



Validation and Practicality of ESD-Based Ecology and Biodiversity Materials in Enhancing Students' Digital and Environmental Literacy

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ABSTRACT

Purpose of the study: This study aims to determine the validity and practicality of learning media on ecology and biodiversity, incorporating Education for Sustainable Development (ESD), in improving the digital literacy and environmental literacy skills of lower secondary school students.

Methodology: The research method employed was Research and Development (R&D) using Thiagarajan's development model, which comprises the define, design, develop, and disseminate stages. Experts in media, subject matter, digitalization, and environmental education validated the learning media, whereas 28 Year 7 students and six science teachers at MTsN 2 Karanganyar evaluated its practicality.

Main Findings: The study's results indicate that the learning media received a 'highly valid' rating, with validation percentages of 86.75% from media experts, 85.6% from subject matter experts, 82.3% from digitalization experts, and 86.6% from environmental experts. The practicality test yielded 89% ratings from students and 99% ratings from science teachers, both categorized as 'highly practical', thus deeming the media suitable for use in junior high school science education.

Novelty/Originality of this study: A study on the development of learning media on ecology and biodiversity, designed with learning activities incorporating Education for Sustainable Development. The study addressed gaps in the use of learning media in schools. The implications of this study are that teaching materials on ecology and biodiversity incorporating Education for Sustainable Development (ESD) can be used as a valid and practical alternative learning resource to support science education in lower secondary schools and enhance pupils' digital and environmental literacy.

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1. INTRODUCTION

Education plays a vital role in developing human resources capable of keeping pace with 21st-century scientific and technological advancements [1]. The development of digital technology has transformed learning, making it more dynamic, interactive, and focused on literacy skills. Science education, particularly in ecology and biodiversity, demands not only a grasp of concepts but also students' ability to understand digital information and to demonstrate a concern for the surrounding environment. In practice, schools still rely heavily on conventional learning methods, which limit students' active exploration of information and reduce opportunities to develop responsible technology use. This situation has led to low levels of pupils' ability to search for information, understand digital sources, evaluate information, and synthesize knowledge from various digital media [2]. Yulistiawati's research indicates that schools have not optimally integrated digital technology into science education, resulting in low levels of students' digital literacy skills. [3]. According to Arbain's research, low digital literacy among teachers prevents both professional competence and student learning outcomes from developing to their full potential [4]. Judianto's research indicates that the level of digital literacy among teachers and students remains low, resulting in suboptimal digital learning quality [5]. Furthermore, Saputra's research also shows that science learning at the lower secondary school level remains teacher-centered, leading students to be less than active in utilizing digital media as a learning resource [6]. These issues highlight the need for innovative learning media that enhance students' digital literacy through technology-based science learning.

Students' digital literacy skills pose a significant challenge in the learning process, as learners are not only required to operate digital devices but also to understand and evaluate the information obtained. In 21st-century learning, students should be able to search for information effectively online. However, field evidence shows that students still struggle to find relevant and valid learning resources. Students cannot understand the relationships between digital information, leading them to frequently misinterpret learning materials. Sari's research indicates that the digital literacy skills of junior high school students fall into the 'moderate' category and still require strengthening, particularly in the utilization of digital learning resources [7]. Furthermore, Djarwo's research explains that limitations in learning media contribute to students' low digital literacy because the media do not adequately support independent information exploration activities [8]. These issues indicate that the use of interactive learning media is essential to enable students to develop the skills to search for and understand digital information more effectively in the study of ecology and biodiversity.

The low level of students' digital literacy is also evident in the fact that many students are unable to distinguish between accurate and inaccurate information on the internet, leading them to use information without analysis. This situation results in a superficial understanding of science concepts, as students merely accept information instantly without evaluating the sources used. Furthermore, students' ability to synthesize information from various digital sources into new knowledge remains low. Research conducted by Albardía indicates that limitations in digital media and a lack of literacy-based learning result in students being less able to process information critically [9]. Another study by Nelyza explains that digital-based science-learning innovations are needed to help students build more meaningful understanding through the active use of technology [10]. This situation indicates that the learning media developed need to be engaging, interactive, and practical to train students to evaluate and organize digital information independently during the learning process.

Another issue in science education is the low level of students' environmental literacy. According to Fetiana, environmental literacy encompasses environmental knowledge, cognitive skills, an attitude of environmental concern, and responsible behavior towards the environment [11]. Ecology and biodiversity topics should enhance students' awareness of their surroundings. However, current teaching practices still tend to emphasize theoretical aspects, leaving students unable to link concepts to real-world environmental issues. Xiong research indicates that junior high school students' environmental literacy remains at a moderate level and needs to be improved through more contextualized learning [12]. Another study by Maharani found that students still face limitations in understanding the relationship between human activities and environmental degradation, meaning that environmentally conscious behavior has not yet developed optimally [13]. Takyi research findings indicate that students' environmental literacy remains low, particularly in understanding environmental issues and adopting environmentally conscious behavior [14]. Furthermore, Carmi and Alkaher notes that low environmental literacy among students affects their ability to make decisions regarding everyday environmental issues [15]. These issues highlight the need for teaching materials that link science concepts to real-world environmental conditions, so that students can develop a better understanding of and greater concern for the environment.

Low levels of environmental literacy are also evident in the fact that many students are still unable to analyze environmental issues or identify appropriate solutions to the degradation of their surrounding ecosystems. Furthermore, students' concern for the environment remains low because teaching has not yet provided learning experiences that encourage their active engagement. Active learning approach can significantly improve students' environmental literacy and awareness. Applying an environmental literacy learning model can enhance students' knowledge and awareness of the importance of protecting the environment

[16]-[18]. The environment-based Project-Based Learning (PBL) model effectively improves students' environmental literacy and eco-friendly behavior. These findings indicate that practical, interactive learning media can be an effective means of improving students' environmental literacy in ecology and biodiversity.

In light of these issues, there is a need to develop practical learning materials on ecology and biodiversity to improve students' digital literacy and environmental literacy. The learning materials developed must facilitate students' search for information, understanding of digital sources, evaluation of information, and independent construction of knowledge. Furthermore, the media must foster students' awareness and responsibility towards the environment through the presentation of contextual, interactive material. Interactive learning media can increase student engagement in science learning and strengthen students' scientific literacy [19], [20]. Articulate Storyline-based media is effective in science education as it enhances student activity and understanding. Therefore, research on the validation and practicality of educational media for ecology and biodiversity is essential to ensure that the developed media is suitable for enhancing junior high school students' digital literacy and environmental literacy.

2. RESEARCH METHOD

This study was conducted in February 2026 at MTsN 2 Karanganyar. The research design employed was Research and Development (R&D), using Thiagarajan's development model, which comprises the define, design, develop and disseminate stages [21]. This study focused on the development stage to produce learning materials on ecology and biodiversity incorporating Education for Sustainable Development (ESD). The research subjects comprised media experts, subject matter experts, digitalisation experts, environmental experts, science teachers at MTsN 2 Karanganyar and students. The student sample used in the feasibility test consisted of one Year 7 class comprising 28 students. The sampling technique employed was simple random sampling, which involved selecting one class at random from all available Year 7 classes. The research instruments used included validation sheets for media experts, subject matter experts, digitalisation experts, and environmental experts to measure the validity of the media, as well as teacher and student feedback questionnaires to measure the practicality of the learning materials. The data obtained consisted of quantitative and qualitative data. Quantitative data came from the expert validation scores and teacher and student responses, whilst qualitative data was obtained from the suggestions and feedback provided by the validators. Data collection was carried out by distributing validation questionnaires to the experts and response questionnaires to teachers and students following the use of the learning media. Data analysis was carried out using quantitative descriptive methods by calculating the percentage of validation results and practicality using percentage formulas. The percentage results were then interpreted based on validity and practicality criteria to determine the suitability of the developed learning media. The equations used in the expert validation are as follows:

$$\text{Criteria} = \frac{\text{Total Score}}{\text{Score Maximal}} \times 100\% \dots (1)$$

Table 1 presents the assessment categories from Riduwan [22].

Table 1. Expert Validation Score Categories	
Score Percentage (%)	Category
81–100	Highly Valid
61–80	Valid
41–60	Less Valid
21–40	Invalid
0–20	Highly Invalid

For the practicality test, the study administered student and teacher response questionnaires and calculated the percentage of practicality assessment results using the following equation.

$$P = \frac{\sum X}{\sum Xi} \times 100\% \dots (2)$$

Notes:

P : The percentage figure

$\sum X$: Total score obtained from the assessment

$\sum Xi$: Maximum Score

The practicality of the developed learning media was determined based on the percentage scores obtained from the practicality questionnaires completed by teachers and students. The scores were interpreted using the practicality level criteria presented in Table 2 Syibli, [23].

Table 2. Guidelines for the Practicality Level of Learning Media

Score Percentage (%)	Category
80–100	Very Practical
60–79	Practical
40–59	Not very practical
≤ 39	Not practical

These criteria were used to classify the practicality level of the developed learning media based on the overall percentage scores obtained from the respondents' evaluations.

3. RESULTS AND DISCUSSION

In this study on the development of ecology and biodiversity teaching materials, experts in media, subject matter, digitization, and environmental education validated the materials according to their respective areas of expertise. Table 3 presents the results of the media expert's validation.

Table 3. Results of Media Expert Validation

Aspect	Percentage Score	Category
Teaching Material Presentation Techniques	95%	Highly Valid
Presentation Suitability	85.7%	Highly Valid
Learning Media Design	86.6%	Highly Valid
Layout and Typography	80	Valid
Presentation Techniques for Learning Media	95%	Highly Valid
Overall	86.75	Highly Valid

Based on Table 3, the overall average obtained was 86.75%, which falls within the 'highly valid' category. Okhawati's research indicates that the use of web-based spatial geometry learning media on the topics of ecology and environmental conservation, employing a tutorial model, yielded a media aspect percentage of 69%, which falls within the 'valid' category [24]. Furthermore, Table 4 presents media experts' suggestions for improvement and the researchers' follow-up actions.

Table 4. Suggestions for Improvement and Follow-up by Media Experts

Suggestions for Improvement	Follow-up
The display on the home menu should combine activity sections such as 'let us observe', 'let us analyze', and 'let us discuss' into a single menu, namely the 'materials' menu.	The home menu template has been updated in line with the suggestions and improvements, so that the activity sections 'Let's Observe', 'Let's Analyze', 'Let's Practice', 'Let's Discuss', and 'Science Facts' are now grouped into a single menu: the 'Materials' menu.
The researchers replaced some essay answers in the activity sections with "correct" or "incorrect" categories.	In some sections, the learning media present students with true-or-false statements and provide explanations as feedback.
The developers included the bibliography in the "Materials" menu.	The developers incorporated the bibliography template section into the course material menu template as a reference source.

Next, Table 5 presents the validation results from subject matter experts.

Table 5. Results of Validation by Subject Matter Experts

Aspect	Percentage Score	Category
Content	85%	Highly Valid
Construction	72%	Valid
Language	100%	Highly Valid
Overall	85.6%	Highly Valid

The overall average content score reached 85.6%, placing the material in the “highly valid” category. Rahmawati’s research on the development of an Android-based *e-magazine* learning medium to improve science literacy in terms of content obtained 97.6%, which falls into the ‘highly valid’ category [25]. Furthermore, there are suggestions for improvement from subject matter experts and follow-up actions taken by the researcher, as presented in Table 6.

Table 6. Suggestions for Improvement and Follow-up from Subject Matter Experts

Suggestions for Improvement	Follow-up
The study communicated information regarding the scope of the target subject group intended to benefit from the developed media.	The developers clarified the target audience by specifying lower secondary school students as the intended users of the educational media, in alignment with the ecology and biodiversity content.
Alignment of learning outcomes with the curriculum	The developers aligned the learning outcomes with Elementary, Junior High, and Senior High School Decree No. 046 of 2025 and added learning objectives to the developed media.
Systematic flow of information delivery in the developed media	The presentation of the material has been organized systematically and adapted to the concepts in the ecology and biodiversity curriculum to make it easier for students to understand.

Furthermore, Table 7 presents the validation results from digitalization experts who evaluated the integration of digital literacy in the development of ecology and biodiversity learning media.

Table 7. Validation Results by Digitalization Experts

Aspect	Percentage Score	Category
Accuracy of digital feature integration in the media	80%	Valid
Ease of access and digital navigation	87%	Highly valid
Security and ethical use of digital technology	70	Valid
Alignment of digital content with learning objectives	87%	Highly Valid
Integration of digital components with students’ digital literacy	90%	Highly Valid
Suitability of digital display and functionality in supporting learning	80	Valid
Overall	82.3%	Highly Valid

Based on the digitalization expert validation results, the overall average was 82.3%, which falls within the ‘highly valid’ category. Furthermore, the experts provided suggestions and improvements that the researcher followed up on, as presented in Table 8.

Table 8. Suggestions for Improvement and Follow-up by Digitalization Experts

Suggestions for Improvement	Follow-up
Strengthening the link to Learning Objectives. The media already presents content on ecology and biodiversity engagingly, but this needs to be improved by: - Displaying learning objectives and outcomes (CP/TP) explicitly at the beginning of the media - Aligning each feature/scene with specific indicators (e.g., exploration → analysis → evaluation) Development of Meaningful Interactive Assessment Features. Currently, the exploration phase contains the highest level of interactivity; therefore, the study recommends the following improvements: - Aligning each feature/scene with specific indicators (e.g., exploration → analysis → evaluation) - Adding scenario-based interactive quizzes (e.g., cases of ecosystem damage)	The developers improved the learning media by adding learning objectives to the learning outcomes section. Furthermore, every feature and scene in the media has been aligned with learning indicators to ensure a more focused and systematic learning flow. The developers equipped the learning media with scenario-based, environmental interactive quizzes that provide immediate feedback through explanations for correct and incorrect answers, thereby helping learners better understand the concepts.

- Providing immediate feedback (correct/incorrect + explanation of the concept) To strengthen the Education for Sustainable Development (ESD) aspects promoted by the media, the study emphasizes the following points: - Developing mini-simulations or problems based on real-world environmental issues Optimizing digital safety and ethics. Although the media is relatively safe, improvements are needed: - Citing reference sources (images/materials) as a form of digital ethics	The learning media have been developed by adding real-world environmental problems related to ecology and biodiversity to strengthen the application of the ESD approach. The developers improved the learning media by citing the sources of the images, videos, and materials used.
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Furthermore, environmental experts have validated the ecology and biodiversity learning materials to ensure they meet the indicators of students' environmental literacy. Table 9 presents the results of the environmental expert validation.

Table 9. Results of Environmental Expert Validation

Aspect	Percentage Score	Category
Alignment of content with the principles of <i>Education for Sustainable Development</i> (ESD)	80%	Valid
Relevance of the material to current environmental issues	100%	Highly Valid
The media's ability to foster environmental awareness	100	Valid
Reinforcement of environmentally responsible behaviour	80%	Valid
Environmental illustrations	80%	Valid
Integration of knowledge, skills, attitudes, and pro-environmental behavior.	80%	Valid
Overall	86.6%	Highly Valid

Based on the environmental experts' scores, the overall average was 86.6%, indicating a high level of validity. In addition, the environmental experts provided suggestions for improvement, which the researcher subsequently followed up on, as presented in Table 10.

Table 10. Suggestions for Improvement and Follow-up by Environmental Experts

Suggestions for Improvement	Follow-up
The developers need to add a unifying theme to connect the explanations of waste, pollution, ecology, and biodiversity materials.	The learning materials have been improved by adding content on pollution and links between topics, so that the learning sequence from waste to pollution, ecology, to biodiversity has become more systematic and interconnected.
Understanding of the SDGs and sustainability needs to be reinforced in the learning materials so that it is not limited to cognitive, psychomotor, and affective domains, but is internalized and becomes part of students' culture.	The developers enhanced the learning media by reinforcing SDG and sustainability concepts through real-world environmental issues, reflective activities, and encouragement to adopt environmentally responsible behavior in daily life, thereby helping students internalize sustainability values.

Based on expert validation, the learning media on ecology and biodiversity are deemed suitable for use, with some improvements, resulting in Product I. Subsequently, the study conducted a practicality test using questionnaires completed by 28 Year 7 students from one class and six science teachers from MTsN 2 Karanganyar to evaluate the practicality of the ecology and biodiversity learning materials. Table 11 presents the results.

Table 11. Results of the Student Practicality Test

Statement	Percentage	Categorisation
I can study the content of the ecology and biodiversity learning materials carefully	83%	Very Practical
The content presented is very interesting	90%	Very practical
The use of animated images and videos in learning materials on ecology and biodiversity helps me to generate many ideas	86	Very practical
The language used is easy to understand	96%	Very practical
I can quickly <i>log in to</i> the ecology and biodiversity learning	88%	Very practical

Statement	Percentage	Categorisation
platform		
I can easily run the learning resources on ecology and biodiversity via a <i>smartphone</i> or a laptop	90%	Very practical
I can easily understand the presentation of information in the learning resources on ecology and biodiversity	89%	Very Practical
Can be beneficial for students	94%	Very practical
I was able to gain useful information that I can apply in my daily life	89%	Very practical
I can easily understand the material in the learning resources on ecology and biodiversity	81	Very Practical
The use of learning materials on ecology and biodiversity is very efficient	97%	Very Practical
I can use the buttons or features on the ecology and biodiversity learning materials effectively	84%	Very practical
Overall	89%	Very Practical

Based on the results of the practicality of the ecology and biodiversity learning media by students, the overall average was 89%, which falls within the ‘very valid’ category. Furthermore, there are results regarding the practicality of the ecology and biodiversity learning media as assessed by teachers as science education practitioners.

Table 12. Results of the Science Teachers’ Practicality Test

Statement Item	Percentage Score	Category
Alignment of learning media content with ecology and biodiversity material	100%	Very Practical
The content presented is very engaging	100%	Very practical
The use of animated images and videos in learning materials can support the teaching of ecology and biodiversity	100%	Very practical
The language used is easy to understand	100%	Very practical
The speed of logging into the ecology and biodiversity learning platform is excellent	97	Very practical
Students can easily access the ecology and biodiversity learning resources through smartphones or laptops	100%	Very practical
The ecology and biodiversity learning resources are very practical for use in the learning process	100%	Very Practical
The presentation of information is easy to understand	100%	Very Practical
Useful for teachers and students	100%	Very practical
It can be useful for obtaining information on ecology and biodiversity	100%	Very practical
Ease of understanding the material in the ecology and biodiversity learning resources	100	Very practical
Teachers and students can use the ecology and biodiversity learning materials efficiently	100%	Very Practical
The buttons or features in the ecology and biodiversity learning resources work well	100%	Very Practical
Overall	99%	Very Practical

The practicality test conducted by science teachers produced an overall average score of 99%, placing the ecology and biodiversity learning media in the “very practical” category. These findings indicate that ESD-based ecology and biodiversity media effectively support classroom use in science learning, thereby improving students’ digital and environmental literacy.

The research findings indicate that this learning resource has been shown to be capable of presenting material effectively, systematically, interactively and engagingly through the integration of animations, videos and learning activities. This finding aligns with Dayanti et al, research, which explains that interactive educational media based on respiratory system educational games are valid when they feature a simple interface, clear navigation, and an attractive visual design that facilitates students’ understanding of the learning material [26]. Furthermore, Kurnia’s research also indicates that aspects of layout, typography, and visual presentation have a significant influence on the success of Canva media in enhancing students’ attention and learning motivation [27]. The ecology card media used in IPAS learning on the concept of environmental ecology in Year

10 at Vocational High School Islam Al-Qudsyiah achieved a media suitability percentage of 85%, which falls within the ‘highly valid’ category, and students were motivated during the learning process [28]. Kolengsusu, [29] The media aspect developed in Canva on the subject of ecology and environmental conservation achieved a 89% score, which falls within the ‘highly valid’ category; the Canva media can enhance students’ conceptual understanding and make learning more meaningful. The media expert validation results indicate that the developed media meet the standards for valid digital learning media and support effective use in science education.

The results of the subject-matter expert validation achieved an overall percentage of 85.6%, placing it in the “highly valid” category. The content aspect achieved a score of 85%, whereas the language aspect reached 100%, indicating that the material aligns with ecology and biodiversity concepts and supports students’ understanding. The content validation emphasized the importance of aligning the material with learning outcomes and of a systematic presentation of concepts. The improvements, which involved aligning learning outcomes with the curriculum and organizing the material more systematically, demonstrate that the media not only present information but also consider the interconnections between concepts, thereby helping students to understand the material progressively. These findings align with Wanazziezah’s research, which states that video-based learning media in science education achieve validity when the material aligns with the curriculum, follows a systematic structure, and supports the achievement of learning objectives [30]. Furthermore, research by Agustina also indicates that the use of simple language and the coherent presentation of concepts can enhance students’ understanding of science material, specifically ecology and biodiversity [31]. Alvia’s research demonstrates that the development of a senior high school biology learning module on ecology, integrated with Islamic values, achieved a material validation percentage of 85%, which falls within the ‘highly valid’ category [32]. Thus, the results of the subject-matter expert validation indicate that the learning media have met the criteria of content, construction, and linguistic feasibility, making it suitable for use in science education.

The results of the digitalization expert validation achieved 82.3%, placing it in the ‘highly valid’ category. This assessment indicates that the media has successfully integrated digital features with learning objectives and indicators of students’ digital literacy [33]. The integration of digital components with digital literacy achieved the highest score of 90%, indicating that the media supports students’ ability to search for information, understand digital content, and evaluate information through interactive activities. The validators also provided recommendations to enhance interactive assessment features, strengthen ESD aspects, and promote digital ethics by including reference sources. These improvements demonstrate that the developers designed the media not only to emphasize technology but also to foster critical thinking skills and ethical use of digital technology. It aligns with research by Margalita, which shows that PBL e-books on ecosystem material can integrate interactive features, simple navigation, and problem-based evaluation to support students’ digital literacy [34].

Furthermore, research by Azizah also indicates that an ESD-based digital encyclopedia on taro diversity effectively enhances digital literacy skills when supplemented with exploratory activities and immediate feedback on students’ answers [35]. The development of an Android-based construction alphabet learning medium to improve students’ digital and reading literacy achieved a feasibility score of 97.5%, indicating that this medium can assist students in learning the alphabet interactively [36]. Another study by Setiawan and Rahman showed that the feasibility of the digital literacy-based interactive Articulate Storyline learning media in science education was feasible category [37]. Therefore, expert validation of digitalization indicates that the learning media have fulfilled the digital integration aspects that support 21st-century learning.

The validation results from environmental experts yielded an overall score of 86.6%, classified as ‘highly valid’. This assessment indicates that the teaching materials comply with the principles of Education for Sustainable Development (ESD) and support the enhancement of students’ environmental literacy. The material’s relevance to current environmental issues scored 100%, demonstrating that it can link ecological and biodiversity concepts to real-world environmental problems. Furthermore, the media can foster an environmentally conscious attitude and responsible behavior by presenting reflective activities and environmentally based problems. The developers implemented the validators’ suggestions by adding a common thread across the materials and strengthening SDG concepts, making the media more contextual and sustainability-oriented. These findings align with Demirci research, which explains that environmental issue-based animated videos achieve validity when they connect science concepts to real-world environmental problems and foster environmentally conscious attitudes in students [38]. [39] The integration of ESD into module teaching materials can enhance students’ environmental literacy. Noverita’s research indicates that the development of comic-based learning media rooted in local wisdom to enhance environmental literacy skills among junior high school students achieved a validity score of 85.6%, indicating the comic media is highly valid [40]. Furthermore, Kasmini’s research found that the development of locally-based animated video media to improve environmental literacy in science lessons on ecosystems achieved a 95% success rate, which falls within the ‘highly valid’ category [41]. Thus, validation by environmental experts demonstrates that learning media can optimally support the development of students’ environmental literacy.

Furthermore, the results of the practicality test conducted by students achieved an overall percentage of 89%, placing them in the 'highly practical' category. These results indicate that the learning media are easy to use, engaging, and effective in helping students understand ecology and biodiversity. The efficiency of use aspect received the highest score of 97%, whilst the language aspect scored 96%. It indicates that the media features simple navigation and clear communication, thereby facilitating students' learning. Furthermore, the use of animated images and videos effectively supports the emergence of ideas and students' understanding of the material. This finding aligns with Melsita's research, which found that Augmented Reality-supported RME-based worksheets achieve practicality when students can access them easily, understand them clearly, and engage actively during the learning process [42]. It is also consistent with Susilowati's research, which shows that multimedia use increases interest in learning and makes it easier for students to understand abstract science concepts [43]. These results indicate that the learning media developed are highly practical from the students' perspective.

The media also demonstrate practicality by helping students acquire information that they can apply in daily life. Students responded very positively to the benefits of the media in understanding environmental issues and their connections to real life. It indicates that the media not only functions as a tool for conveying information but also helps students build contextual understanding of ecology and biodiversity. The integration of activities based on real-world environmental problems makes students more engaged and interested in the learning process. It aligns with Hasbiyalloh's research, which explains that practical, environment-based learning media can enhance student engagement in learning and help students connect the material to their daily lives [44].

Furthermore, Dudung's research indicates that interactive ESD-based media can enhance students' learning experiences because the material is presented contextually and is closely related to the learners' surrounding environment [45]. Nadzif's [46] research on the development of interactive science learning media based on the Articulate Storyline for the junior high school solar system curriculum achieved a practicality test score of 83%, which falls into the 'very practical' category; the media can facilitate interactive learning and help students understand the solar system material. The practicality results for Articulate Storyline learning media in understanding derivative concepts were 82%, which falls into the 'very practical' category; this learning media can serve as an alternative and is easy for students to use in mathematics learning [47]. Therefore, the developed learning media demonstrate practicality by providing meaningful learning experiences for students.

The results of the practicality test conducted by science teachers yielded a 99% score, placing it in the 'very practical' category. This assessment indicates that the learning media greatly assist teachers in delivering material on ecology and biodiversity effectively and efficiently. Teachers assessed that the media content was aligned with the learning material, easy to understand, and accessible via both smartphones and laptops. Furthermore, the buttons and features on the media worked well, making it easier for teachers to operate it during lessons. This finding aligns with Milala's research, which explains that learning media using Adobe Flash Player is considered practical if it is easy for teachers to use, does not require a long time to operate, and supports the learning process effectively [48]. Another study by Juneda showed that digital media with simple and flexible features can help teachers improve the quality of science learning in the classroom [49]. Thus, the media developed has met the practicality aspect from the educators' perspective.

The practicality of learning media is also evident in its ability to support a flexible and efficient learning process. Teachers rated the media's efficiency very highly because users can access it anytime on various digital devices. This finding demonstrates that the media support 21st-century learning by promoting flexibility and integrating digital technology. The media also helps teachers create a more interactive learning environment by using animations, videos, quizzes, and problem-based activities. This finding aligns with research by Febrian and Nasution, who argue that Google Sites, as a practical digital collaborative learning medium, can enhance learning effectiveness by supporting active interaction between teachers and students [50]. Furthermore, research indicates that the PBL-based Articulate Storyline platform is highly practical for science education as it is user-friendly and can boost student motivation and engagement [51]-[53]. These findings indicate that ESD-integrated ecology and biodiversity learning media are highly practical for enhancing students' digital and environmental literacy in science education. The implications of this study are that teaching materials on ecology and biodiversity incorporating Education for Sustainable Development (ESD) can be used as a valid and practical alternative learning resource to support science education in lower secondary schools, enhance pupils' digital and environmental literacy.

4. CONCLUSION

Based on the research findings, the development of educational media on ecology and biodiversity incorporating Education for Sustainable Development (ESD) yielded an average overall score of 85.31% from experts in media, content, digitalisation and the environment, which falls within the 'highly valid' category; meanwhile, the practicality scores were 89% for student responses and 99% for teacher responses, both of which

fall within the ‘highly practical’ category. The validation results by experts in media, content, digitalisation and the environment showed that the media met the criteria for content suitability, presentation, integration of digital literacy, and strengthening of environmental literacy, falling into the ‘highly valid’ category. Furthermore, the practicality test results from science students and teachers indicated that the media was easy to use, engaging, efficient and supported the learning process interactively. The media was also able to support the improvement of students’ digital literacy and environmental literacy through learning activities based on real-world environmental issues.

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AUTHOR CONTRIBUTIONS

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CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT

Prior to participation, each subject was provided with a detailed explanation of the study’s objectives, procedures, potential risks, and benefits. All participants voluntarily agreed to participate and signed a written informed consent form. All images in this article have been authorized and are the property of the authors.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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