



Development e-module through problem-based learning on ecosystem concepts to improve environmental literacy

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ABSTRACT

This study developed an e-module based on problem-based learning (PBL) on ecosystem materials to enhance environmental literacy using the 3D model. The research novelty lies in the systematic integration of environmental literacy indicators directly into the PBL syntax, synchronizing ecosystem problem-solving with ecological knowledge. The development progressed through define, design, and development stages, involving rigorous competency analysis, interactive storyboarding, and expert validation. Results demonstrated an overall feasibility score of 74.8% (feasible), with the material expert rating it at 66.6% (Feasible) and the media expert at 83.3% (very Feasible). Based on these findings, it is recommended that educators utilize this e-module as a supplementary tool to foster environmental awareness. Furthermore, future development should refine the material depth by incorporating recent local ecological data and expanding into the Dissemination stage through large-scale field testing to measure long-term behavioral impacts. This digital-interactive approach effectively bridges abstract biological concepts with real-world environmental challenges for students

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INTRODUCTION

The 21st century is a time of increasingly rapid development of information and communication technology. Learning in the 2013 curriculum has the goal of mastering 21st-century life skills, which consist of critical thinking skills, creative thinking skills, communication skills, and collaboration skills (Redhana, 2019). To achieve these competencies, students must develop scientific literacy-the ability to understand science concepts, identify inquiry-based questions, and utilize evidence-based explanations to navigate modern life (Chatzidaki et al., 2026; Lestari et al., 2020; Li et al., 2020; Pratiwi et al., 2019)

A crucial extension of scientific literacy is environmental literacy, which empowers (Yang et al., 2024), which empowers individuals to engage deeply with socio-scientific and ecological issues (Kaya & Elster, 2018; Saribas, 2015). Ideally, a scientifically literate student should inherently possess the awareness to maintain ecological balance; however, a significant gap remains between academic goals and reality. Many schools have yet to effectively integrate environmental education, resulting in low mastery of these skills among students (Lubis et al., 2022; Singleton, 2016). This gap is evident at MAS Assasun Najaah, where low environmental literacy is manifested in littering behaviors and lack of ecological awareness, exacerbated by inadequate waste management infrastructure and minimal reinforcement from the family and community environments (Haul et al., 2021; Hidayat & Abdillah, 2019)

To bridge this gap, the development of digital teaching materials, specifically e-modules based on problem-based learning (PBL), offers a modern solution. Unlike conventional modules, these e-modules leverage information technology to create interactive learning experiences that guide students in constructing knowledge by solving real-world problems (Mahendri et al., 2022). The integration of PBL syntax into a digital textbook format allows ecosystem topics to be directly linked to students' immediate environmental context, making the learning process more relevant and impactful (Lubis et al., 2024). Through this approach, the mastery of scientific literacy is transformed into practical environmental action, ultimately fostering a generation capable of ensuring ecological sustainability (Lubis et al., 2024; Sari & Hafandi, 2022; Serevina et al., 2018).

The urgency of developing this specific product is further underscored by research indicating that traditional, static learning materials often fail to foster the higher-order thinking skills required for environmental literacy. Studies have shown that the integration of PBL syntax, such as orienting students to problems and organizing them for study, significantly enhances students' ability to analyze complex ecological data compared to conventional methods (Løkke et al., 2023). Moreover, the inclusion of interactive simulations and multimedia within a digital module provides a "cognitive scaffold" that allows students to visualize abstract ecosystem cycles, a pressing need for a product that transforms scientific knowledge into sustainable habits.

The transition from passive learning to active, technology-based models is essential to increase student independent study motivation (Triyono, 2021). PBL is a relevant approach due to its constructivist nature, which bridges theory with real-world challenges (Løkke et al., 2023; Monica et al., 2019). Furthermore, the use of e-modules that integrate with simulations and videos is more effective than printed textbooks in increasing students' engagement and critical thinking (Setiawan & Rahayu, 2024; Sudarmin et al., 2019; Sugiyanto & Erviana, 2022). Based on the aforementioned challenges, this study seeks to address the following problem: How can a PBL-based biology e-module on ecosystem materials be developed to effectively and practically improve environmental literacy?

METHODS

Research Design

The research method is research and development (R&D). This research design uses the 4D models (define, Design, Develop, Disseminate) (Thiagarajan et al., 1974), which has been modified by Hariyanto et al. (2022). Which has been modified to 3D (define, design, and develop) (Auria et al., 2025; Oktaviani et al., 2025)

Population and Samples

The subjects in this study were two material experts and two media experts. The purpose of selecting these research subjects was to evaluate whether e-module-based PBL could be applied to students. The study population comprised all students at MAS Assasun Najaah during the even semester of the 2024/2025 academic year, totalling 132 individuals across six classes. A purposive sampling technique was employed to select the participants, the study selected Grade X (n=44) as the research sample. This selection was strategically determined based on the subjects' exposure to ecosystem materials, ensuring the sample met the specific thematic requirements of the study. The detailed sample distribution is presented in [Table 1](#).

Table 1.

Research Sample

class	Male	Female	Total
X1	10	14	24
X2	9	11	20

Instrument

The research instrument utilized in this study was a validation rubric specifically developed to evaluate the pedagogical and technical integrity of the e-module-based PBL. The instrument facilitated a systematic quality assessment by a panel of experts, including both content specialists and media professionals. The specific eligibility criteria and feasibility metrics governing this instrument are detailed in [Table 2](#).

Table 2.

E-Module Eligibility Instrument Grid for Media Expert

Assessment Aspect	Indicator
Design Aspect Screen	Color composition against the background Layout Synchronization between graphic illustrations with visual and verbal Clarity of title
Ease of Use Aspect	The attractiveness of design Systematic presentation Ease of operation Navigation function
Consistency aspect	Consistency in the use of words, terms, and sentences Consistency in the use of font shapes and sizes Layout consistency
Aspect of Usefulness	Attracting students' attention Ease of interaction with the module Facilitating teaching and learning activities
Graphic aspect	Use of letters Use of illustrations Use of video Use of color

Source: Edris (2018)

The specific eligibility criteria and feasibility metrics governing this instrument are detailed in [Table 3](#).

Table 3.

E-module Feasibility Instrument Grid for Subject Matter Experts

Assessment Aspect	Indicator
Content suitability aspect	Clarity of characteristics Ability to motivate students Compliance with KD Compliance with the material Clarity of purpose Suitability to student needs The truth of the substance of the material Benefits of increasing knowledge insight Conformity with moral and social values Assignment and quizzes match
Language aspects	Clarity of information Conformity with Indonesian language rules Effective and efficient use of language
Presentation aspects	Presentation systematics Completeness of information Providing motivation
Self-learning aspect	The biology e-module on ecosystem material can attract students' interest in learning
Problem-based learning aspect	Relevance of the problem presented Student involvement in the problem-solving process Suitability of PBL tasks with learning objectives Quality of feedback and support from the module Integration with other learning materials

Source: Edris (2018)

This research instrument is valid because it has been validated by experts. Validity analysis is used to determine whether the instrument items are valid or not. To prove the validity of the instrument, the researchers assessed the expert agreement index based on the Aiken index (V). The reliability of the instrument is determined based on the Cronbach's alpha coefficient. The reliability of the Media Expert instrument is 0,82, and for the Subject Matter Experts instrument is 0,83, the reliability value of the instrument is in the high category (Taber, 2018).

Procedure

This research consists of three stages: define, design, and development. The research did not reach the dissemination stage due to time and funding limitations. This research aims to produce a PBL-based e-module product only. Therefore, the dissemination stage will be conducted as a continuation of future research. The following is an explanation of the three stages used in the 3D model for developing a PBL-based biology e-module product.

Table 4.

E-module development stages

Stages	Activity
Define	analyzing problems, concepts, tasks and formulating learning objectives
Design	Creating an e-module framework Identifying material Determining the module's display design Creating an e-module flowchart and storyboard Developing an e-module assessment instrument
Development	Carry out product assessments that have been developed by experts to see the suitability of the product to produce a product that is suitable for use Make improvements to the findings obtained during the feasibility test

This study utilizes a modified 4D framework to produce an e-module-based PBL, specifically detailing the systematic progression through the define, design dan develop phases. The define phase is

initiated by a multi-dimensional analysis aimed at gathering diagnostic information. The scope of this “define” stage includes: (a) student competency assessment: Aligning the module with academic standards; (b) learner characteristics analysis: determining the target audience’s needs; (c) contextual gap analysis: identifying discrepancies between ideal and actual classroom conditions; (d) resource feasibility study: checking the accessibility of necessary learning media; (e) material evaluation: appraising the quality and limitations of previously utilized resources; (f) instructional goal setting: formulating precise learning targets.

The design stage focuses on the systematic architectural development of the instructional materials through a structured sequence of procedures. This phase begins with the creation of a comprehensive e-module framework and the identification of relevant core content, followed by the determination of the visual and interface design. To ensure a logical pedagogical flow, a detailed flowchart and storyboard are developed to map the user experience. Finally, the process concludes with the construction of a dedicated assessment instrument to evaluate the e-module’s effectiveness and technical quality.

The development stage represents the core phase of the 4D model, where the conceptual designs are transformed into a tangible instructional product. This process primarily involves a rigorous expert validation to evaluate the module’s feasibility and educational quality, ensuring it meets the necessary standards for classroom implementation. Based on the feedback and findings gathered during this validation phase, iterative revisions are conducted to address any deficiencies, ultimately resulting in a refined and technically sound final product ready for use. The research flowchart can be seen in the following [figure 1](#).

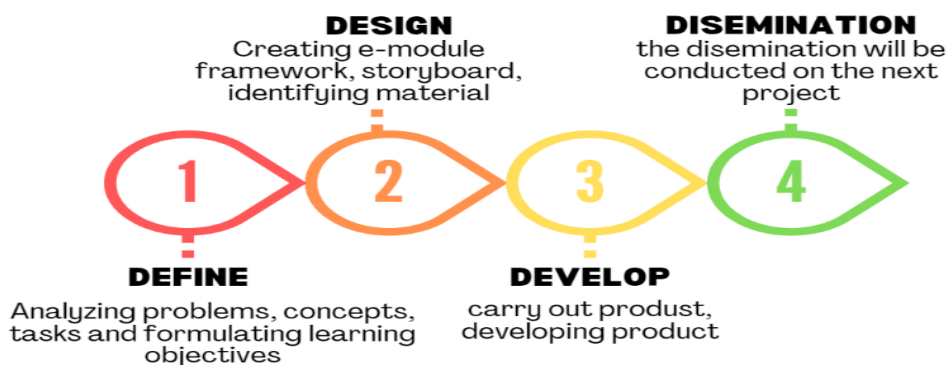


Figure 1. Research Flowchart

Data Analysis Techniques

The data analyzed in this study will be validated by material and media experts. The results of this study were analyzed using quantitative description methods to determine the development process of the PBL-based biology e-module. Expert validators reviewed e-module-based PBL to provide constructive refinements. Following this, a validation analysis was conducted to quantify the module’s feasibility level based on the experts’ professional evaluations.

RESULTS AND DISCUSSION

Define

This defining stage is the initial stage that begins with analyzing the problems that exist in the school environment, especially in MAS Assasun Najaah. At this stage, first analyze the competencies of students before designing effective learning modules. The next stage analyzes the characteristics of students, which aims to understand the background, interests, learning styles, and individual needs of students. Based on the results of the identification, low environmental literacy in MAS Assasun Najaah is a complex problem caused by a lack of understanding, minimal education programs, inadequate facilities and infrastructure, bad habits of throwing away garbage, and low involvement of parents and the community. This condition causes the school environment to become dirty and unhealthy, and has an impact on the formation of the character of students who are less concerned about the environment.

Analysis of the availability of learning facilities and infrastructure in schools as one of the important reviews to design a product that can help overcome the problem of low environmental

literacy skills of students. The limitations of facilities and infrastructure from the results of the field review can be seen from the lack of relevant textbooks, adequate teaching aids and limited internet access. Therefore, PBL-based biology e-modules are present as an innovative solution.

Initial and final analyses were conducted to identify fundamental problems in biology learning that require the development of digital teaching materials. Learning success depends heavily on teachers' design in developing systematic materials that enable students to learn independently (Irmita & Atun, 2018; Lin & Wu, 2016). Therefore, innovation in electronic teaching materials is an essential solution to achieving learning targets (Sutarto et al., 2021).

Design

The preparation of the e-module framework serves as a vital reference for developing a digital learning module, acting as a systematic guide for developers to organize material, activities and evaluation. With a well-defined structure, the creation process becomes more focused, resulting in higher-quality educational outputs. This framework typically encompasses a comprehensive display design, partitioned into the opening section, the core content, and the closing section. Furthermore, the material identification process involves aligning content with specific competencies and indicators, establishing learning objectives, mapping material logically, and determining both the depth of information and the appropriate learning resources.

To ensure the effectiveness of the e-module, several design principles must be considered: (a) maintaining consistency in colors, font, and visual elements throughout the module, (b) avoid displays that are too busy, (c) utilizing an attractive layout, (d) ensuring the design matches the pedagogical material, (e) incorporating interactive elements, such as animations or video, to enhance engagement and, (f) ensuring accessibility to all users.

The technical execution of these principles is facilitated through the creation of e-module flowcharts and storyboards. A flowchart is utilized to determine the sequential progression of materials and to visualize user interactions such as button clicks and menu selections. Meanwhile, a storyboard provides a detailed series of sketches or images that depict the visual appearance and functional flow of each screen. Ultimately, the design of the e-module, which encompasses essential navigation guides, competency indicators, and integrated PBL symbols, is deliberately structured to satisfy the professional standards of digital learning materials. Such a multifaceted design is imperative to guarantee that the e-module is both practically usable and educationally sound for students in a contemporary learning environment (Kautsari et al., 2022; Musa'ad & Suparman, 2023).

Development

The development stage is the stage where the previously created design is transformed into a final product in the form of an e-module. The process of creating an e-module is carried out according to the needs of the students. In this case, the creation of a learning e-module uses the PBL model, which aims to improve students' environmental literacy skills in ecosystem material. The first part of the e-module is the opening section. The opening section consists of a front cover (cover), followed by a foreword, core competencies, basic competencies, competency achievement indicators (IPK), learning objectives, table of contents, list of images, module usage instructions, module characteristics, and concept maps. The following are some of the opening sections that are displayed.

Subject Matter Expert Validation

The next stage of validation by material and media experts is important in developing the e-module. The validation process by material experts was carried out by two material experts. The following are the results of the validation assessment from 2 material experts. The material analysis was reviewed from four aspects: content feasibility, language, presentation, independent learning, and PBL. The outcome of the validation process for e-module-based PBL is presented in Table 5.

The significance of validation scores from stage 1 to stage 2 indicates that this e-module has met quality standards and is highly suitable for use in learning. With a primary focus on environmental literacy, this e-module is designed to empower ecosystem awareness through the integration of real-world problems according to PBL syntax (Rosidi et al., 2023). As an efficient teaching tool, this medium has been proven to improve student learning achievement and understanding of environmental change (Cabrero, 2025; Kadir et al., 2024b). This confirms the findings of Diana et al., (2015) and Daud et al., (2025) That combination of the PBL model with an engaging e-module is an effective approach to

improving learning outcomes holistically, while also serving as a comprehensive self-study guide for students (Nurhidayati et al., 2022)

Table 5.
Results of validation by the material expert, stages 1 and 2

Assessment Aspect	Average values		Average	Information
	Stage I	Stage II		
Content feasibility	63.5	75.0	69.3	Feasible
Language	75.0	83.3	79.2	Feasible
Presentation	63.5	76.0	69.8	Feasible
Independent learning	37.5	62.5	50.0	Fairly Feasible
PBL	54.2	75.0	64.6	Feasible
Average	58.7	74.4	66.6	Feasible

Media Expert Validation

The expert judgment process or media expert validation was carried out by two media experts. The material analysis was reviewed from five aspects: screen design appearance, ease of use, consistency, usability, and graphics. The result of media expert validation for e-module-based PBL is presented in Table 6.

Table 6
Results of Media Expert validation stage 1 and 2

Assessment Aspect	Average values		Average	Information
	Stage I	Stage II		
Screen design appearance	83.9	85.7	84.8	Highly Feasible
Ease of use	79.2	83.3	81.3	Highly Feasible
Consistency	87.5	83.3	85.4	Highly Feasible
Usability	81.3	81.3	81.3	Highly Feasible
Graphics	82.1	85.7	83.9	Highly Feasible
Average	82.8	83.9	83.3	Highly Feasible

The results of the media expert validation in Table 5 show an increase in the average score to 83,3 (Highly Feasible category) after the second stage of revision, which confirms that this problem-based learning (PBL)-based e-module is valid. The advantages of this module lie in its interactive design and comprehensive structure from introduction to evaluation, which support student independence and active involvement in solving real-life problems, in line with the flipped classroom concept (Daud et al., 2022; Firdaus & Pahlevi, 2022; Sari et al., 2019). Supported by various previous studies, the use of the flipbook format and the integration of PBL stages have been proven to improve students' conceptual understanding, creativity, and problem-solving skills, more engaging and practical than conventional media (Kusumasari et al., 2022; Meldrawati et al., 2021; Setiawan & Rahayu, 2024). The specific recommendations and constructive feedback provided by the media experts regarding the development of the e-module are synthesized in Table 7.

Table 7.
Media expert validation revision suggestion

Suggestion/input for Improvement	Improvement Result
Add a "search" function for content searching	Has displayed search or the appearance of buttons and links in
Fix the video that doesn't appear and looks dark	It has been fixed by bringing the image in front of it

Based on the suggestions and feedback from validators regarding the media in the e-module, as presented in Table 6, several crucial improvements were made, such as adding a search function and optimizing the video splash screen to ensure it no longer appears dark. These user-friendly design enhancements are reflected in the careful selection of font types, sizes, colors, and the clarity of icons and menus, all of which were tailored to meet user needs. The strategic use of typography aims to clearly

distinguish between titles, subtitles, and body text, aligning with Prayoga et al. (2024) those who state that appropriate font variation assists readers in navigating pages more easily. Furthermore, text readability was enhanced by ensuring a high contrast between the font and the background, a step reinforced by Febriana et al. (2024) those who argue that effective color combinations significantly influence student comfort and interest in reading. Ultimately, the e-module was made more engaging by integrating visual aesthetics with child psychology, consistent with the view Astuti et al. (2023) that the right choice of colors can psychologically stimulate and leave a lasting impression on the reader, thereby increasing overall engagement

Product characteristic

This PBL-based e-module has several key characteristics that distinguish it from conventional learning resources and other modules. First, this e-module adopts a PBL approach, where material is presented through contextual problems related to ecosystems that stimulate critical thinking and solution-finding. This encourages students to play an active role in constructing their own knowledge, rather than simply passively receiving information. This aligns with the research findings of Diana et al. (2015), who stated that the combination of the PBL model and engaging e-modules is an effective approach to holistically improving student learning outcomes. Furthermore, Nurhidayati et al. (2022) stated that the development of PBL-based learning e-modules aims to provide learning guidelines for students in teaching and learning activities.

Second, the primary focus of this e-module is on improving students' environmental literacy. The material is designed to help students gain a deep understanding of ecosystem concepts, including their impact on human life and the importance of preserving the environment. Thus, students are expected to have a better understanding of environmental issues and be motivated to contribute to maintaining ecosystem sustainability. This aligns with research findings conducted by Rosidi et al. (2023) that PBL learning emphasizes real-world problems in the surrounding environment, so that each PBL stage in the e-module can empower students' environmental attitudes. PBL-based e-modules are also efficient teaching tools that can improve student achievement and understanding of environmental change (Kadir et al., 2024a; Lubis et al., 2024).

Third, this e-module presents an interactive and engaging design. The engaging visuals, complemented by images, quizzes, and puzzles, aim to increase student motivation and make learning more enjoyable. This way, students are not simply focused on the text but actively engaged in the learning process. In line with research by Daud et al. (2022), this PBL-based e-module is specifically designed to improve students' understanding and skills in online learning. Its attractive appearance and interactive features make learning more enjoyable and effective. Furthermore, Firdaus & Pahlevi (2022) state that PBL-based e-modules are more practical, and the use of flipbooks makes them more creative and innovative.

Fourth, this e-module has a complete structure, consisting of an introduction, content, and conclusion. The introduction presents important information, such as core competencies, basic competencies, learning objectives, and instructions for using the module. The content section presents ecosystem material in detail and comprehensively, supplemented with contextual examples. The conclusion contains a summary of the material and practice questions to test students' understanding. This is in line with Sari et al (2019), who stated that PBL e-modules have a complete structure, including an introduction (competencies, objectives, instructions), content (detailed ecosystem material and examples), and a conclusion (summary, practice questions), thus providing a more comprehensive discussion. The complete structure demonstrated in this PBL-based e-module can improve students' problem-solving skills, encourage active learning, and deepen their understanding of the material's concepts through the experience of facing and solving real-life problems (Ayubi et al., 2025; Martin et al., 2025; Setiawan & Rahayu, 2024).

Fifth, this e-module is integrated with an assessment system. Student worksheets (LKPD) are provided to measure student understanding after studying the material. Furthermore, quizzes and puzzles serve as formative evaluation tools, helping students and teachers monitor learning progress. This aligns with the findings of Kusumasari et al., (2022), who showed that the implementation of PBL-based e-modules involves an assessment and evaluation process, as the learning process supports a flipped classroom, incorporating assignments and discussions that adhere to the PBL stages. Furthermore, the development of this e-module has undergone validation by material and media experts to ensure its quality and suitability as a learning resource. The validation results indicate that

this e-module is suitable for use with several revisions for further improvement. Consistent with the opinion expressed by Meldrawati et al. (2021), expert validation of PBL-based e-modules is crucial to ensure alignment with learning objectives, accuracy of material content, fulfillment of teaching material needs, and improvement of student insight, ensuring the module remains relevant, accurate, and effective in facilitating meaningful learning.

CONCLUSION

The result of the study shows that the development of biology e-module based Problem-based learning is classified as Highly Feasible and can be used in learning. The result of validation by material expert showed that the developed e-module met the five established assessment criteria. Likewise, from the point of view of a media expert, the five assessment indicators have been met, and even achieved a score of > 80.

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