



Developing a project-oriented problem-based learning (PoPBL) e-module on coastal and marine biodiversity in east Nusa Tenggara to support critical and creative thinking skills

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Abstract

Background: Biology learning materials often provide limited opportunities for students to address authentic environmental problems and develop critical and creative thinking skills. Integrating Project-Oriented Problem-Based Learning (PoPBL) with local coastal and marine biodiversity offers a contextual approach to addressing these challenges.

Aims: This study aimed to develop and evaluate the validity, feasibility, and preliminary learning outcomes of a PoPBL-based e-module integrating coastal and marine biodiversity in East Nusa Tenggara.

Methods: This research employed a research and development (R&D) approach using the ADDIE model. Two subject-matter experts and two media experts assessed the e-module's validity, while teachers and students evaluated its feasibility through questionnaires. Changes in critical and creative thinking were examined descriptively using pretest and posttest scores from two Grade 10 classes.

Results: The e-module achieved a validity score of 96.35%, indicating high validity. Teacher and student feasibility ratings reached 92.08% and 89.42%, respectively. The PoPBL group demonstrated gains of 28.60 points in critical thinking and 29.90 points in creative thinking, compared with 15.40 and 14.60 points in the discussion-based learning group.

Conclusion: The developed PoPBL-based e-module demonstrated high validity and feasibility. Greater descriptive improvements in critical and creative thinking suggest its potential as a contextual biology learning resource, although causal effectiveness cannot be established from the available evidence.

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INTRODUCTION

Biology education is expected to move beyond the reproduction of scientific terms toward students' ability to assess evidence, examine alternatives, and formulate defensible explanations. Critical thinking and creative thinking are related but distinct outcomes: the former concerns reasoned judgment and evaluation, whereas the latter concerns the generation and elaboration of possible responses. Research on problem- and project-based learning links authentic problems with opportunities to exercise these forms of reasoning, although their development depends on how tasks and assessments are designed (Loyens et al., 2023; Anggraeni et al., 2023; Yu & Zin, 2023). Comparative scholarship also cautions against treating every student-centered approach as pedagogically interchangeable (Goodwin, 2024). In secondary science education, the challenge is to

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make disciplinary content sufficiently rigorous while giving students meaningful responsibility for inquiry and project decisions (Markula & Aksela, 2022; Magaji et al., 2024).

The instructional context of this study revealed a concrete need for such a shift. The needs analysis conducted at SMAN 1 Kupang indicated that teachers generally relied on printed textbooks, worksheets, presentation slides, and publicly accessible videos. Although these materials could communicate biological information, the observed learning activities offered limited structured opportunities for independent investigation or the production of alternative solutions. Teachers also described student dependence on direct guidance, and the analysis characterized motivation for independent inquiry as relatively low. Related studies have drawn attention to the value of problem-centered instruction for critical-thinking development and to the importance of task design, classroom support, and reflection (Durnali, 2022; Santos-Meneses et al., 2023; Dias-Oliveira et al., 2024; Witarsa & Muhammad, 2023). These observations informed the decision to develop a contextualized rather than merely digitized learning resource.

Coastal and marine biodiversity provides a meaningful context for biology lessons in East Nusa Tenggara because ecosystems and their use are directly connected with communities in the region. Marine organisms, ecosystem interdependence, and conservation choices can be considered through biological concepts while also generating questions for evidence gathering and problem solving. International ocean-literacy research emphasizes that educational resources should represent local environments accurately and help learners connect ecological knowledge with environmental decisions (Freitas et al., 2024; Kevrekidis et al., 2024; McRuer et al., 2024). Curriculum comparisons further reveal that ocean-related concepts are unevenly integrated into formal science instruction (Lu et al., 2025), while Indonesian coastal-education research identifies a need for more contextual learning approaches (Istiana et al., 2021; Hunaepi et al., 2019; Irwansyah et al., 2026; Rahmat et al., 2026). For the present product, the local environment therefore functions as the source of instructional problems rather than as decorative material.

A digital module can bring scientific descriptions, photographs, videos, prompts, and student worksheets into a coherent learning sequence. Yet the presence of multimedia alone does not establish that students are engaged in higher-order thinking. Studies of digital science learning suggest that the value of a platform depends on the forms of representation, guidance, feedback, and interaction it supports (Cirkony et al., 2022; Wang et al., 2023; Hadianito & Festiyed, 2020). Research in biology has also examined e-modules oriented toward analytical skills, curiosity, or critical thinking (Jayanti & Pertiwi, 2023; Khasanah & Indah, 2024; Arifin et al., 2024; Sriyati et al., 2026), while broader accounts relate digital learning resources to self-directed activity (Dhani, 2021; Sanova et al., 2022; Wulandari et al., 2025). Accordingly, the proposed e-module was organized around learning tasks and student-generated project work, with technology used to deliver those tasks consistently.

Project-Oriented Problem-Based Learning (PoPBL) connects the analysis of a problem with the planning, execution, and evaluation of a project. Chang et al. (2022) examined interdisciplinary PoPBL as a context for creativity, whereas Suwistika et al. (2024) considered critical- and creative-thinking outcomes among secondary students. Research on project-based learning more broadly highlights authentic student work and the importance of making project components explicit (Markula & Aksela, 2022; Chang et al., 2024; Mota et al., 2025). Creative problem-based instruction has also been associated with higher-order thinking in science learning (Affandy et al., 2024; Ji & Wong, 2025), and meta-analytic evidence suggests that creativity-related outcomes can vary with the problem-solving pedagogy used (Zhan et al., 2024; Zhang et al., 2024; Zhang et al., 2022). These findings support PoPBL as a reasonable design choice but do not show that every PoPBL module will produce comparable learning effects.

Earlier work provides relevant foundations while leaving a design question specific to this setting. A study of test development in PoPBL addressed how critical and creative thinking may be assessed (Muhajir et al., 2019), and an Indonesian needs analysis identified requirements for PoPBL biology e-modules (N. F. Usman et al., 2024). Other research has examined general PBL outcomes (Suradika et al., 2023; A. Usman et al., 2024), digital materials (Millah et al., 2025), and learning achievement under PoPBL (Sari, 2023). However, these strands do not by themselves explain how a single e-module can align the sequence of a project-oriented problem, coastal biodiversity content, the intended thinking indicators, and classroom usability in Kupang. Recent work on ocean education

and scientific creativity reinforces the need for alignment between local context, instructional resources, and assessable student work (Haim et al., 2024; Thorkelsdóttir et al., 2026; Coe et al., 2026). The principal gap addressed here is therefore the development and preliminary assessment of this particular combination, not a claim that digital or project-based biology learning has never been studied.

The study aimed to develop a PoPBL e-module using coastal and marine biodiversity in East Nusa Tenggara and to examine its expert validity, perceived classroom feasibility, and reported pretest–posttest score patterns for critical and creative thinking. The design used the ADDIE development sequence to connect identified needs to instructional objectives, e-module construction, revision, classroom use, and evaluation. Critical thinking was operationalized with indicators drawn from Ennis, and creative thinking with indicators drawn from Guilford, as specified in the research design. The intended contribution is a documented example of aligning regional biodiversity content with a project-oriented problem sequence and related thinking indicators. The analysis distinguishes expert judgments and user perceptions from measured student-score changes, thereby keeping the claims proportionate to the available results.

METHOD

Research Design and Setting

This research used a research and development (R&D) approach organized by the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. The primary purpose was to develop and obtain preliminary evidence about a contextualized biology e-module, rather than to establish a definitive intervention effect. The needs-analysis and product-response activities were associated with SMAN 1 Kupang, East Nusa Tenggara, Indonesia. The learning-outcome evaluation involved two Grade 10 classes at SMAN 3 Kupang. The available report identifies the instructional conditions as discussion-based learning and learning with the PoPBL e-module; it does not specify a random allocation procedure. Accordingly, the two-condition results are treated as descriptive comparisons.

Participants and Study Stages

The development stage included two subject-matter experts and two media experts who reviewed the e-module. The study description identified four biology teachers and ten students at SMAN 1 Kupang as participants in product-response activities. The implementation-stage results separately summarized responses from four biology teachers and 60 students. Because these figures originate from separately described activities, they are presented by study stage rather than merged into a single student sample. The evaluation stage involved two Grade 10 classes at SMAN 3 Kupang, representing the discussion and PoPBL e-module conditions. The reported learning-outcome values are aggregate pretest and posttest scores for these conditions.

Data Collection Instruments and Measurement Scope

The reported instruments comprised interview guidelines, expert-validation sheets, teacher and student response questionnaires, and tests of students' critical and creative thinking. The expert appraisal covered four features of the e-module: content suitability, language, presentation, and visual design. Feasibility responses addressed attractiveness, ease of use, and usefulness. Critical-thinking tasks were organized around the Ennis indicators of elementary clarification, basic support, inference, advanced clarification, and strategies and tactics. Creative-thinking tasks were based on Guilford's fluency, flexibility, originality, and elaboration indicators. Expert validation in this study concerned the e-module as a learning product; the reported percentages are not interpreted as reliability or construct-validity coefficients for the student tests.

Development and Evaluation Procedure

The Analysis stage examined curriculum requirements, teacher and student needs, available instructional media, and relevant biology content. Design translated those needs into learning objectives, coastal and marine biodiversity materials, PoPBL-aligned worksheets, and critical- and creative-thinking activities. During Development, the authors assembled the e-module from written explanations, visual materials, multimedia resources, and interactive components; subject-matter and media experts then reviewed the prototype, and the authors revised it in response to their recommendations. Implementation involved teacher and student questionnaires on attractiveness,

ease of use, and usefulness. Evaluation used pretest and posttest scores to describe changes in critical and creative thinking under the two instructional conditions. Figure 1 summarizes the sequence of activities described in the study. The sequence of development and evaluation activities is summarized in the following flowchart.

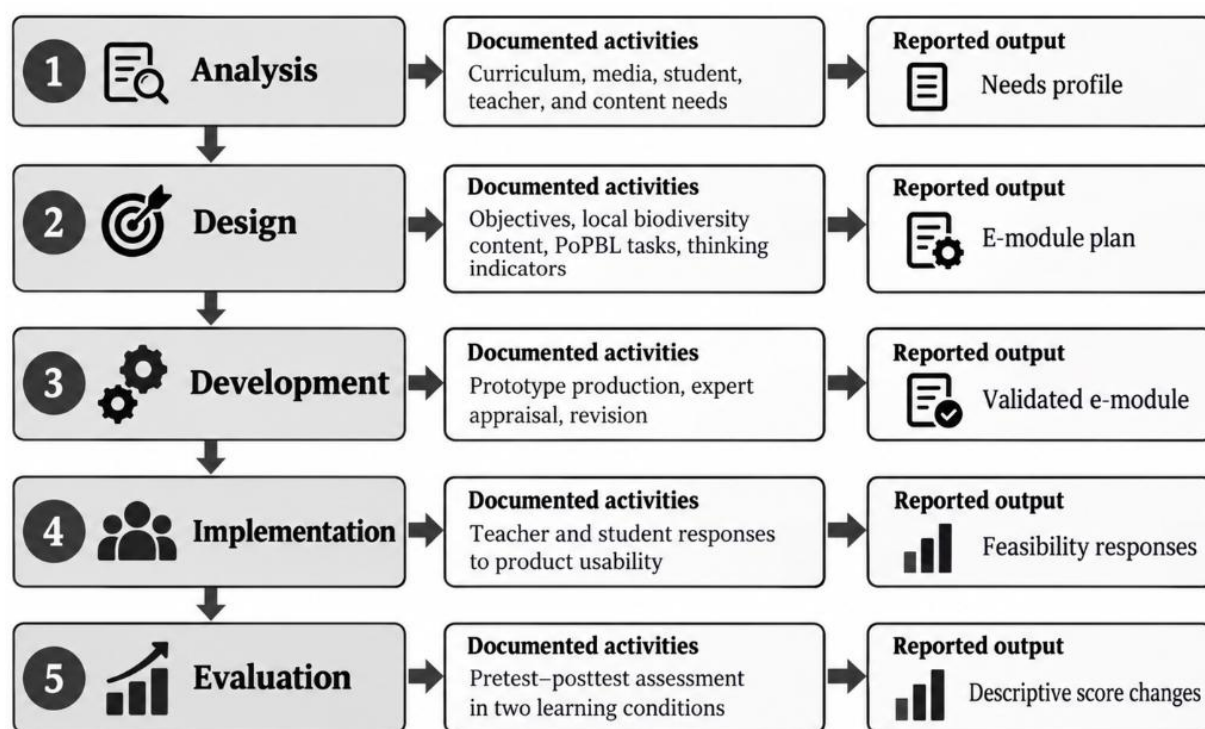


Figure 1. ADDIE-Based Development and Evaluation Process

The process links information from the school setting to content selection, product construction, feedback-based revisions, and descriptive outcome assessment. The arrows indicate the order reported for this development study.

Data Analysis

Expert appraisal and classroom-feasibility questionnaires were reported as percentages and classified using the study's five-level rating categories. The four expert-appraisal aspect percentages were summarized by their arithmetic mean; the stated mean was 96.35%. The teacher and student overall feasibility percentages were likewise the means of the three reported aspects. For student outcomes, the raw gain was defined as posttest score minus pretest score, expressed in score points. Only group-level descriptive pretest, posttest, and gain values were available for the instructional comparison; no inferential effect estimate is presented. Table 1 reproduces the expert-validation categories used in the development report. Table 1 displays the category thresholds applied to percentages obtained from the expert-validation sheets.

Table 1. Reported Categories for Expert Validation

No.	Validation category	Percentage
1	Invalid	0–20%
2	Less valid	21–40%
3	Moderately valid	41–60%
4	Valid	61–80%
5	Highly valid	81–100%

The highest classification corresponds to 81–100%. The classroom-feasibility instrument used the analogous labels not feasible, less feasible, moderately feasible, feasible, and highly feasible across the same percentage intervals. These labels describe judgments under the study's rating scheme, not independent evidence of measured learning effects.

RESULTS AND DISCUSSION

Analysis and Design Outputs

The needs analysis showed that biology instruction at SMAN 1 Kupang relied mainly on textbooks, printed worksheets, PowerPoint presentations, and publicly accessible videos. The reported student-learning characteristics included dependence on teacher guidance and limited independent engagement with inquiry and project tasks. Based on these findings, the module content was organized around coastal and marine biodiversity as a familiar setting in which students could analyze environmental problems and propose responses. The worksheets reflected four PoPBL stages: problem orientation; organization for learning; project design and implementation; and presentation and evaluation of project outcomes (Rongbutstri, 2017). Examples of the resulting module content, including explanations and locally contextualized material, are shown in Figure 2.



Figure 2. Illustrative Pages from the PoPBL-Based E-Module

The pages illustrate the use of biological descriptions, environmental images, and supporting digital materials within a single learning resource. They are examples of the developed product rather than independent evidence of learning effectiveness. Figure 3 shows selected student worksheet pages through which the module presented problem prompts and spaces for task responses.

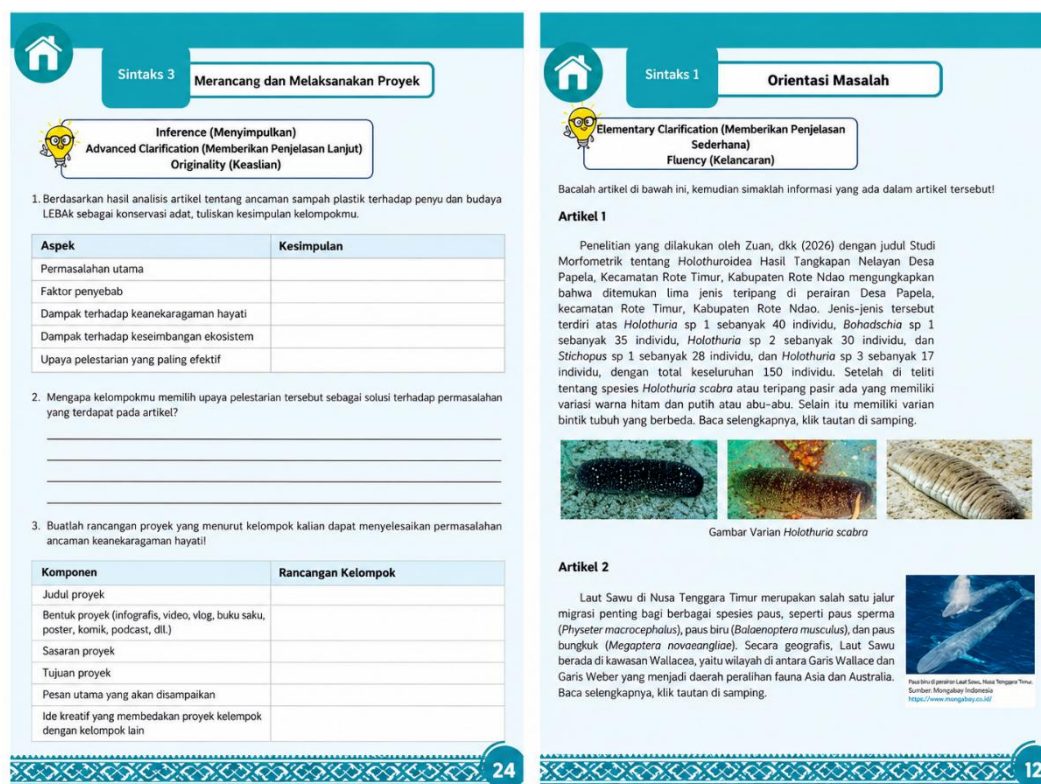


Figure 3. Student Worksheets Aligned with the PoPBL Stages

The worksheets position students as respondents to contextual problems and project tasks. Their structure provides a plausible route for practicing reasoning and idea generation, although the screenshots alone do not establish that the skills improved.

Expert Validation and Revisions

The prototype was examined by two content experts and two media experts. Their ratings covered content suitability, language, presentation, and visual design. Table 2 reproduces the aspect scores and reported validation percentages.

Table 2. Expert Validation of the PoPBL E-Module

Aspect	V1	V2	V3	V4	Total	Validity (%)	Category
Content suitability	50	50	51	50	201	99.01	Highly valid
Language	20	20	18	18	76	91.56	Highly valid
Presentation	49	50	52	52	203	98.54	Highly valid
Visual design	38	38	40	40	156	96.29	Highly valid
Reported mean					636	96.35	Highly valid

All four reported aspect percentages were within the highest classification range, and their arithmetic mean was 96.35%. Language received the lowest reported percentage (91.56%), whereas content suitability received the highest (99.01%). These figures describe expert ratings of e-module attributes; they should not be interpreted as evidence of the psychometric quality of the learning tests. Because the assessment is presented at the aspect level, Table 2 retains the original totals and percentages rather than reconstructing item-level or rater-level calculations.

Experts also recommended targeted improvements to instructions, digital resources, visual consistency, and worksheet text. The changes documented during the development stage are summarized in Table 3.

Table 3. Expert Feedback and Documented E-Module Revisions

Component	Before revision	Revision reported
E-module instructions	Instructions were incomplete	Instructions were clarified and expanded
Content links	Some YouTube links were inaccessible	Links were made accessible
Typography	Font sizes were inconsistent	Font sizes were standardized
Student worksheets	Several typographical errors were present	Words and sentences were clarified

The revisions addressed access, clarity, and consistency rather than replacing the original PoPBL instructional framework. They show how expert judgments were used to improve the prototype before classroom feedback was collected.

Implementation-Stage Feasibility

The implementation-stage results include questionnaire responses from four biology teachers and 60 students. The questionnaire summarized perceptions of attractiveness, ease of use, and usefulness. Table 4 reports the percentages given for each aspect.

Table 4. Teacher and Student Responses to E-Module Feasibility

Aspect	Teachers (%)	Students (%)	Teacher category	Student category
Attractiveness	92.75	87.25	Highly feasible	Highly feasible
Ease of use	90.75	89.25	Highly feasible	Highly feasible
Usefulness	92.75	91.75	Highly feasible	Highly feasible
Mean	92.08	89.42	Highly feasible	Highly feasible

The mean percentages for teachers and students were 92.08% and 89.42%, respectively, and both were classified as highly feasible. Of the three student ratings, attractiveness was lowest (87.25%) and usefulness was highest (91.75%); teachers rated attractiveness and usefulness equally at 92.75%. These findings indicate favorable judgments about usability and classroom relevance within the assessed setting. They do not measure the extent to which individual module features were used or establish changes in thinking skills.

Descriptive Critical- and Creative-Thinking Outcomes

The evaluation described pretest and posttest changes for discussion-based learning and learning with the PoPBL e-module. Both critical- and creative-thinking outcomes were reported for each instructional condition. Figure 4 reproduces the study's graphic presentation of pretest scores, posttest scores, and raw gains.

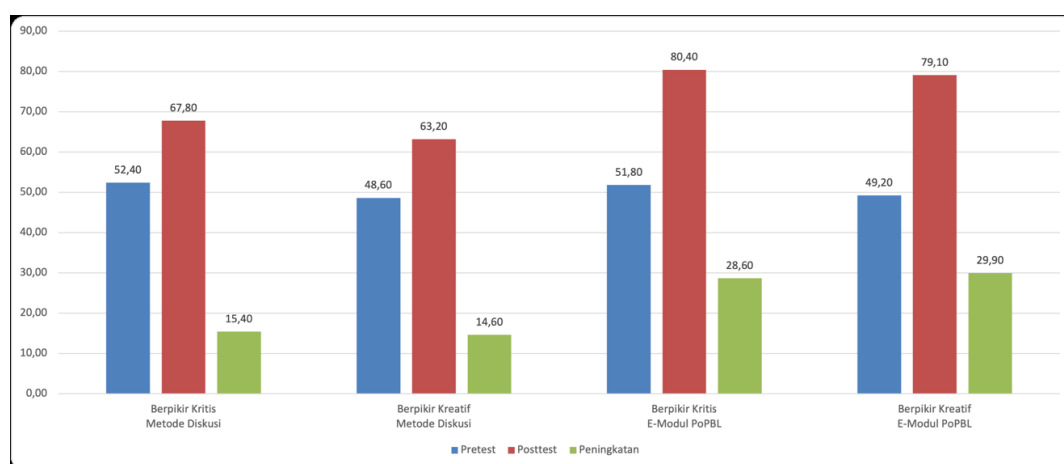


Figure 4. Reported Pretest, Posttest, and Gain Scores by Instructional Condition

Both instructional conditions had higher posttest than pretest scores in the chart, while the PoPBL condition had larger raw gains in both outcomes. The numerical scores underlying these descriptive comparisons are provided in Table 5. Table 5 restates the four pretest–posttest comparisons shown in Figure 4. The gain column is calculated by subtracting each pretest score from its corresponding posttest score; it is not a normalized gain or an inferential estimate.

Table 5. Descriptive Changes in Critical and Creative Thinking Scores

Learning condition	Skill	Pretest	Posttest	Gain
Discussion	Critical thinking	52.40	67.80	15.40
Discussion	Creative thinking	48.60	63.20	14.60
PoPBL e-module	Critical thinking	51.80	80.40	28.60
PoPBL e-module	Creative thinking	49.20	79.10	29.90

The raw gain in critical-thinking scores was 28.60 points in the PoPBL e-module condition and 15.40 points in the discussion condition. For creative thinking, the corresponding gains were 29.90 and 14.60 points. The pretest means were similar but not identical across the instructional conditions.

The group summaries establish a descriptive pattern of larger observed changes under PoPBL; they do not reveal the spread of individual scores or provide a basis for a statistical significance claim.

Discussion

The first substantive outcome is a biology e-module that treats coastal and marine biodiversity in East Nusa Tenggara as the basis for student problems and projects. This responds directly to the initial observation that biology learning depended heavily on textbooks, printed worksheets, presentation slides, and online videos. In the module materials, students were asked to examine coastal environmental threats and connect their reasoning to biodiversity consequences and possible conservation responses. Such activities differ from merely inserting regional photographs into a conventional lesson because students must use the context to organize and justify a response. [Markula and Aksela \(2022\)](#) similarly identify authentic problems and purposeful student activity as features of project-based science learning. Ocean-literacy research also emphasizes the educational importance of connecting scientific understanding to learners' relationships with marine environments ([Freitas et al., 2024](#); [McRuer et al., 2024](#); [McKinley et al., 2026](#)). The present finding supports the feasibility of designing this context into an e-module; the study did not separately assess students' ocean literacy or environmental behavior.

The second contribution lies in the explicit instructional sequence of the PoPBL worksheets. Students were directed to interpret a contextual problem, organize their investigation, propose and implement project work, and communicate and evaluate what they produced. In the worksheets shown, activities included identifying the problem and its causes, considering biodiversity impacts, and preparing a group project plan. These are opportunities for inference, selecting strategies, generating alternatives, and elaborating responses, which correspond to the stated thinking indicators. Findings from [Chang et al. \(2022\)](#) support the educational potential of project-oriented problem solving, while [Goodwin \(2024\)](#) stresses that different student-centered approaches should not be treated as equivalent. Digital-learning research further suggests that representation and interaction are important components of the learning task ([Cirkony et al., 2022](#); [Wang et al., 2023](#)). The present data document the task design, but not the fidelity of students' project implementation or the quality of their completed products.

Expert appraisal provided the first form of evidence about the product's instructional suitability. The reported aspect scores ranged from 91.56% for language to 99.01% for content suitability, with an overall mean of 96.35%. The expert recommendations were specific: complete the instructions, restore inaccessible video links, standardize typography, and clarify wording in the student worksheets. These revisions matter because unclear instructions or inaccessible resources could impede students' progress through a structured problem and project sequence even when the biological content is appropriate. Previous research on project-oriented instruction likewise emphasizes the quality of scaffolding and teacher support ([Magaji et al., 2024](#); [Lavado-Anguera et al., 2024](#); [Anwar et al., 2026](#)). The appraisal therefore supports the reported quality of the revised e-module under the applied criteria. It does not independently establish the validity or reliability of the critical- and creative-thinking tests.

Teacher and student questionnaires provided a second source of evidence by capturing perceptions of attractiveness, ease of use, and usefulness. Both mean scores were in the highest category, although the students' mean of 89.42% was below the teachers' 92.08%. Students also gave a lower rating to attractiveness than to usefulness, which suggests that the resource's instructional value and its immediate visual appeal need not be experienced in the same way. The questionnaire results do not establish why those differences arose, and the study does not quantify engagement during specific PoPBL stages. Work on authentic projects and digital environments suggests that students' engagement depends on both instructional structure and the activities learners actually undertake ([Chang et al., 2024](#); [Wang et al., 2024](#); [Huang et al., 2026](#)). For this study, the appropriate conclusion is that respondents perceived the e-module favorably, rather than that favorable perceptions necessarily produced better reasoning.

Pretest–posttest scores added an outcome-oriented perspective, but the evidence remains descriptive. Critical-thinking gains were 28.60 points in the PoPBL condition and 15.40 points in the discussion condition; creative-thinking gains were 29.90 and 14.60 points, respectively. The larger changes under PoPBL are compatible with literature linking carefully structured problem solving

and project work to reasoning and creative responses (Affandy et al., 2024; Anggraeni et al., 2023; Yu & Zin, 2023). Related studies have examined explicitly designed creativity tasks and project-oriented activities (Fleissner-Martin et al., 2025; Haim et al., 2024; Li & Tu, 2024; Ji & Wong, 2025; Pawar et al., 2026). Nevertheless, the present report does not document the group sample sizes, individual-score variability, class assignment, or inferential analysis needed to establish a reliable comparative effect. The numerical differences must therefore be interpreted as observed learning-score patterns, not evidence that the e-module alone caused the change.

Critical and creative thinking must be interpreted as distinct assessment targets. The critical-thinking indicators adapted from Ennis focus on clarification, evidential support, inference, advanced clarification, and strategic judgment. The Guilford-based creative-thinking indicators focus on fluency, flexibility, originality, and elaboration. The e-module attempts to address both through activities that require students to justify responses and consider alternative projects or solutions. This design alignment is conceptually consistent with work examining higher-order thinking in problem- and project-based environments (Loyens et al., 2023; Suwistika et al., 2024; Zhan et al., 2024). However, the results aggregate performance within each skill; they do not separate outcomes by indicator or show which particular worksheet activity was associated with score changes. The findings consequently support an integrated instructional design more directly than they support claims about which cognitive processes improved most.

The study contributes to the practice of contextualizing science learning through nearby biodiversity problems, while its broader theoretical contribution is limited. An e-module may make local cases available for repeated analysis and project planning, but successful implementation still depends on how teachers organize classroom activities and respond to student work. Research on coastal conservation education and ocean literacy similarly indicates that marine content requires deliberate integration into instructional materials and curricula (Kevrekidis et al., 2024; Lu et al., 2025; Thorkelsdóttir et al., 2026; Coe et al., 2026). The developed product provides one example of how PoPBL stages and thinking indicators can be mapped onto a regional biological topic. The evidence establishes a favorable preliminary appraisal and descriptively promising score patterns within the participating schools, not general effectiveness across different locations or student populations. The paper is therefore best positioned as a documented development and preliminary classroom evaluation rather than an effectiveness trial.

Study Limitations

Three constraints define the interpretation of this development study. First, the available participant account reports different student totals for product-response activities and implementation-stage questionnaires, while the numbers of students in the two evaluation classes are not specified; for that reason, the stages are described separately and no combined sample size is inferred. Second, the reported expert percentages appraise the e-module as a product, whereas psychometric properties of the critical- and creative-thinking tests are not documented in the results. Third, outcome evidence consists of group-level pretest, posttest, and raw-gain summaries without a reported inferential comparison, allocation method, or measure of score variability. These constraints limit interpretation of effectiveness and generalizability, but do not negate the documented product-development process or the favorable initial assessments.

CONCLUSION

This study developed a PoPBL-based e-module that links coastal and marine biodiversity in East Nusa Tenggara with structured problem analysis, project planning, and critical- and creative-thinking activities. Its reported mean expert-appraisal score was 96.35%, and the teacher and student feasibility means were 92.08% and 89.42%, respectively. Both instructional conditions showed increases in pretest–posttest scores, with larger raw gains in the condition using the PoPBL e-module. These results support the product’s preliminary suitability and favorable reception in the participating school context. They do not establish a statistically tested or causal superiority of PoPBL over discussion-based learning. The main practical contribution is a contextualized digital instructional resource aligned with explicit problem and project tasks; stronger effectiveness claims require more complete evaluation evidence.

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AUTHOR CONTRIBUTIONS STATEMENTS

ARD contributed to conceptualization, methodology, and manuscript preparation. RAD contributed to data collection, investigation, and data curation. MJS contributed to formal analysis and interpretation of results. N contributed to the literature review and data validation. IRL contributed to methodology and visualization. YM contributed to drafting and critical revision. DAB contributed to supervision, project administration, and final manuscript review.

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