content, language, and visual aspects of science learning materials as expert validators through validation sheets. The validation was conducted using standardized validation sheets. Results indicate that the developed e-module achieved a "very valid" classification across five key validity aspects, namely content feasibility, ESD suitability, suitability of scientific literacy skill with content of the e-module, visual feasibility, and language feasibility. Table 2 presents a detailed breakdown of the validation results.

Table 2. E-Module Validity Results by Experts

Validity Aspect	Average	Category
Content Feasibility	3,78	Very Valid
ESD Suitability	3,75	Very Valid
Scientific Literacy Suitability	3,93	Very Valid
Visual Feasibility	3,75	Very Valid
Language Feasibility	3,94	Very Valid
Avergae Score	3,83	Very Valid

Analysis of the validation data as shown in Table 2, reveals that all five validity aspects scored within the range of 3,5 – 4,0. This result firmly established the ESD based e-module on low-carbon energy as "very valid". In this developed e-module, there are three validation indicators based on the ICT teaching materials development guide released by *Kemendikbud* in 2012, which are the indicators of content feasibility (material substance), language feasibility (communication display), and visual feasibility (device design). The results of e-module validation are part of the validity indicators to obtain validation results in accordance with predetermined indicators (Handayani et al., 2021).

The content feasibility indicators consist of systematic presentation of material, accuracy of content, reliability of information and data provided, and appropriateness of the material for the target educational level. The ESD suitability indicators focuses on three primary indicators; alignment of content with ESD objectives, congruence between material and ESD competencies, and the capacity of the content to foster students' sustainability awareness. Regarding scientific literacy, the indicators are designed to evaluate the material's efficacy in stimulating students to attain scientific literacy skills. Visual feasibility indicators consist of aspects such as font size, colors, navigation, layouts, image or videos being used. Language feasibility indicators consist of the linguistic fluency, interactivity of language use, dialogic and educational nature of the content, and educational-appropriate language selection.

The developed ESD based e-module on low carbon energy aligns with the growing recognition of the need to incorporate sustainability principles into science education. A study by Hudha et al. (2021) identified strategies to integrate ESD into STEM education, including incorporating SDG concepts into lessons and promoting hands-on activities. The high validity scores obtained by the developed e-module (average score = 3,81) reflect successful integration of sustainability concepts, addressing the challenge of insufficient ESD integration in science curricula.

The data for reliability is obtained from practicality sheet assessed by three practitioners, in this case is science teachers, in the form of Likert scale and readability test by 12 students in the form of multiple choices questions. The score from the practicality sheet and multiple choices questions are then calculated by the PA equation. The score of reliability from practicality sheet can be seen on Table 3 dan the data for reliability from multiple questions can be seen on Table 4.

Table 3. Reliability Score Analysis by Teachers

Practicality Aspect	PA Average	Category
Material Substance	80%	Reliable
User Friendly	100%	Reliable
Attractiveness	100%	Reliable
Language Feasibility	100%	Reliable
Average score	95%	Reliable

Table 4. Reliability Score Analysis by Students

Reliability Test	PA Average	Category
40 multiple choices questions	90,78%	Reliable

Table 3 demonstrates that the average score of Percentage Agreement (PA) from practicality sheet and multiple-choices questions exceeded 75%, with the practicality sheet yielding an average PA score of 95%. According to the Borich method, these results indicate that the e-module is highly practical and reliable for use by both students and teachers in the learning process.

As shown in Table 4, the Pa score for the readability test conducted by 12 students was 90,78%. Suggesting that the majority of students could comprehend the main ideas presented in each paragraph of the e-module. This further supports the e-module's reliability for use in subsequent learning processes. However, the readability test also revealed that students identified some "difficult" words that might impede their understanding of certain paragraphs. Consequently, there remains room for revision and improvement before advancing to the implementation and evaluation stages.

The high practicality (95% PA) and readability (90,78% PA) score of the e-module align with findings from the other studies on digital learning tools in STEM education. Research by Yani et al. (2024) found that STEM-based e-modules met excellent standards in terms of language, content, and presentation, with practicality scores above 88%. This supports the potential of well-designed digital resources to enhance student engagement and understanding of complex sustainability topics.

The validity and reliability assessments conducted in previous tests indicate that the Education for Sustainable Development (ESD) based e-module on low-carbon energy topic is appropriate for use as learning material. Nevertheless, the validators provided several suggestions to enhance specific aspects of the product including incorporating a dedicated section (apart from the post-chapter evaluation) to stimulate students' scientific skills, adding a segment or student activity to promote sustainability awareness, and simplifying certain sentences for improved comprehension. These recommendations will be considered for future iterations of the e-module to further improve its effectiveness and align it more closely with educational objectives.

Conclusion

The developed ESD based e-module on low carbon energy to enhance students' scientific literacy skill demonstrates high validity and reliability, as confirmed by expert reviews and practicality testing with teachers and students. Validation scores for content, ESD suitability, scientific literacy integration, visual feasibility, and language all fell into the vary valid category. Furthermore, practicality assessments by teachers and student readability indicating the e-module's feasible for classroom use. These findings suggest that the e-module is a feasible tool for effectively integrating ESD principles, promoting scientific literacy, and providing a user-friendly and engaging learning experience, making it a promising tool for enhancing students' understanding of low-carbon energy concepts. While suggestions were made to further improve stimulation for sustainability awareness, the overall results confirm the e-module's potential as a valid and reliable resource for science education.

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