Development of a low carbon education (LCE)-based stem-lab flipbook on renewable energy to enhance students' sustainability literacy

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Abstract
Students' low sustainability literacy and limited understanding of renewable energy pose challenges in science education. This study aims to develop a STEM-Lab Flipbook based on Low Carbon Education (LCE) on the topic of renewable energy to enhance the sustainability literacy of middle school students. The study employed the Research and Development (R&D) method using the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. Data collection was conducted through observation, interviews, needs assessments, expert validation, and teacher and student feedback surveys. The product's feasibility was assessed by subject matter experts, media experts, and language experts using Gregory's validity coefficient. The research results show that the STEM-Lab Flipbook developed is interactive, easy to use, and includes STEM-based hands-on activities as well as content on Low Carbon Education. The validation results show that the product was rated as "highly suitable," with a validity coefficient of 1.00 for subject matter experts, 0.90 for media experts, and 1.00 for language experts. In addition, the response test results indicate that teachers and students responded positively to the use of the media. Thus, the Low Carbon Education-based STEM-Lab Flipbook is suitable for use as a learning medium for renewable energy and has the potential to enhance students' sustainability literacy.

1. Introduction

Advances in digital technology have brought about significant changes in various aspects of life, including the field of education. The use of technology in learning no longer serves merely as a medium for conveying information, but also as a tool capable of creating learning experiences that are more interactive, flexible, and learner-centered (Fajriyatin et al., 2024). Digital transformation in education requires teachers to be able to develop innovative learning media that can increase student engagement in the learning process. The use of appropriate learning media is a key factor in supporting learning success because it helps students understand concepts more concretely, boosts their motivation to learn, and facilitates independent learning (Abong et al., 2025). However, in reality, the science learning process in schools is still often dominated by the use of conventional teaching materials that focus on the textual presentation of content (Ainun Afwina et al., 2021). This situation causes students to tend to be passive in the learning process and to experience difficulties in understanding abstract concepts. . Science content related to natural phenomena, technology, and the environment requires instructional media capable of providing visualizations and more realistic learning experiences so that students can connect the concepts they learn with their application in everyday life. Therefore, there is a need for innovative learning media that not only presents content but also facilitates exploration, investigation, and problem-solving activities (Tamami, 2021).

One such innovation in learning media that has rapidly evolved alongside technological advancements is the digital flipbook. A flipbook is an electronic learning medium that integrates various multimedia components such as text, images, audio, video, animations, and interactive links into a single learning platform (Maharcika et al., 2021). The use of flipbooks allows students to have a more engaging learning experience compared to printed instructional materials because they present information visually and interactively. In addition, flipbooks offer high flexibility because they can be accessed via various digital devices anytime and anywhere. These characteristics make flipbooks a promising medium for supporting 21st-century learning, which emphasizes critical thinking, creativity, communication, and collaboration (Putra et al., 2023).

In science education, particularly when covering renewable energy, students are expected not only to understand concepts theoretically but also to be able to apply those concepts in real-life contexts. Renewable energy is a topic closely linked to technological advancements and global environmental issues (Verina Dwisari et al., 2023). This topic covers various complex concepts, such as the operating principles of solar power plants, wind power plants, and hydroelectric power plants. The complexity of these concepts often causes students to

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struggle with understanding the relationship between theory, technology, and their application in daily life (Irawati et al., 2021). Therefore, there is a need for learning media capable of integrating scientific concepts with hands-on activities and contextual problem-solving.

The Science, Technology, Engineering, and Mathematics (STEM) approach is one strategy that can be used to address these needs. The STEM approach integrates concepts from science, technology, engineering, and mathematics into learning activities focused on solving real-world problems (Lou et al., 2014). Through the STEM approach, students not only gain conceptual knowledge but also have the opportunity to develop critical thinking, creative thinking, communication, and collaboration skills, as well as the ability to design solutions to various problems they face. STEM-based learning also provides a more meaningful learning experience because students are actively involved in the process of designing products or solutions (Oktarina et al., 2023).

The implementation of the STEM approach can be optimized through the development of the STEM-Lab Flipbook. The STEM-Lab Flipbook is a digital learning tool that integrates learning materials with STEM-based laboratory activities into a single interactive platform. This tool not only presents learning concepts in an engaging visual format but also provides hands-on experiments, simulations, instructional videos, worksheets, and investigative activities that enable students to build conceptual understanding independently (Ismail et al., 2016b). The STEM-Lab Flipbook serves as a relevant solution, particularly for schools with limited laboratory facilities, as students can still gain learning experiences similar to hands-on laboratory activities through digital media (Kodi et al., 2019).

In addition to mastering STEM concepts and skills, renewable energy education should also focus on raising students' awareness of environmental and sustainability issues (Ismail et al., 2016a). One approach that can be used is Low Carbon Education (LCE). LCE is an educational approach that emphasizes understanding carbon emission reduction and the adoption of environmentally friendly behaviors in daily life. Integrating LCE into renewable energy education can help students understand the relationship between energy use, carbon emissions, and their impact on the environment (Ye et al., 2017). Thus, learning is not only oriented toward mastering concepts but also toward fostering awareness and responsibility for environmental sustainability.

Various studies have shown that the use of digital flipbooks can enhance students' motivation to learn, interest in learning, and conceptual understanding. Other studies have also shown that the STEM approach can improve students' problem-solving abilities and critical thinking skills. However, research integrating the STEM-Lab Flipbook with the principles of Low Carbon Education in renewable energy curriculum remains relatively limited. Most studies have focused only on developing flipbooks as a learning medium or on applying STEM in learning activities without comprehensively integrating aspects of low-carbon education. Therefore, there is a need to develop a learning medium that combines elements of STEM, virtual laboratories, and Low Carbon Education into a single, integrated medium.

Based on the above discussion, this study aims to develop a STEM-Lab Flipbook based on Low Carbon Education (LCE) on the topic of renewable energy, describe the characteristics of the developed media, assess the media's feasibility based on expert evaluation, and determine the responses of teachers and students to the use of this media in science education.

2. Method

The research method used was Research and Development (R&D) based on the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. The analysis stage was conducted to identify learning needs through observation, interviews, and a literature review on renewable energy. The design phase involved designing a Low Carbon Education (LCE)-based STEM-Lab Flipbook, developing content, planning STEM lab activities, and creating research instruments. During the development phase, the designed product was validated by subject matter experts, media experts, and language experts to assess its suitability. Next, the implementation phase was carried out through a limited pilot test with junior high school teachers and students to gather feedback on the developed resource. Research data were collected using validation sheets and response questionnaires, then analyzed using quantitative descriptive methods including Gregory's validity coefficient and percentage to determine the level of suitability and user acceptance of the developed STEM-Lab Flipbook. STEM-Lab Flipbook Development Stages Based on the ADDIE Mode can be seen in Figure 1.

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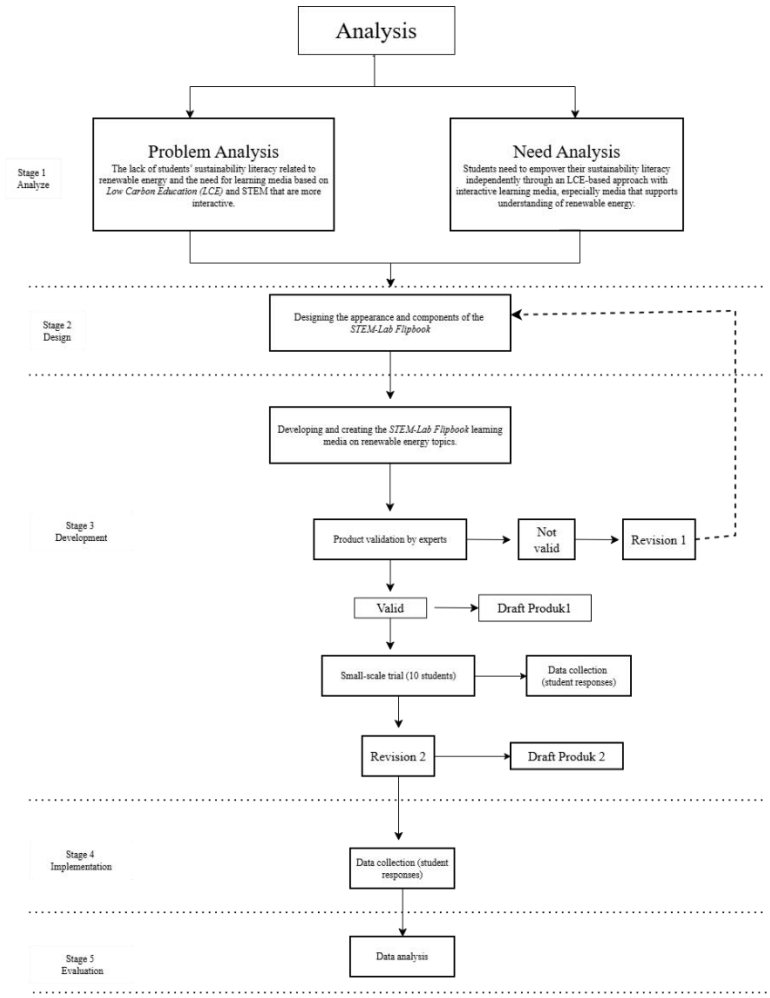


Figure 1. STEM-Lab Flipbook Development Stages Based on the ADDIE Mode

3. Results and Discussion

3.1. Results

The result of this research is a Low Carbon Education (LCE)-based STEM-Lab Flipbook learning resource on renewable energy for middle school students. The product was developed as a digital flipbook that can be accessed via computers or smartphones, thereby enhancing the convenience of the learning process. This resource is designed to support self-directed learning while facilitating STEM-based laboratory activities through the presentation of content integrated with various interactive digital features.

In terms of content, the STEM-Lab Flipbook covers renewable energy topics, including wind power plants (PLTB), solar power plants (PLTS), and hydroelectric power plants (PLTA). Each topic is systematically organized, ranging from the presentation of concepts and contextual phenomena to hands-on activities, instructional videos, student worksheets, and learning assessments. In addition, the principles of low-carbon education are integrated into each lesson through discussions on the benefits of renewable energy, carbon emission reduction, and the practice of energy-saving behaviors in daily life.

From a technological perspective, the STEM-Lab Flipbook was developed by integrating various multimedia components such as images, illustrations, QR code-based educational videos, interactive flows, and digital hands-on activities that enable students to have a more engaging and meaningful learning experience. The use of digital technology in the flipbook serves not only as a medium for conveying information but also as a tool for visualizing abstract concepts of renewable energy, making them easier for students to understand.

The key feature of the STEM-Lab Flipbook lies in the integration of STEM-based laboratory activities with indicators of sustainability literacy. Each lab activity is designed to connect aspects of Science, Technology, Engineering, and Mathematics with real-world issues related to the use of renewable energy. Through these activities, students not only learn scientific concepts but also develop the knowledge, skills, and values necessary

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to address future environmental challenges. The integration of STEM components and sustainability literacy in each lab activity is illustrated in Figure 2.

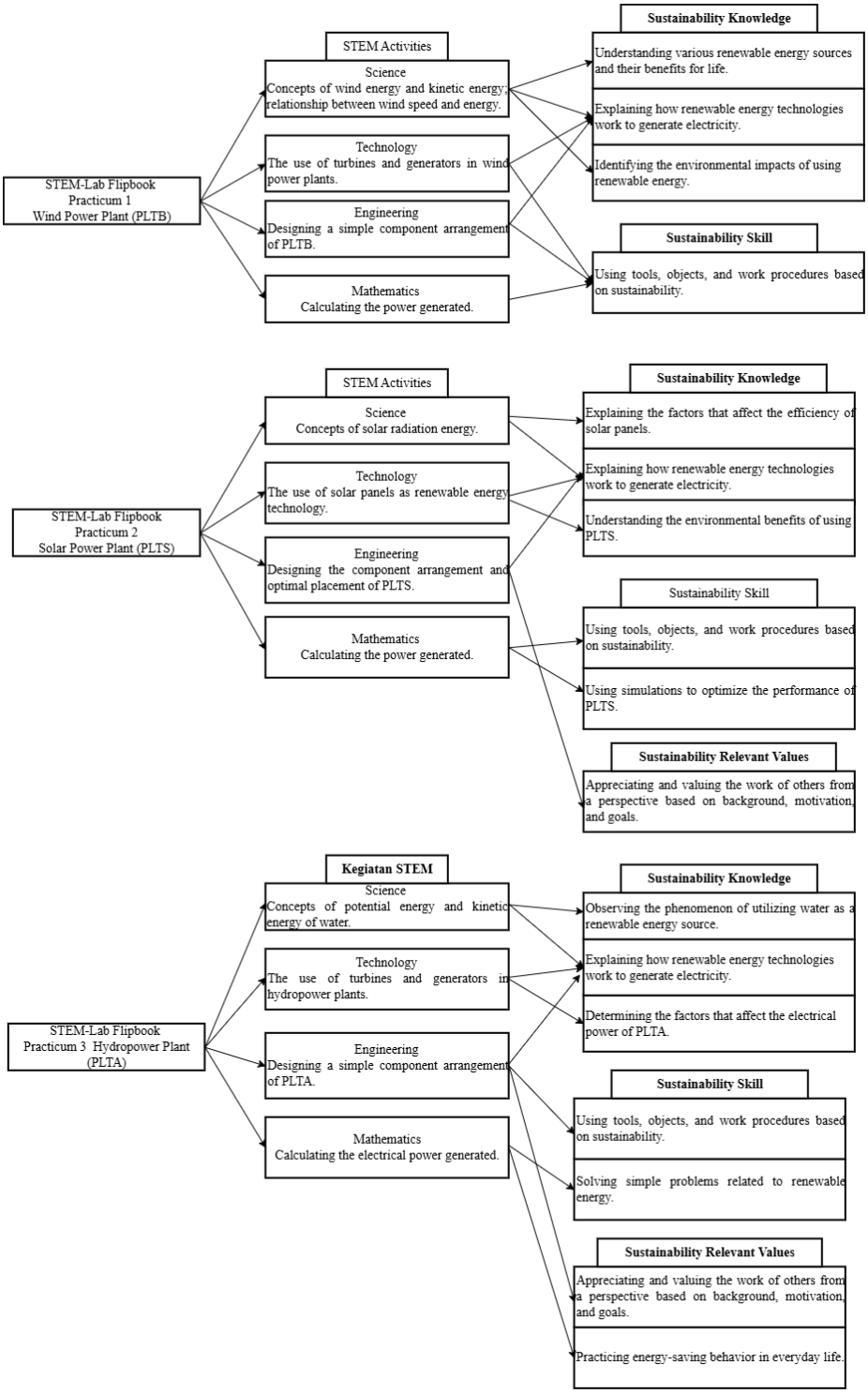


Figure 2. STEM-Lab Flipbook Concept to Empower Students' Sustainability Literacy

Based on Figure 2, the STEM-Lab Flipbook consists of three laboratory activities: wind power, solar power, and hydroelectric power. In the wind power lab, the Science component focuses on the concepts of wind energy and kinetic energy; the Technology component covers the use of turbines and generators; the Technology component addresses the design of a simple wind power system; and the mathematics component involves calculating the electrical power generated. These activities are designed to develop sustainability literacy through an understanding of renewable energy sources, how renewable energy technologies work, and their impact on the environment. In addition, students are also trained to use tools and follow procedures based on their own initiative as part of their sustainability skills.

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After the STEM-Lab Flipbook product based on Low Carbon Education (LCE) was designed, a needs analysis was conducted to determine the initial state of learning, students' needs regarding learning media, and the relevance of developing such media for renewable energy topics. The needs analysis was carried out by distributing questionnaires to students and conducting interviews with science teachers. The results of the needs analysis showed that students required learning media that was more interactive, easily accessible, and capable of helping them understand the concept of renewable energy through visualizations and hands-on activities. In addition, the results also indicated that the use of STEM-based digital media remains limited, necessitating media innovations that can integrate science, technology, engineering, and mathematics into the learning process. The complete results of the student needs analysis are presented in Table 1

Table 1. The Student Needs Analysis

Category	Sub-Category	Results
Teaching Methods and Learning Resources	Teaching methods implemented by teachers in the classroom	25% Lecture Method; 36.2% Question and Answer; 11.1% Discussion; 25% Practical/Outdoor Activities
	Learning media and instructional materials	61.1% Textbooks; 16.7% PowerPoint (PPT); 5.6% Picture Media; 5.6% Educational Videos; 5.6% Models/Teaching Aids; 5.6% Student Worksheets (LKPD)
Technology Utilization	Use of technology for learning	100% Use technology in learning; 0% Do not use technology
	Ownership of smartphones to support learning	100% Own smartphones that support learning; 0% Do not own smartphones
Students' Interest in the STEM-Lab Flipbook	Interest in interactive learning media	94.4% Interested; 5.6% Not Interested
	Interest in practical-based learning to facilitate understanding of learning materials	100% Yes, Helps Learning; 0% Does Not Help
	Interest in the development of the STEM-Lab Flipbook	100% Interested; 0% Not Interested

Based on the results of the needs analysis, students require learning materials that can present renewable energy content in a more engaging, interactive, and easy-to-understand manner. Therefore, the STEM-Lab Flipbook based on Low Carbon Education (LCE) was developed as a digital learning tool that integrates renewable energy content, STEM-based hands-on activities, instructional videos, and sustainability literacy indicators. The resource was developed using the Canva platform and converted into a digital flipbook so it can be accessed via computers or smartphones. The use of various multimedia features—such as images, videos, interactive links, and QR codes is expected to enhance students' learning experience and facilitate the visualization of abstract renewable energy concepts.

The validators' assessment results were then analyzed using Gregory's validity coefficient to determine the validity level of the developed medium. The Gregory analysis was used to measure the level of agreement among validators on each aspect evaluated, thereby allowing for an objective assessment of the product's suitability. Based on the analysis results, the STEM-Lab Flipbook received a validity score of 1 from the subject matter expert, indicating that the media meets high-level criteria and can be considered valid; validation by the media expert showed that the media's validity level was 0.9. This indicates that the results of the assessments by both media validators fall within the "high" criteria and can be considered valid; furthermore, validation by language experts showed that the language validity level was 1. This indicates that the results of the assessments by both language validators fall within the "high" criteria and can be considered valid. These results indicate that the developed media has met the feasibility criteria in terms of content, media, and language, making it suitable to proceed to the user testing phase. The complete results of the expert validation are presented in Table 2.

Table 2. Results of the Expert Validation

Validator	Score	Category
Material Expert	1.0	Highly Valid
Media Expert	0.9	Highly Valid
Language Expert	1.0	Highly Valid

Based on expert validation results, the Low Carbon Education (LCE)-based STEM-Lab Flipbook was deemed suitable for pilot testing with students. The next phase is a small-scale pilot test aimed at assessing the practicality, ease of use, and initial student responses to the developed educational resource. Through this pilot test, students evaluated the media's visual design, presentation of material, interactive features, and effectiveness in supporting renewable energy learning. The results of the small-scale pilot test showed that the

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STEM-Lab Flipbook received a score of 86.43, falling into the "Very Good" category. The complete results of the small-scale pilot test are presented in Table 3.

Table 3. Student Response Questionnaire Results for the STEM-Lab Flipbook (small-scale pilot test)

No.	Assessment Aspect	Score (%)	Category
1	STEM-Lab Flipbook Appearance	85.15	Very Good
2	Language	92.70	Very Good
3	Material Presentation	87.49	Very Good
4	Sustainability Literacy	81.86	Very Good
5	Renewable Energy	85.15	Very Good
Total	Overall Average	86.43	Highly Valid

After undergoing a small-scale pilot test and yielding positive results, the Low Carbon Education (LCE)-based STEM-Lab Flipbook was subsequently tested on a limited-scale group involving 32 students. This pilot test aimed to determine the level of practicality and acceptance of the medium among a broader user base. The results of the small-scale trial showed that the medium received an average score of 86.43, which falls into the "very good" category, making it suitable for progression to the limited-scale trial phase. The results of the limited-scale trial showed that the STEM-Lab Flipbook received a score of 85.97, also in the "very good" category, indicating that the medium can be effectively used in renewable energy education. The complete results of the limited-scale trial are presented in Table 4.

Table 4. Student Response Questionnaire Results for the STEM-Lab Flipbook (limited-scale trial)

No.	Assessment Aspect	Score (%)	Category
1	STEM-Lab Flipbook Appearance	84.42	Very Good
2	Language	87.30	Very Good
3	Material Presentation	86.40	Very Good
4	Sustainability Literacy	84.62	Very Good
5	Renewable Energy	87.15	Very Good
Total	Overall Average	85.97	Highly Valid

In addition to receiving feedback from students, the Low Carbon Education (LCE)-based STEM-Lab Flipbook also elicited responses from science teachers as users of the resource in the learning process. Teacher feedback is essential for assessing the suitability and quality of the resource in terms of content relevance, visual presentation, ease of use, and its effectiveness in supporting renewable energy education. Teachers' evaluations provide insight into the potential use of the STEM-Lab Flipbook as a learning resource that can assist teachers in delivering content while facilitating STEM- and Low Carbon Education-based learning activities. The results of teachers' responses to the STEM-Lab Flipbook are presented in Table 5.

Table 5. Teachers' Responses to the STEM-Lab Flipbook

No.	Respondent	Score (%)	Category
1	Teacher 1	93.33	Very Good
2	Teacher 2	85.32	Very Good
Total	Average Score	89.16	Very Good

Based on the teachers' responses presented in Table 5, the Low Carbon Education (LCE)-based STEM-Lab Flipbook received a score of 89.16%, falling into the "very good" category. These results indicate that the developed educational resource meets the criteria for suitability in terms of content, presentation, ease of use, and its effectiveness in supporting renewable energy education (Fidelchristo Pijoh, 2024). Teachers assessed that the STEM-Lab Flipbook is capable of presenting material in a systematic, engaging, and easily understandable manner for students. Furthermore, the integration of STEM-based laboratory activities, multimedia features, and Low Carbon Education content within the resource was assessed as helping teachers create more interactive and contextual learning experiences (Nurramadhani et al., 2022). Thus, the LCE-based STEM-Lab Flipbook has the potential to be used as a supplementary resource for science education on renewable energy topics.

The results of the needs analysis indicate that science education is still dominated by the use of conventional teaching methods, with textbooks serving as the primary learning resource. Nevertheless, students are already accustomed to utilizing technology in their learning activities and have access to devices that can support digital learning (Fajriyatin et al., 2024). These conditions suggest an opportunity to develop technology-based learning media capable of supporting a more interactive and engaging learning process.

In addition to their readiness to use technology, students also show interest in more innovative learning media (Pranata & Yulianti, 2021). Students believe that learning accompanied by hands-on activities helps them

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understand concepts better than learning that focuses solely on the delivery of content. The results of the needs analysis also indicate a high level of interest in the development of the STEM-Lab Flipbook as a learning medium that integrates digital technology with hands-on activities (Rosdiani & Erlin, 2022). These findings form the basis for the development of a Low Carbon Education (LCE)-based STEM-Lab Flipbook on the topic of renewable energy.

After undergoing the development and validation stages, the resulting educational media was tested with students through a small-scale pilot study. The results of the pilot study showed that the STEM-Lab Flipbook received an excellent response from students. The media was evaluated as having an attractive design, being easy to use, and helping students understand renewable energy concepts through a systematic and interactive presentation of the material (Pranata & Yulianti, 2021). The integration of educational videos, illustrations, and STEM-based hands-on activities also provided a more meaningful learning experience for students.

The next phase involved a limited-scale pilot test to assess the media's acceptance among a broader user group. The pilot test results showed that the STEM-Lab Flipbook can be effectively used in the learning process and received positive feedback from students. The medium facilitates independent learning, increases engagement in the learning process, and helps students connect renewable energy concepts with their applications in daily life (Irawati et al., 2021).

Teachers' responses to the STEM-Lab Flipbook also showed excellent results. Teachers assessed that the developed learning material was appropriate for the students' characteristics and met the science learning needs regarding renewable energy (Amartha Raqzitya et al., 2022). In addition to having an attractive design and being easy to use, the resource was also deemed capable of supporting STEM-based learning through the integration of content, hands-on experiments, and digital technology within a single learning platform (Rosdiani & Erlin, 2022). Thus, the Low Carbon Education (LCE)-based STEM-Lab Flipbook has the potential to serve as an effective alternative learning resource to support renewable energy education while fostering students' sustainability literacy.

3.2. Discussion

The development of a Low Carbon Education (LCE)-based STEM-Lab Flipbook on renewable energy has made a positive contribution to supporting more interactive and learner-centered learning. The integration of the STEM approach with digital technology enables students not only to gain a theoretical understanding of renewable energy concepts but also through hands-on activities and contextual problem-solving (Oktarina et al., 2023). The results of the needs analysis indicate that students require more engaging learning media capable of facilitating technology-based learning activities. Therefore, the STEM-Lab Flipbook was developed as a solution to accommodate these needs by presenting content integrated with instructional videos, hands-on activities, and other interactive features (Sari* et al., 2022).

Validation results from subject matter experts, media experts, and language experts show that the STEM-Lab Flipbook meets the criteria for excellent quality. These findings indicate that the developed media aligns with the learning objectives, learner characteristics, and principles of digital learning media development (Fajriyatin et al., 2024). Furthermore, the results of pilot tests with students and teacher feedback show positive acceptance of the developed media. Students reported that the media helped them understand renewable energy concepts more easily, while teachers noted that the media effectively supported the learning process by integrating content, hands-on activities, and technology into a single learning platform (Kosim et al., 2023).

The key feature of the STEM-Lab Flipbook lies in the integration of STEM components with sustainability literacy indicators, which is achieved through hands-on activities involving wind power, solar power, and hydroelectric power. Through these activities, students not only learn scientific and technological concepts but also develop skills in designing simple solutions, performing calculations, and understanding the importance of utilizing renewable energy to support environmental sustainability (Rony et al., 2023). The integration of Low Carbon Education into each hands-on activity also provides students with the opportunity to connect the concept of renewable energy with efforts to reduce carbon emissions and adopt environmentally friendly behaviors in their daily lives (Amin et al., 2020).

The use of the STEM-Lab Flipbook also provides a more flexible learning experience because it can be accessed via students' own digital devices. The presentation of material, which includes images, videos, QR codes, and interactive activities, enhances student engagement during the learning process (Vikiantika et al., 2022). Thus, the developed media not only serves as a learning resource but also as a tool that supports 21st-century learning through the use of digital technology, the development of critical thinking skills, and increased awareness of sustainability issues.

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4. Conclusion

The development of the Low Carbon Education (LCE)-based STEM-Lab Flipbook on renewable energy has produced a digital learning resource that integrates content, STEM-based laboratory activities, and sustainability literacy indicators into a single learning platform. The resource was developed to meet the needs of students and teachers, supporting more interactive, contextual, and easily accessible learning via digital devices. The STEM-Lab Flipbook helps students understand renewable energy concepts through hands-on activities on wind power (PLTB), solar power (PLTS), and hydroelectric power (PLTA) that integrate Science, Technology, Engineering, and Mathematics (STEM), enabling students to gain not only conceptual understanding but also a more meaningful learning experience.

Results from expert validation, student pilot tests, and teacher feedback indicate that the LCE-based STEM-Lab Flipbook has an excellent level of suitability for use in science education. The integration of multimedia features, hands-on activities, and low-carbon educational content enables this resource to support student engagement in the learning process while enhancing their understanding of renewable energy utilization and the importance of sustainable behavior. Thus, the STEM-Lab Flipbook based on Low Carbon Education (LCE) has the potential to serve as an effective learning tool for supporting education on renewable energy and fostering students' sustainability literacy.

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All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

Data Availability

The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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