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ECO-STEAM: A STEAM-BASED DIGITAL LEARNING WEBSITE FOR ECOSYSTEM TOPICS

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Abstract

This study aims to develop Eco-STEAM, a digital learning website based on the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach, specifically designed to support ecosystem learning. The development process was carried out using the Research and Development (R&D) method, employing the 4D model, which includes the stages of define, design, develop, and disseminate. The developed media was evaluated for feasibility by experts in material, media, and language aspects, and the development testing involved teachers and students. The average assessment results by the experts across all aspects were categorized as highly feasible (94.75%). The results of the development trials conducted by biology teachers, small group trials, and large group trials also received an average rating in the highly feasible category (90.33%). The effectiveness of the media in enhancing students' understanding of ecosystem concepts was measured on a small scale using a one-group pretest-post-test research design. The dependent t-test and effect size test results showed a significant improvement in students' understanding of ecosystem concepts after using the Eco-STEAM media, with a strong effect size. These findings demonstrate that Eco-STEAM is a validated, feasible digital learning website that effectively enhances students' understanding of ecosystem concepts. This product can also enrich biology learning media and support more interactive and contextual learning, particularly in ecosystem topics.

Keywords – 21st-century skills, Digital learning, Eco-STEAM, Ecosystem, Interactive website.

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1. Introduction

21st-century learning is characterized by the rapid advancement of science and technology, particularly in Information and Communication Technology (ICT) (Montes, Barquero, Martínez-Carbonell, Aloy, Ferrer, Romero et al., 2024; Nuraini, Fajri, Asri & Waluyo, 2023; Utomo, Hasanah, Hariyadi, Narulita, Suratno & Umamah, 2020). This development presents a significant challenge: the effective ability to utilize ICT to support learning activities (Leavy, Dick, Mavrotheris, Paparistodemou & Stylianou, 2023; Jesionkowska, Wild & Deval, 2020; Herlina, Rahmawati & Hasri, 2022; Fielding & Murcia, 2022). Within the framework

of 21st-century competencies, learning innovations are required to prepare creative and innovative students who are capable of critical thinking, communication, and collaboration (Chistyakov, Zhdanov, Avdeeva, Dyadichenko, Kunitsyna & Yagudina, 2023; Belbase, Mainali, Kasemsukpipat, Tairab, Gochoo & Jarrah, 2021; Patresia, Silitonga & Ginting, 2020; Huang, Spector & Yang, 2019). One of the essential subjects that students must learn in the 21st century is science.

Biology is one of the science subjects taught at the secondary school level (Nurdin, Gofur, Sari & Munzil, 2025; Ristanto, Zubaidah, Amin & Rohman, 2018). Biology encompasses various aspects of life sciences, with one of the foundational topics being ecosystems. The ecosystem topic deals with the interaction between living organisms and their physical environment. This topic covers the structure, function, and dynamics of relationships among organisms within a community and their interactions with environmental factors (Jupiter, 2019; Yu, Piao, Zhang, Liu, Peng & Niu, 2021). Students are introduced to key concepts such as food chains, biogeochemical cycles, and interdependence among organisms within a specific habitat.

Field survey results reveal challenges in ecosystem learning faced by students. A needs analysis questionnaire administered to high school students in several regions of Indonesia (Jakarta, Bogor, Depok, Tangerang, Bekasi) indicated that many students experience difficulties in understanding ecosystem concepts (11.10% found it very difficult, 26.40% difficult, 40.30% difficult). One contributing factor is the lack of engaging learning media (48.20%). Additionally, 26.40% of respondents rated the learning media as ineffective, and 2.80% considered it highly ineffective. Similarly, 29.2% stated that the media used failed to capture their interest, with 9.70% rating it as entirely uninteresting. The survey also revealed that the needed learning media should be interactive (44.40%), provide comprehensive and easy-to-understand content (75%), and be practical and easy to use (44.40%). According to the teachers' needs analysis, the commonly used media in ecosystem learning, such as textbooks (100%), whiteboards and markers (100%), PowerPoint presentations (100%), and educational videos (44.40%), are still considered insufficiently effective (55.60%).

The challenges in ecosystem learning are also supported by previous studies. Research by Firmaningrum and Anggraito (2022) shows that most students struggle to understand ecosystem concepts, particularly when faced with a lack of visual representation and less interactive media. This complicates concept comprehension and diminishes students' interest in learning. Similarly, Rahmah & Risnani's (2023) study highlights that a learning approach that is too theoretical and lacks practical interaction can hinder a more comprehensive learning experience. In this context, the importance of developing more innovative and interactive learning media is evident. Nuriyah, Anggraini, Yulianti, Sa'id, Aziza, Maiyanti et al. (2023) found that the use of learning media involving visual aspects, simulations, and interaction can enhance students' understanding and interest in ecosystem topics.

These challenges indicate that one of the main factors contributing to the difficulties in ecosystem learning is the lack of effective learning media. This issue, in turn, impacts students' concept comprehension. Learning media serves as a tool that facilitates the transfer of information from teachers to students (Lutfi, Aftinia & Permani, 2023; Setiawan & Muchlas, 2021; Zulfarina, Syafii & Putri, 2021). Effective learning media must be able to create an engaging, interactive learning environment that better facilitates concept understanding (Pacheco-Velazquez, Rodés & Salinas-Navarro, 2024; Patresia et al., 2020; Firmaningrum & Anggraito, 2022; Rahmah & Risnani, 2023). The ideal characteristics of learning media for ecosystem education should present concepts visually, enable student interaction with the learning material, and stimulate student interest. One form of learning media that aligns with these characteristics is an interactive website-based learning media.

The use of websites as learning media offers several advantages, such as allowing students to learn anytime and anywhere, supporting the use of various multimedia formats like videos, images, and audio to explain difficult concepts more engagingly, and creating an interactive learning experience (Doyan, Susilawati, Harjono, Annam, Ikhsan, Ardianti et al., 2025; Pandiangan, 2021; Susanti & Suripah, 2021). The interactive features on a website enable students to engage directly in learning. This not only creates a

more engaging learning environment but also allows students to understand complex concepts through practical experiences (Balalle, 2024; Ferdiansyah & Irfan, 2021; Bond & Bedenlier, 2019). The potential interactivity of a website can be utilized as an efficient learning medium to increase student engagement and create a more profound and meaningful learning experience.

The use of innovative learning media must be accompanied by appropriate learning strategies to achieve optimal learning outcomes. Recognizing the complexity of 21st-century learning challenges, teachers are required to create meaningful learning experiences for students (Leavy et al., 2023; Patresia et al., 2020; Anisimova, Sabirova & Shatunova, 2020). An approach that aligns with the demands of the 21st century and has the potential to address these challenges is the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach (Liu & Wu, 2025; Chistyakov et al., 2023; Singh, 2021; Belbase et al., 2022). This approach not only emphasizes the understanding of science, technology, and mathematics concepts but also incorporates elements of art and engineering to provide a holistic and real-world relevant learning experience (Liu & Wu, 2025; Montés et al., 2024; Yeomans, Chappell, Hetherington, Bresciani, Unterfrauner, Fabian et al., 2025; Anisimova et al., 2020; Herlina et al., 2022). Therefore, by applying the STEAM approach, teachers can create more dynamic learning, stimulate creativity, and develop 21st-century skills such as critical thinking, collaboration, and effective communication (Leavy et al., 2023; Ellinawati, Subali, Putra, Wahyuni, Dwijananti, Adhi et al. , 2025; Jesionkowska et al., 2020; Sigit, Ristanto & Mufida, 2022; Hasibuan, Fitri & Dewi, 2022). This aligns with constructivist learning theory, which emphasizes student-centered, contextual, and active engagement in constructing knowledge through meaningful experiences.

Thus, to maximize ecosystem learning and address the challenges of 21st-century education, it is essential to conduct research on the development of innovative learning media in the form of an interactive website based on the STEAM approach for ecosystem topics, named Eco-STEAM. Eco-STEAM is specifically designed to address challenges in teaching ecosystem concepts through an interactive and engaging approach. The website consists of several sections such as home, topics, games, glossary, and credits. The standout feature of this media is the "Exploration Zone," which provides activities to deepen understanding and sharpen students' skills and creativity through interactive worksheets, projects, and virtual simulations. This media is expected to contribute positively to supporting ecosystem learning, creating a more interactive learning experience, and actively engaging students in the learning process.

2. Research Question

This research focuses on the development of a validated and feasible Eco-STEAM learning media, oriented towards enhancing the understanding of ecosystem concepts. Based on the research background and focus, the research question is: "How is the development and feasibility of the Eco-STEAM website oriented towards improving students' understanding of ecosystem concepts?"

3. Research Method

This research employs the research and development method using the 4D model introduced by Thiagarajan, Semmel and Semmel (1974). This model consists of four stages: define, design, develop, and disseminate, with the detailed process flow illustrated in Figure 1.

The define stage is conducted through a literature review and field surveys. This stage consists of a series of analyses, beginning with a front-end analysis. This process involves examining the challenges in ecosystem learning, particularly focusing on students' understanding of ecosystem concepts. Learner analysis is carried out by exploring relevant literature sources and conducting field surveys through the distribution of needs analysis questionnaires alongside the initial analysis. Task analysis is performed by considering the results of the previous two analyses, namely front-end analysis and learner analysis. Concept analysis is also conducted to identify and understand the key concepts related to ecosystems that will be integrated into the product. The final step in the definition stage is specifying instructional

objectives, which involves drafting a series of structured learning objectives based on the results of concept analysis and curriculum review.

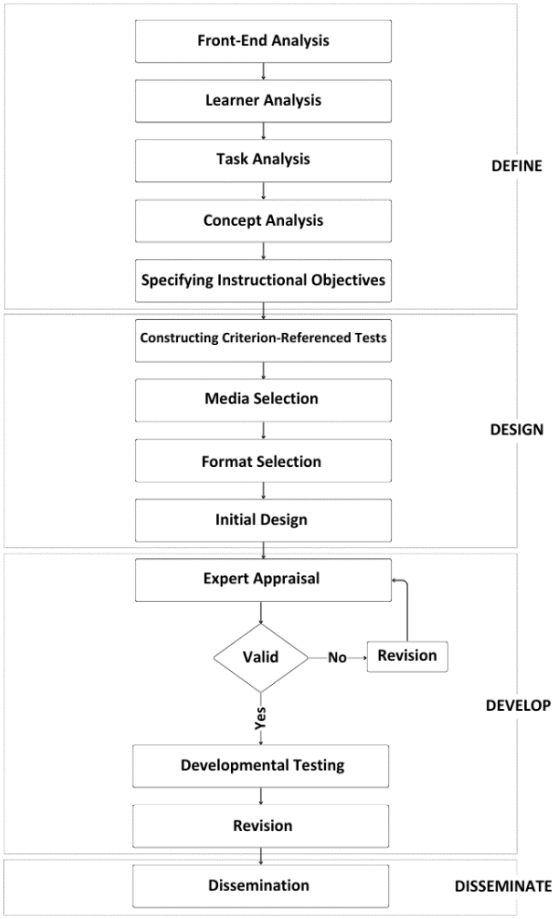

Figure 1. Flow of the 4D Model Development Process

The second stage, design, begins with the process of constructing criterion-referenced tests. This involves the development of assessment instruments to evaluate the extent to which the product meets the pre-established learning objectives. Subsequently, media selection is carried out by considering the characteristics of ecosystem learning to create an engaging learning experience for students, while also ensuring the novelty of the product compared to existing ones. Then, format selection is undertaken to determine the features to be integrated into the media, along with considerations for content presentation techniques. The outcome of this stage is the initial design of the Eco-STEAM website, which is then prepared for feasibility testing to evaluate the quality of the developed media.

The third stage, develop, involves the evaluation of the designed Eco-STEAM website by experts and development trials. Expert evaluation aims to assess the feasibility of the designed media, involving media experts, material experts, and language experts. Development testing is conducted after revising the product based on suggestions and feedback from the experts. These trials are performed on both a small and large scale, involving teachers and students. This stage also includes testing the impact of the media on students' understanding of ecosystem concepts using a one-group pretest-post-test research design.

The final stage in this research is disseminate. In this stage, dissemination is carried out by distributing the product on a limited basis to a specific school, SMAN "X" Bekasi, through a barcode printed on various types of merchandise. Additionally, the media has been registered on the Google Search Console platform to ensure it is indexed by Google's search engine.

3.1. Research Subjects

The subjects in this study include students, teachers, and experts, with the details of their involvement presented in Table 1.

Subject	Involvement
72 high school students	Distribution of student needs analysis questionnaires
9 biology teachers	Distribution of teacher needs analysis questionnaires
1 media expert, 1 language expert, and 1 material expert	Feasibility test by experts
10 students in class XI MIPA and 1 biology teacher	Small scale product trials
40 students in class XI MIPA	Large scale product trials

Table 1. Research subjects and their involvement

3.2. Research Instruments

The assessment instruments developed in this study include feasibility evaluation instruments by experts in the aspects of media, material, and language, as well as product trial instruments by students and teachers. The instrument grids were created based on guidelines for the development of educational media, sourced from BSNP (2014). The feasibility evaluation in the media aspect is essential to ensure that the technology and interface used in the media meet the student's needs and support effective interaction. The instrument grid for the media feasibility evaluation by experts is presented in Table 2.

Category	Items	Number
Design	1, 2, 3	3
Typography	4, 5, 6	3
Feature Completeness	7, 8, 9	3
Attractiveness	10, 11	2
Feature Quality	12, 13, 14	3
Total Items		14

Table 2. Grid of the Feasibility Test Instrument by Media Experts

Subsequently, the feasibility evaluation in the content aspect is conducted to ensure that the learning content presented in the media is accurate, relevant, and aligned with the current curriculum standards. The instrument grid for the content feasibility evaluation by experts is shown in Table 3.

Category	Items	Number
Language and readability	11, 12, 13, 14, 15, 16, 17, 18	8
Content coverage	1, 2, 3, 4	4
Content accuracy	5, 6, 7, 8, 9, 10	6
Total Items		18

Table 3. Grid of the Feasibility Test Instrument by Material Experts

The next feasibility evaluation is conducted in the language aspect, aiming to ensure that the language used in the media is easy to understand, appropriate for the student's comprehension level, and free from ambiguity. The instrument grid for the language feasibility evaluation by experts is presented in Table 4.

Category	Items	Number
Appropriateness to the developmental level of students	1,2	2
Writing structure	3	1
Readability	4, 5, 6	3
Use of terms and symbols	7	1
Clarity of sentences	8	1
Providing motivation	9, 10	2
Total Items		10

Table 4. Grid of the Feasibility Test Instrument by Language Experts

Through the product evaluation process across these three aspects by experts, it can be confirmed that the developed learning media meets the quality standards required to provide meaningful learning experiences for students (Supriyatno, Susilawati & Hassan, 2020; Suryanda, Azrai & Julita, 2019; Mudinillah, 2019). Meanwhile, the Eco-STEAM product trial instruments were designed to measure the product's effectiveness in actual usage contexts, involving both students and teachers (Herlina et al., 2022; Rahmah & Risnani, 2023; Firmaningrum & Anggraito, 2022). The involvement of students in the product trial will evaluate the effectiveness and acceptance of the learning media by its target users. The instrument grid for the product trial by students can be seen in Table 5.

Category	Items	Number
Clarity and completeness of material	1	1
Relevance to everyday life	2	1
Presentation technique	3, 4	2
Presentation support	5, 6	2
Use of grammar	7, 8, 9, 10	4
Appearance	11, 12, 13, 14	4
Motivation	15, 16, 17, 18	4
Understanding of material	19, 20	2
Ease of use	21	1
Total Items		20

Table 5. Grid of the Product Trial Instrument by Students

Next, the product trial instrument by teachers is created to involve teachers in providing insights into how the learning media can be integrated into classroom instruction and gathering feedback on potential shortcomings or necessary improvements (Mudinillah, 2019; Suryanda et al., 2019). The instrument grid for the product trial by teachers is presented in Table 6. The feedback obtained from this trial will provide information for refining and optimizing the media before it is widely disseminated.

Category	Items	Number
Clarity and completeness of material	1, 2	2
Relevance to everyday life	3	1
Presentation technique	4, 5, 6	3
Presentation support	7	1
Material presentation	8, 9, 10	3
Use of grammar	11, 12	2
Appearance	13, 14, 15	3
Motivation	16, 17	2
Understanding of material	18	1
Total Items		18

Table 6. Grid of the Product Trial Instrument by Teachers

Meanwhile, the instrument used to measure student's understanding of ecosystem concepts is the Ecosystem Misconception Diagnostic Test (EMD-Test), developed by Ristanto, Suryanda and Indraswari (2023). This instrument is designed to identify misconceptions in understanding ecosystem concepts. It has been proven to be valid and reliable, making it suitable for assessing students' conceptual understanding of ecosystem material in this study.

3.3. Analysis Technique

In this research, various types of data were collected, as seen in Table 2, so data analysis was conducted in stages according to the type of data. The results of the needs analysis by students and teachers were analyzed quantitatively by calculating the percentage of responses from the distributed questionnaires. This data was then processed to determine the most urgent needs and the aspects that require solutions. The results of expert evaluations, including media, content, and language feasibility tests, as well as development trials, were also analyzed quantitatively by referring to the interpretation table from Ratumanan and Laurens (2011), as shown in Table 7.

Category Interval	Criteria	Information
3.25 – 4.00	Very feasible	Can be used without revision
2.50 – 3.24	Feasible	Can be used with minor revisions
1.75 – 2.49	Less feasible	Can be used with multiple revisions
1.00 – 1.7 4	Not feasible	Cannot be used yet and needs guidance

Table 7. Interpretation of Eco-STEAM feasibility test scores

Meanwhile, the data from the media's impact on students' understanding of ecosystem concepts, represented by pretest and post-test scores, were analyzed quantitatively using the Statistical Package for the Social Sciences (SPSS) version 27, involving descriptive statistical calculations such as minimum and maximum values, mean, standard deviation, and normalized gain (N-gain). The N-gain calculation was performed to assess the level of improvement in students' understanding of ecosystem concepts before and after using the media, categorized into three levels according to Meltzer (2002), as shown in Table 8.

N (Gain)	Interpretation
$N \geq 0.70$	High
$0.30 \leq N \leq 0.70$	Medium
$N \leq 0.30$	Low

Table 8. Criteria for normalized gain values (N-gain)

The effectiveness of the Eco-STEAM website can be determined using a dependent t-test. Before conducting the dependent t-test, the data were tested for analysis prerequisites using the Kolmogorov-Smirnov test for normality and the Levene test for homogeneity. All tests were conducted with a significance level of $\alpha = 0.05$. An effect size test was also performed using Cohen's d to measure the strength or magnitude of the difference between two sample groups. The criteria for effect size values can be categorized according to Cohen, Magnion and Morrison (2018), as shown in Table 9.

Effect size	Interpretation
0.00 – 0.20	Weak
0.21 – 0.50	Modest
0.51 – 1.00	Moderate
> 1.00	Strong

Table 9. Criteria for effect size values

4. Findings and Discussion

4.1. Development of the Eco-STEAM Website

The development of the Eco-STEAM website began with analyzing the urgency and needs for the planned product development. At this stage, literature reviews and field surveys were conducted to determine the key aspects that must be accommodated in the learning media. The analysis phase was carried out according to the define stage in the 4D development model. The results of this analysis can be seen in Table 10.

Stages	Results
Front-end analysis	Students' understanding of ecosystem concepts is not yet optimal due to several influencing factors, one of which is the lack of adequate learning media.
Learner analysis	Students are more responsive to technology-based learning, and education needs to adapt to this development through the integration of dynamic and interactive digital learning media.
Task analysis	There is a need to develop digital learning media to enhance students' understanding and interest in ecosystem materials.
Concept analysis	The ecosystem concepts to be included are those studied by students in Grade X of Senior High School with the 'Merdeka' curriculum. These concepts include five key areas: ecosystem components, interactions among ecosystem components, energy flow, ecological pyramids and productivity, and biogeochemical cycles.
Specifying instructional objectives	Learning Objective: Students can create solutions for issues related to ecosystem components and interactions among ecosystem components. Learning Objective Flow: 1. Students can identify biotic and abiotic components within an ecosystem. 2. Students can explain interactions between biotic components and other biotic components within an ecosystem. 3. Students can explain the concepts of food chains and food webs, understand the concept of energy flow through food chains and food webs, and create a food web project. 4. Students can differentiate types of ecological pyramids and analyze ecosystem productivity. 5. Students can create a biogeochemical cycle chart (nitrogen cycle, carbon cycle, sulfur cycle, and phosphorus cycle) based on literature review.

Table 10. Results of the Urgency and Needs Analysis for the Development of the Eco-STEAM Website

The development of Eco-STEAM addresses the identified issues through various analyses. The advantages of this media include the integration of innovative learning approaches with the latest technology, enabling a more interactive, dynamic, and engaging presentation of learning materials for students. The use of Eco-STEAM in the learning process provides students with opportunities to actively engage through interactive features available on the platform. The media also offers content tailored to the curriculum and students' needs. The Eco-STEAM website allows for flexible learning, enabling students to learn independently according to their own pace and learning style, while still being guided by set learning objectives. Therefore, the use of Eco-STEAM can offer a more enjoyable and meaningful learning experience for students.

A major advantage of the Eco-STEAM website is its integration of the STEAM approach. This approach focuses on problem-solving, creativity, collaboration, and communication, aiming to equip students with 21st-century skills necessary for future success (Prahani, Nisa, Nurdiana, Krisnaningsih, Amiruddin & Sya'roni, 2023; Hendriawan, Yunianta & Setyadi, 2023; Puspitasari, Solfiah & Zulkifli, 2022). The integration of multiple disciplines provides a holistic and comprehensive approach to learning, allowing students to develop a broad range of skills and understanding (Chistyakov et al., 2023; Montés et al., 2024; Nuraini et al., 2023; Herlina et al., 2022). The STEAM approach in ecosystem learning enables students to not only grasp ecological concepts deeply but also engage in exploring aspects related to technology, engineering, arts, and mathematics connected to ecosystems. Thus, the STEAM approach in the Eco-

STEAM website can broaden students' understanding of ecosystems and stimulate creativity and innovation in learning.

The Eco-STEAM website is developed using Google Sites, a Google service that allows users to create and publish websites easily without requiring knowledge of web programming. The main advantage of Google Sites is its ease of use, enabling users to quickly create websites without additional costs (Ardiel & Rusli, 2024; Mustofa, Hayuana, Damopolii, Ibrohim & Susilo, 2024; Hendriawan et al., 2023). In addition to using Google Sites, the development of the Eco-STEAM website involves integrating various relevant platforms to support the desired content development, such as Canva, wizer.me, wordwall.net, fliphtml5.com, and various trusted online news platforms. By utilizing these platforms collectively, the Eco-STEAM website can present diverse, interactive, and high-quality content, providing a richer and more engaging learning experience for its users.

The Eco-STEAM website has undergone evaluation by experts in media, content, and language. The results of the media feasibility test can be seen in Table 11.

Evaluation Indicators	Average	Category
Design	4.00	Very feasible
Typography	4.00	Very feasible
Feature Completeness	4.00	Very feasible
Attractiveness	4.00	Very feasible
Feature Quality	3.67	Very feasible
Average	3.93	Very feasible

Table 11. Results of the Feasibility Test by Media Experts

Table 11 shows that the media expert evaluation results categorized the product as very feasible (3.93 or 98.25%). The media expert recommended adding hyperlinks to subtopic menus and providing explanations about the integrated STEAM approach in the Eco-STEAM interactive website. Therefore, revisions were made to the product according to the recommendations. Next, the feasibility results from the material expert can be seen in Table 12.

Evaluation Indicators	Average	Category
Language and readability	4.00	Very feasible
Content coverage	3.83	Very feasible
Content accuracy	3.87	Very feasible
Average	3.90	Very feasible

Table 12. Results of the Feasibility Test by Material Experts

Table 12 shows that the material expert evaluation results categorized the product as very feasible (3.90 or 97.5%). The material expert recommended adding a glossary feature to explain less familiar biological terms, so the product was revised based on this feedback. The feasibility results from the language expert can be seen in Table 13.

Evaluation Indicators	Average	Category
Appropriateness to the developmental level of students	4.00	Very feasible
Writing structure	4.00	Very feasible
Readability	3.33	Very feasible
Use of terms and symbols	3.00	Feasible
Clarity of sentences	3.00	Feasible
Providing motivation	4.00	Very feasible
Average	3.55	Very feasible

Table 13. Results of the Feasibility Test by Language Experts

Based on Table 13, the results of the language expert evaluation indicate a suitability level categorized as very feasible (3.55 or 88.75%). The language expert stated that the language used in Eco-STEAM is appropriate for the target audience's understanding, with good grammar and easily understandable sentences. The writing style and terminology are consistent, accompanied by relevant images.

Assessment by experts is crucial to ensure that the website provides an effective and beneficial learning experience for its users (Supriyatno et al., 2020; Suryanda et al., 2019; Mudinillah, 2019). The overall average rating from the experts indicates that the website is categorized as very feasible, with a score of 3.79 or 94.75%. This result demonstrates that the Eco-STEAM interactive website has successfully met high-quality standards in terms of media, content, and language use.

The Eco-STEAM website has also undergone development trials involving product testing by students and teachers. This is aimed at measuring the effectiveness of the product in real usage contexts by both students and teachers. The results of the product testing by biology teachers are detailed in Table 14.

Evaluation Indicators	Average	Category
Clarity and completeness of material	3.50	Very feasible
Relevance to everyday life	4.00	Very feasible
Presentation technique	3.66	Very feasible
Presentation support	3.00	Feasible
Material presentation	3.66	Very feasible
Use of grammar	3.00	Feasible
Appearance	3.33	Very feasible
Motivation	3.00	Feasible
Understanding of material	4.00	Very feasible
Average	3.90	Very feasible

Table 14. Results of the Product Trial by Biology Teachers

Table 14 shows that the results of the product testing by biology teachers received a very feasible rating with a score of 3.46 or 86.5%. The biology teacher indicated that the website and its materials were overall good. The interactive Eco-STEAM website was then tested by students in both small-scale and large-scale trials. The average results of the product testing by students are summarized in Table 15.

Evaluation Indicators	Average	Category
Clarity and completeness of material	3.75	Very feasible
Relevance to everyday life	3.74	Very feasible
Presentation technique	3.67	Very feasible
Presentation support	3.56	Very feasible
Use of grammar	3.64	Very feasible
Appearance	3.72	Very feasible
Motivation	3.66	Very feasible
Understanding of material	3.74	Very feasible
Ease of use	3.73	Very feasible
Average	3.69	Very feasible

Table 15. Results of the Product Trial by Students

Based on Table 15, the student product testing results indicate a very feasible rating of 3.69 or 92.25%. Students provided various positive comments, noting that the Eco-STEAM website was highly interactive and beneficial for learning, making learning more enjoyable and helping them understand developments in science and technology. Students also appreciated the more engaging and easier learning methods provided by the Eco-STEAM website and found it suitable for independent study. They felt that using this website facilitated their understanding of ecosystem concepts. Suggestions included increasing the number of games on the website, considering the creation of an offline app to enhance accessibility, adding more biology content features, and improving the drawing features on interactive worksheets. Overall, students expressed enjoyment with the materials and games provided and viewed the use of this digital learning media as a fun and effective way to enhance their understanding.

The overall average score of the Eco-STEAM website development trial received a very feasible rating of 3.61 or 90.25%. This result indicates that the interactive Eco-STEAM website has received positive feedback and good acceptance from its main users, namely teachers and students. This result also reflects that the website meets the expected quality standards and effectively fulfills the needs of students and teachers in the learning process.

4.2. Characteristics of the Eco-STEAM Website

The Eco-STEAM website is designed with characteristics that support interactive learning to facilitate deep and contextual learning. The user interface is designed to be simple and intuitive, with easy-to-understand navigation, allowing students to quickly access the desired features. The website consists of five main pages: Home, Topics, Games, Glossary, and Credits. The learning material on ecosystems presented on this website is written concisely and clearly and is reinforced with supporting images and videos. Each topic has a set learning objective to be achieved. The format of the subtopic pages on the Eco-STEAM website can be seen in Figure 2.

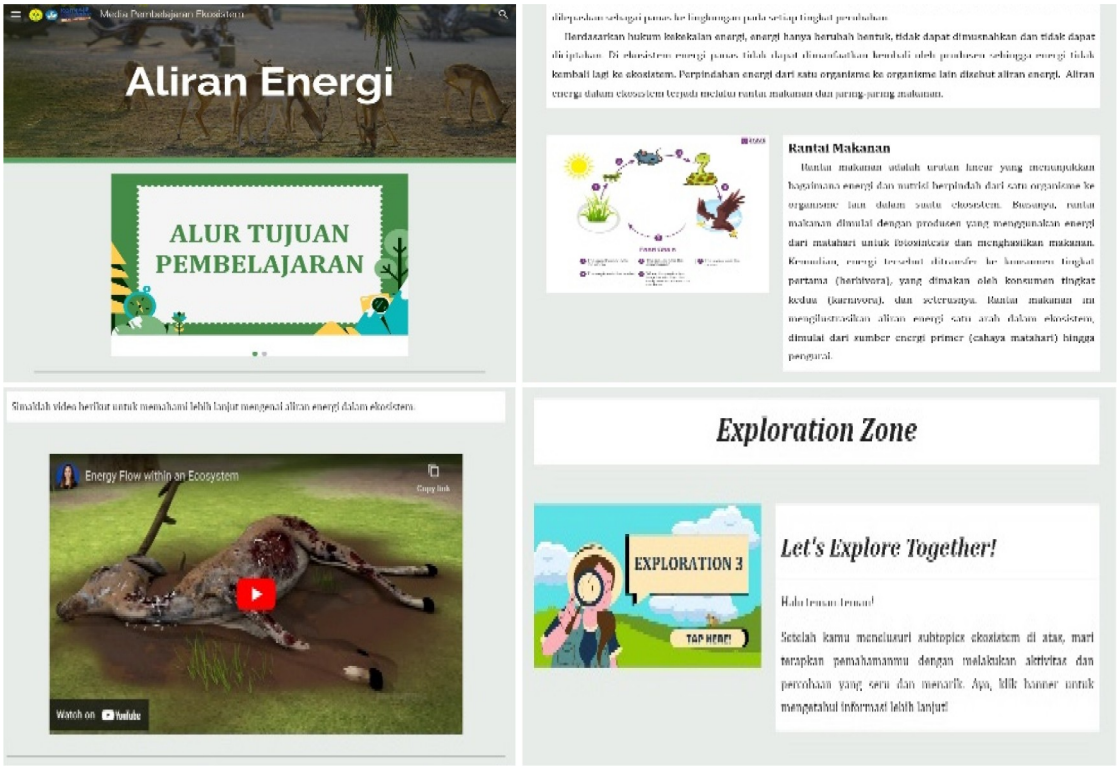

Figure 2. Display of subtopic pages on the Eco-STEAM website

In each subtopic of the Eco-STEAM website, there is a feature that leads to the Exploration Zone page. The appearance of the Exploration Zone page can be seen in Figure 3.

In this feature, students can find a variety of activities designed to deepen their understanding and develop their skills and creativity after studying a particular subtopic. These activities are presented in the form of interactive worksheets that allow teachers to provide direct feedback to students on their work. Other activities include projects, such as creating products or virtual simulations, which enable students to practice their skills and creativity.

The projects in the Exploration Zone feature are STEAM-based, facilitating students to apply the knowledge they have learned in real-world contexts, integrating aspects of science, technology, engineering, arts, and mathematics in problem-solving. The STEAM approach has been proven effective in developing the critical skills needed in the modern era. According to research by Mulder, Khoiri and Hayat (2023), the application of the STEAM approach can enhance students' understanding of scientific and technological concepts and their ability to think critically and creatively. Additionally, this approach fosters collaboration and communication, as students work together to brainstorm ideas, test hypotheses, and refine their solutions through iterative processes (Ellinawati et al., 2025; Bertrand & Namukasa, 2023). Through these projects, students are encouraged to identify problems, design solutions, and implement their designs, whether in the form of physical products or virtual simulations (Chistyakov et al., 2023). This way, students not only learn to understand ecosystem concepts theoretically but also develop collaborative, critical, and innovative skills essential for facing real-world challenges. This is supported by research from Siregar, Rahmawati and Suyono (2023), which states that STEAM-based projects can encourage students to think across disciplines, connect various concepts they have learned, and apply them creatively to solve complex problems. Similarly, findings by Sigit et al. (2022) show that project-based learning encourages students to be more engaged and able to apply their knowledge in contexts relevant to daily life.

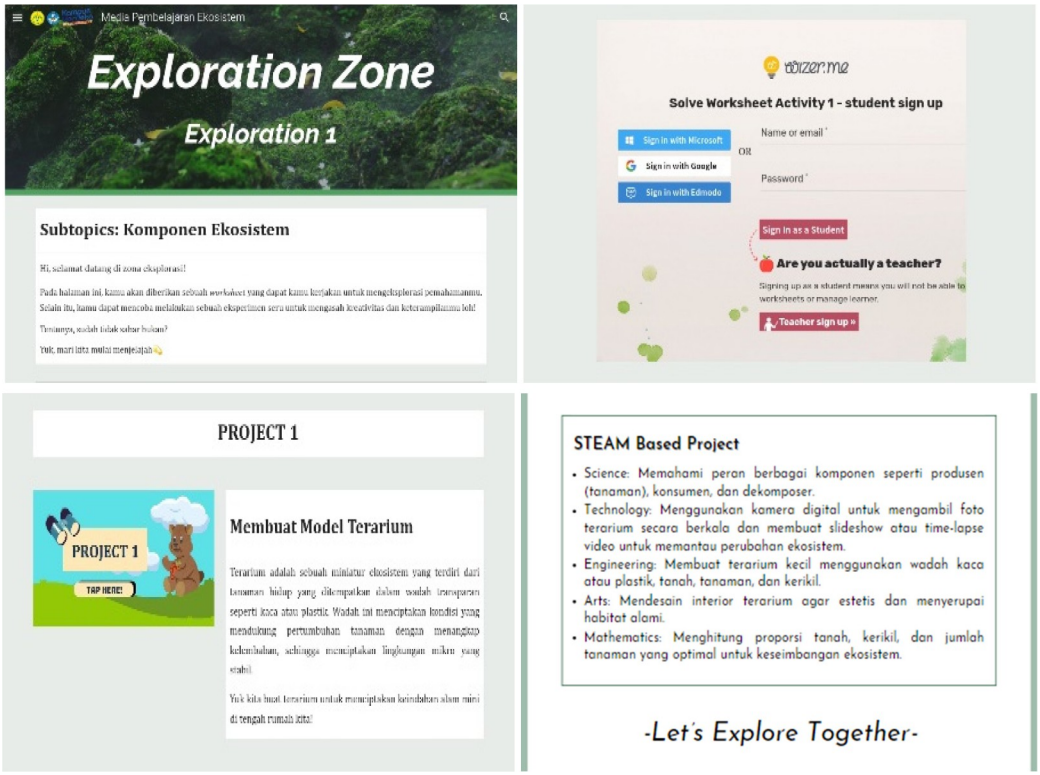

Figure 3. Display of the Exploration Zone page in the Eco-STEAM website

There are five projects that students can undertake, each corresponding to its subtopic. The details of these projects are presented in Table 16.

The Eco-STEAM website also offers educational game features. Each type of game covers different materials, although some may have the same type. The total number of games available is 15. A list of these games can be found on the Games page, as shown in Figure 4.

All games are created using the platform wordwall.net, which is accessible for free and does not require downloading additional applications. This provides convenience for users in accessing various games. The use of game elements in learning has been proven to increase student engagement and motivation by making the learning process more enjoyable and engaging (Rahmah & Risnani, 2023; Wang, Chen, Hwang, Guan & Wang, 2022). These games are designed to reinforce students' understanding of the material learned interactively and entertainingly. Gamification in learning leverages these game mechanics to create an engaging and immersive educational experience, where students are motivated by earning points, unlocking levels, or competing on leaderboards (Dahalan, Alias & Shaharom, 2024; Mercan & Selçuk, 2024). According to Balalle (2024), research has shown that these approaches not only boost motivation but also improve knowledge retention and critical thinking skills by transforming passive learning into an interactive experience. By providing various types of games covering different material, students can learn through varied methods, thus increasing their engagement and motivation (Henry & Arnab, 2024). This is consistent with research by Setiawan and Muchlas (2021) which shows that variation in teaching methods can overcome boredom in learning and make the learning process more effective.

Subtopic	Project	Description
Ecosystem Components	Creating a Terrarium Model	Students will create a miniature ecosystem with living plants in a transparent container, creating a stable microenvironment for plant growth.
Interactions Among Ecosystem Components	Plant and Animal Interaction Experiment	Students will conduct simple experiments to observe plant and animal interactions more closely.
Energy Flow	Mini Ecosystem with Solar Panels	Solar panels convert sunlight into electrical energy. In this experiment, students will create a mini ecosystem to simulate the flow of energy from the sun to various ecosystem components.
Ecological Pyramid and Productivity	Virtual Simulation of Ecological Pyramid	Students will perform a virtual simulation to understand the ecological pyramid and energy flow within an ecosystem and categorize organisms into different trophic levels.
Biogeochemical Cycles	Calculating Ecological Footprint	Students will explore their personal ecological footprint to measure natural resource use and waste generated from their lifestyle. Through this calculation, students will understand how human activities impact ecosystem balance and the planet.

Table 16. Details of STEAM-Based Projects Included in the Eco-STEAM Website

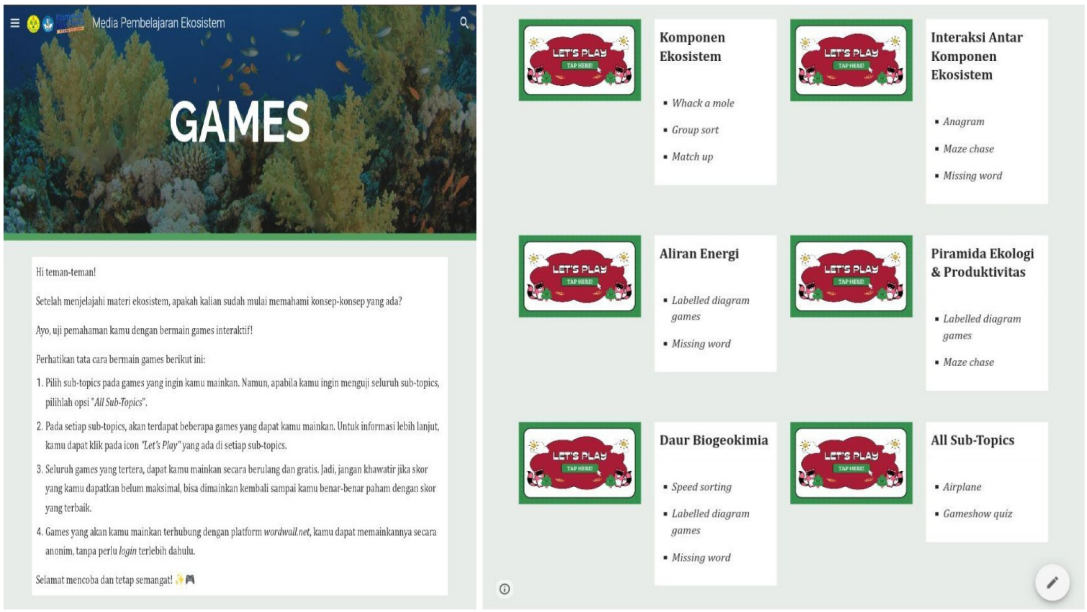

Figure 4. Display of the Games page in the Eco-STEAM website

The website is also equipped with a glossary feature containing a list of terms and definitions related to ecosystem learning material. This glossary feature aims to help users, especially students, understand new or difficult terms that appear in the learning content. Through the glossary, students can easily refer to and search for the meanings of these terms without having to leave the website. According to Landauer, McNamara, Dennis and Kintsch (2007), having direct access to definitions and explanations of key terms in the learning process helps speed up understanding and supports students' memory of the information learned. This not only accelerates the learning process but also helps strengthen students' understanding of complex ecosystem concepts by ensuring that students have a clear understanding of the terms used in the learning content.

Another standout feature of the website is Ecosystem News, where users can access the latest news about ecosystems. This news is connected to various reputable news platforms such as Kompas.com, Detik.com, Liputan6.com, and Sindonews.com, ensuring accuracy and continuity of information. The availability of regularly updated news provides users with easy access to stay updated on the latest developments about ecosystems. Knowing the latest news about ecosystems is an important step in improving digital literacy.

Digital literacy is the ability to search, evaluate, and effectively use information in the digital world (Tinmaz, Lee, Fanea & Baber 2022; Pangrazio, Godhe & Ladesma, 2020). Through online access to this news, students can develop research skills, enhance environmental understanding, build awareness of environmental issues, and encourage participation and action in environmental conservation efforts (Yustika & Iswati, 2020; Ricoy & Sánchez-Martinez, 2022).

On the Eco-STEAM website, there is a feedback form feature that allows users to provide responses after using the website. This feature is designed to give users, both students and teachers, a space to share opinions, suggestions, or feedback related to their experience using the website. User feedback is an essential component in the media development process, as it allows for adjustments and continuous improvements according to students' needs (Firmaningrum & Anggraito, 2022; Mulder et al., 2023). Thus, the website can continue to adapt and improve over time in line with users' needs and preferences.

Unlike other digital platforms that often provide only static content or focus on general science topics, Eco-STEAM offers ecosystem-specific materials that are enriched with STEAM-integrated projects and interactive simulations. This focus allows for a deeper and more targeted exploration of ecological concepts, which is particularly valuable given the complexity of ecosystem dynamics. By engaging with activities such as virtual experiments, ecological footprint analysis, and interdisciplinary project-based tasks, students are encouraged to think critically, solve problems creatively, and connect theoretical knowledge to real-world environmental issues. These features are rarely present in existing digital resources, which typically lack the level of interactivity, contextual relevance, and cross-disciplinary integration found in Eco-STEAM.

4.3. The Impact of Using the Eco-STEAM Website on Ecosystem Concept Understanding

The effect of using the Eco-STEAM website on students' understanding of ecosystem concepts was tested with 40 students using a one-group pretest-post-test design. The results of the descriptive statistical analysis of the students' understanding of ecosystem concepts are presented in Table 17.

Data	Pretest	Posttest
Minimum value	14.29	50.00
Maximum value	92.86	100.00
Average	52.32	75.89
Standard deviation	16.84	14.44
N-gain	0.49	

Table 17. Results of descriptive statistical analysis of tests of understanding of ecosystem concepts

The use of the Eco-STEAM website in ecosystem learning has had a significant impact on improving students' understanding of concepts. According to the results from Table 12, the minimum score on the pretest was 14.29, while the post-test score increased to 50.00. The maximum score also improved, from 92.86 on the pretest to 100.00 on the post-test. The average pretest score was 52.32, which increased to 75.89 on the post-test. This indicates a substantial improvement in understanding. Additionally, the standard deviation decreased from 16.84 on the pretest to 14.44 on the post-test, indicating that the variation in student scores became smaller after using this media. This shows that learning outcomes became more consistent across the student group. The average N-gain score was 0.49, indicating a moderate level of improvement in understanding.

The results of prerequisite analysis tests show that the significance values for the normality test of both pretest and post-test data (0.087 and 0.104) are greater than the significance level of $\alpha = 0.05$. This indicates that both sets of data are normally distributed. Similarly, the homogeneity test results show a significance value greater than α ($0.652 > 0.05$), indicating that the variances of pretest and post-test data are homogeneous. Furthermore, the dependent t-test results show a significance value of $0.000 < 0.05$,

meaning there is a significant difference in students' understanding of ecosystem concepts before and after using the Eco-STEAM website as a learning medium. The effect size test results show an estimate of 1.579, indicating a strong effect. Thus, it can be concluded that the use of the Eco-STEAM website has a positive impact on improving students' understanding of ecosystem concepts. These results align with constructivist learning theory, which emphasizes contextualized and active engagement. The interdisciplinary and project-based features of Eco-STEAM allow students to construct meaning from ecological concepts by linking them to real-world challenges, supporting deeper understanding.

The use of STEAM-based learning media, such as the Eco-STEAM website, has the potential to enhance students' understanding of concepts. With an interdisciplinary approach, this media allows students to learn holistically. The STEAM approach, which integrates various disciplines into learning, enables students to understand concepts more deeply and applicably, thereby enhancing their understanding of the subject matter (Martín-Cudero, Cid-Cid & Guede-Cid, 2024; Wang et al., 2022). According to constructivist learning theory, students learn more effectively when they actively engage in constructing their own understanding based on experience. The Eco-STEAM website supports this by providing interactive simulations and real-world projects that allow students to apply knowledge meaningfully. STEAM-based projects, such as creating miniaturized ecosystems or simulating energy flow, encourage students to apply ecosystem concepts practically. These projects help students connect theory with real-world applications, deepening their understanding of scientific and ecological principles (Sigit et al., 2022; Patresia et al., 2020). Through these activities, students not only grasp theoretical concepts but also observe how ecological principles operate in real-world contexts. This approach increases student engagement, encourages critical and creative thinking in solving environmental problems, and connects ecosystem concepts with real-world applications. In line with this, research by Siregar et al. (2023) also indicates that project-based approaches in STEAM enable students to develop critical thinking and creativity skills, which are challenging to achieve through conventional teaching methods. Similarly, a study by Chistyakov et al. (2023) found that integrating interdisciplinary projects in science education fosters problem-solving abilities and enhances students' capacity to apply theoretical knowledge in practical contexts. Therefore, students gain a more profound and integrated understanding of ecosystems. These findings confirm the value of interdisciplinary, STEAM-based digital learning in improving conceptual understanding. By simulating real-world problem-solving, the Eco-STEAM platform bridges theory with practice, contributing meaningfully to science education innovation.

4.4. Research Limitations

The Eco-STEAM website has been developed through a series of complex stages, supported by in-depth analysis related to the urgency of its creation and the selection of content tailored to students' learning needs. However, the measurement of the effectiveness of using the Eco-STEAM website on students' understanding of ecosystem concepts is limited to one class with a sample size of 40 students. This limitation in sample size may affect the generalizability of the research findings, thus necessitating further research with a broader scope. Nevertheless, the results of this study are sufficiently representative to demonstrate that this media can significantly improve students' understanding of ecosystem concepts on a smaller scale. This can indicate evaluating the product in this development research.

5. Conclusion

Based on the conducted research, it can be concluded that Eco-STEAM has been successfully developed using the 4D development model. This product has undergone feasibility testing by experts in media, language, and material, as well as development testing involving teachers and students. The results from expert evaluations and development testing demonstrate that this media is highly feasible for use in the learning process. The use of this media has also significantly improved students' understanding of ecosystem concepts. Therefore, the Eco-STEAM website can be utilized as an innovative digital learning media for ecosystem education. Future research can be conducted to analyze the effectiveness of the Eco-STEAM learning media, considering various other variables, on the quality of the learning process and

student outcomes. This will provide a comprehensive understanding of Eco-STEAM's contribution to improving the quality of education.

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