JSER

Journal of Science Education Research
Journal homepage: https://journal.uny.ac.id/index.php/jser/index

ISSN: 2597-9701

Development of PBL E-Module on the Role of Nyale Worms in Coral Reef Ecosystems to Increase Learning Interest and Critical Thinking among High School Students

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Abstract

This study aims to develop a Problem-Based Learning (PBL) e-module with a flipped classroom approach that is valid, Applicable, and effective in enhancing the learning interest and critical thinking skills of Phase E students on the ecosystem topic, particularly the role of nyale worms in coral reef ecosystems. Using the ADDIE development model, the study was conducted at MAN 2 Mataram with 63 students selected through cluster random sampling, where class X-11 served as the experimental group and class X-9 as the control group. The research instruments included expert validation questionnaires, Applicable assessments, critical thinking tests, and learning interest questionnaires. The results indicated that the developed e-module: (1) is valid according to media and content experts, (2) highly Applicable based on evaluations by teachers and students, and (3) effective in increasing learning interest and critical thinking skills, as evidenced by MANOVA analysis. Integrated into the PBL model, the e-module combines local potential with a flipped classroom strategy, offering students an engaging, interactive, contextual, and meaningful learning experience. Based on the research findings, the flipped classroom PBL e-module on the role of nyale worms in coral reef ecosystems is concluded to be feasible, highly Applicable, and effective in enhancing both learning interest and critical thinking skills among Phase E students in ecosystem learning.

History
Received: November 25, 2025
Revised: Januari 8, 2026
Accepted: February 6, 2026

Keywords:
E-Module; Problem-Based Learning; Flipped Classroom; Role of Nyale Worms in Coral Reef Ecosystems; Learning Interest; Critical Thinking Skills

How to cite:
Nuradiah, M. F., Aloysisus, S., Raphasya, F. H., Mutiara, E., Izzurrahmah, N., & Alfiansyah, M. F. (2026). Development of PBL e-module on the role of Nyale worms in coral reef ecosystems to increase learning interest and critical thinking among high school students. *Journal of Science Education Research*, 10(1), 1–14. https://doi.org/10.21831/jser.v10i1.91837.

1. INTRODUCTION

Education is the main foundation in shaping the quality of human resources and the progress of a nation. In the 21st century, education is required to equip students with various essential skills, including critical thinking skills as one of the main competencies (Darling-Hammond et al., 2020). However, Indonesian students' critical thinking skills are still relatively low. This is reflected in the results of the 2022 Programme for International Student Assessment (PISA), which shows a decline in science, mathematics, and reading literacy scores compared to 2018 (Liani et al., 2024; Milliniawati & Isnaeni, 2023). In science literacy, for example, only 42.25% of students were able to explain simple concepts, and only 36% of students were able to solve complex problems.

The problem of low critical thinking skills among Indonesian students is reflected in PISA results, which show that many students struggle to analyze phenomena, evaluate arguments, and solve contextual science

problems, as classroom learning remains predominantly one-way and content-focused, offering limited opportunities for higher-order thinking Anggraeni et al. (2023). This problem shows that school learning has not effectively developed students' critical thinking skills. Abilities such as analyzing, evaluating, and reflecting are key components assessed in PISA, particularly in scientific literacy. PISA measures not only content mastery but also how well students apply knowledge to real situations, understand phenomena, evaluate arguments, and interpret scientific data (Katoningsih & Sunaryo, 2020). Indonesia's low PISA scores, where many students struggle to explain basic concepts or solve science problems, indicate weak critical thinking skills. Interviews with 10th-grade teachers at MAN 2 Mataram also show that students' critical thinking skills are low, partly because they are not accustomed to learning activities that train these skills. This issue is intensified by students' low interest in learning. Current learning media—mainly one-way tools like PowerPoint and YouTube videos—fail to encourage active engagement (Ilmia et al., 2022). In fact, learning interest is crucial because it affects motivation and participation, which are essential for developing critical thinking skills (Lipikuni et al., 2023). Advances in information and communication technology have shifted learning toward a portable, student-centered, multi-platform approach (Idris et al., 2017). E-modules have become an innovative teaching resource, and even in face-to-face settings they remain essential as education must adapt to technological progress and societal needs (Mounsey & Reid, 2019). Unlike printed modules, ICT-based e-modules can be accessed online or offline via laptops or mobile devices.

To address existing learning challenges, an innovative and relevant approach is needed. PBL-based e-modules offer a Appropriate solution, allowing students to learn independently, flexibly, and interactively, supported by multimedia that enhances interest and understanding (Putrianata & Chairunisa, 2019). The PBL approach effectively develops critical thinking through collaborative, real-world problem solving. Combined with the flipped classroom—where content is studied via e-modules and videos at home, and class time is used for discussion and problem solving—this strategy enables greater teacher guidance and stronger two-way interaction. Innovation in teaching materials is strengthened by integrating local potential, such as the theme of the role of nyale worms in coral reef ecosystems. Nyale worms (Annelida: Polychaeta) are unique biota that appear only at certain times on the southern coast of Lombok. Their biological uniqueness and ecological role make them highly relevant for teaching ecosystem, food chain, and adaptation concepts. Using such local phenomena makes learning more contextual, helps students connect theory with real-life situations, and fosters environmental and cultural awareness (Wilujeng et al., 2019). The novelty of this study lies in the systematic integration of Problem-Based Learning (PBL), the flipped classroom model, and the development of an e-module based on local biodiversity (nyale worms) into a comprehensive learning design that was experimentally tested using multivariate analysis (MANOVA) to simultaneously measure cognitive (critical thinking skills) and affective (interest in learning) aspects. Unlike previous studies that generally tested PBL, flipped classrooms, or e-modules separately, this study combined all three in a single learning intervention and explicitly linked improvements in critical thinking skills to FRISCO indicators (Focus, Reason, Inference, Situation, Clarity, Overview). In addition, the use of the local ecological context of nyale worms as a learning resource contributes to the strengthening of place-based education in biology education. Thus, this study offers innovation not only at the level of the learning model, but also at the level of context, analytical approach, and theoretical mapping of critical thinking construction. Based on these issues and potentials, this study developed a PBL e-module with a flipped classroom mode on the topic of nyale worms' role in coral reef ecosystems, aiming to improve students' learning interest and critical thinking skills. This innovation addresses low learning quality while providing contextual, relevant, and adaptive education suited to the digital era and local potential.

2. LITERATURE REVIEW

2.1. Electronic Module (e-module)

An electronic module (e-module) is a module distributed in electronic media that performs functions similar to those of physical modules. E-modules are used as teaching materials that include learning materials, methods, and evaluation tools, designed to attract students' interest in learning (Syahrial, 2020; Wibowo, 2018; Istuningsih, Baedhowi, & Sangka, 2018). Naturally, e-learning modules have instructions tailored to a pace that covers only one literacy material, allowing learners to concentrate solely on the material being taught (Asrial, 2019). Based on these opinions, it can be concluded that e-modules are electronic teaching materials with functions similar to physical modules, designed to attract students' interest in learning by presenting practical learning materials, methods, and evaluations. Their advantage lies in their ability to provide instructions tailored to individual learning speeds, allowing learners to focus on one piece of literacy material at a time, thereby increasing concentration and learning effectiveness.

Sugihartini & Jayanta (2017) explain that the advantage of e-modules in the learning process lies in the problem-based learning stages, namely student orientation based on problems, organizing students to learn, guiding individual and group investigations, developing and presenting work results, and analyzing and

evaluating the problem-solving process. Advances in information and communication technology can be utilized to strengthen and maintain children's thinking, emotional, and interpersonal skills (Kraleva & Kralev, 2018). Learning with e-modules is an example of technological developments that can improve the quality of education. Given the advantages of e-modules, it is hoped that they will further improve the quality of Biology learning. Based on this opinion, it can be concluded that e-modules offer advantages in the learning process, focusing on problem-solving, with stages that include problem orientation, organized learning, individual and group investigations, work development, and analysis and evaluation of problem-solving. The use of information and communication technology in e-module learning can strengthen students' thinking, emotional, and interpersonal skills, thereby improving the quality of learning, especially in Biology.

2.2. Problem Based Learning (PBL)

The problem-based learning (PBL) model is a student-centered learning model in which the educator serves only as a facilitator and guide for students (Wena, 2013). Problem-based learning is a type of learning approach in which real-life problems are used to help students build their thinking and problem-solving skills. This description also states that this learning model can provide students with opportunities to critically examine contextual problems related to scientific concepts to develop solutions (Ariyani et al. 2018). Based on these opinions, the Problem-Based Learning (PBL) model centers on students, with educators serving as facilitators who guide students and use real-world problems to develop their critical thinking and problem-solving skills. This approach allows students to analyze contextual problems related to scientific concepts and produce relevant solutions. Integrated learning that utilizes the potential of local schools and offers different ways to make education more interesting. One of the main reasons educators incorporate local potential into their learning is its ability to help students understand ideas and illustrations in a tangible way. In addition, it serves to hone students' understanding, abilities, and perspectives while also helping build closer relationships with local resources in their communities (Lase et al., 2016; Rahardini et al., 2017).

Achieving optimal performance does not rely solely on intelligence but is also supported by students' intrinsic interest in learning (Christidou, 2011; Nesi & Akobiarek, 2018). If an interest in learning does not arise, students will lose motivation to engage in learning activities. Learning that is interesting and makes students active has a positive impact on student interest (Wahjudi, 2015). Learning that integrates local potential is also useful in building concepts by involving aspects of students' daily lives. Learning is contextual, as it is based on real-life applications that utilize the surrounding environment and local potential of the communities from which students come. Thus, learning that integrates local potential can increase students' interest and motivation by connecting learning materials to their real lives, thereby deepening their understanding and fostering closer relationships with local resources. This contextual learning not only introduces students to regional potential and local traditions but also fosters a greater sense of environmental responsibility, shaping them into knowledgeable individuals with strong moral principles.

2.3. Flipped Classroom Mode

The flipped classroom is an instructional approach that reverses the traditional learning sequence by delivering instructional content outside the classroom—typically through videos or digital materials—while using in-class time for active learning activities such as discussion, problem-solving, and collaboration. This approach aligns strongly with constructivist learning theory and student-centered pedagogy. Research on flipped classroom implementation indicates several pedagogical advantages. The flipped classroom provides students with greater control over their learning pace and allows classroom interactions to focus on higher-order cognitive processes. Mohan emphasizes that flipped learning promotes learner autonomy and supports deeper engagement with learning content, particularly in post-secondary and secondary education contexts (Mohan, 2018). Furthermore, Lo and Hew highlight that flipped classrooms can enhance students' learning outcomes and engagement when supported by well-structured instructional design and adequate technological infrastructure (Lo, 2017). Despite its potential benefits, the flipped classroom also presents challenges, including students' readiness for self-directed learning, access to technology, and the need for carefully designed learning materials. These challenges suggest that flipped classroom implementation should be supported by structured learning resources such as e-modules and guided learning activities to ensure pedagogical effectiveness.

2.4. Learning Interest and Critical Thinking

Interest is important in psychology because it drives people to pursue what they want. People who are attracted to something tend to be more focused and feel happiness from it. Conversely, if something does not evoke positive emotions, interest in it will not arise. As a result, the level of focus or happiness that a person experiences towards something is shaped by their level of interest. Learning interest can influence students' learning outcomes, which, in addition to originating from students themselves, can also be shaped by the

teacher's approach to creating interesting learning (Suriyanti, 2021; Yunitasari & Hanifah, 2020). According to experts, student interest in learning is an important factor that can foster enjoyment, engagement, and involvement in the learning process, which, in turn, affects their learning outcomes. This interest does not come solely from students, but can also be influenced by the teacher's approach to creating interesting and motivating learning experiences. Critical thinking skills are important for students (Bunt & Gouws, 2020). Critical thinking skills involve the ability to assess and examine information used to form well-supported judgments (Agustine et al., 2020). Therefore, it can be concluded that critical thinking is an important skill that involves a complex process of assessing, questioning, and investigating information to draw accurate conclusions. This skill not only helps students find answers but also encourages them to build their own knowledge, develop life skills, and prepare them to solve everyday problems, as well as to recognize problems, formulate logical reasons, and solve them appropriately.

3. RESEARCH METHOD

This R&D study produced a PBL e-module with a flipped classroom mode on the topic of the role of nyale worms in coral reef ecosystems, using the systematic and dynamic ADDIE (analysis, design, development, implementation, evaluation) development model (Rusmayana, 2021), which is considered more effective and simpler than other models. The analysis stage identified students' limited critical thinking skills, minimal use of electronic media, and reduced instructional time, leading to the development of a Problem-Based Learning (PBL)-based e-module with a flipped classroom mode on the topic of the role of nyale worms in the coral reef ecosystem, aligned with Grade X (Phase E) Independent Curriculum learning outcomes. Integrating local potential supports more concrete understanding and strengthens students' connection to their environment (Lase et al., 2016; Rahardini et al., 2017; Shufa & Khusna, 2018). The design stage involved structuring materials and learning activities according to PBL syntax and flipped classroom principles. During development, the product was validated by experts and revised based on feedback, followed by limited trials to assess Applicable. The implementation stage consisted of field testing in experimental classes with observation of learning processes and student engagement. Evaluation was conducted at each stage to determine feasibility, Applicable, and effectiveness in improving students' learning interest and critical thinking skills, resulting in a final product ready for dissemination.

The research was conducted at MAN 2 Mataram, Jl. Pendidikan No.25, Dasan Agung Baru, Mataram City, West Nusa Tenggara. The initial stage involved observations and interviews with teachers regarding the curriculum, student characteristics, facilities, media, and local potential. MAN 2 Mataram was selected because it implements the Merdeka Curriculum, has internet access and allows gadget use, has technologically competent teachers, diverse student abilities, and lacks interactive learning media based on local potential for ecosystem topics. The e-module development procedure is shown in Figure 1. Furthermore, the trial design used in this study is divided into two types, namely limited trials and field trials. Limited trials were conducted in class XI (Phase F) and assessments by teachers were carried out to measure the Applicable of the product. Field trials were selected from two classes using cluster random sampling. The experimental class was conducted in class X-11, while the control class was conducted in class X-9. The field test design using a non-equivalent pretest-posttest control group design can be seen in Table 1 below.

Table 1. Pretest-Posttest Control Group Design

Class	Pretest and Questionnaire	Treatment	Posttest and Questionnaire
Experiment	O_1	X_1	O_2
Control	O_1	X_2	O_2

Source: (Sugiyono, 2018)

Description:

X_1 : Learning using e-modules with the flipped classroom model
X_2 : Learning using printed modules with the non-flipped classroom model
O_1 : Pre-test of critical thinking skills and learning interest questionnaire before learning
O_2 : Post-test of critical thinking skills and learning interest questionnaire after learning

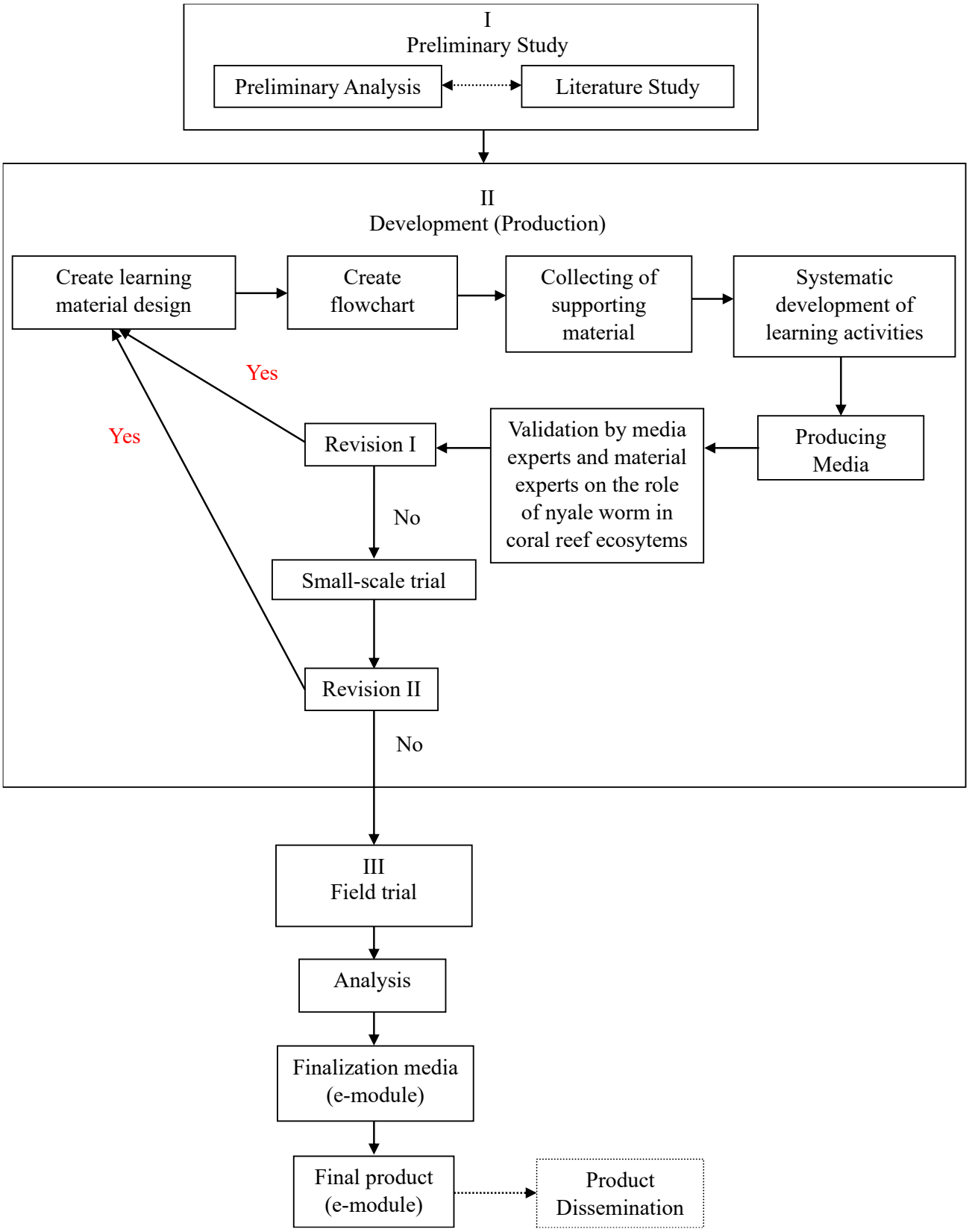

Figure 1. E-Module Development Procedure Flowchart

Data were collected using test and non-test techniques. The test instrument consisted of essay questions to measure students' critical thinking skills, while non-test instruments included Likert-scale questionnaires to assess the e-module and students' learning interest. The questionnaires were validated by media and subject matter experts (face validity). Empirical validity of the critical thinking test items was analyzed using Product Moment correlation with SPSS 25. If the Sig. (2-tailed) value > 0.05, H_0 was accepted and the item was declared invalid; if Sig. (2-tailed) < 0.05, H_0 was rejected and the item was declared valid. Reliability testing was also conducted using SPSS 25 for Windows with the Cronbach's Alpha method (range 0–1); items were considered reliable if $\alpha > 0.60$.

Data analysis employed qualitative and quantitative approaches. Qualitative analysis was conducted by tabulating and analyzing feedback from experts, teachers, and students to determine the feasibility and Applicable of the e-module using closed questionnaires. Quantitative analysis involved descriptive statistics and inferential analysis using MANOVA to examine the effectiveness of the e-module in improving students' learning interest and critical thinking skills. A more detailed description of the data analysis techniques is presented in Table 2 below.

Table 2. Research Data Analysis Techniques

Analysis	Highlighted Data	Validator/Subject	Technique
Qualitative	Assessment of the feasibility and Applicable of e-modules (suggestions and input)	Media experts, matter experts, teachers, and students	Tabulation of all inputs and analysis
Quantitative	Data scores from questionnaires assessing the feasibility and Applicable of e-modules, as well as questionnaires on learning interest		Tabulation of data, averaging, and conversion
	Test instruments (pre-post test questions)	Students	Descriptive statistical analysis
			Inferential statistical analysis: • Prerequisite test • Hypothesis testing: MANOVA test

Based on Table 2, data analysis in this study was conducted comprehensively by combining qualitative and quantitative approaches. The qualitative approach was used to evaluate the feasibility and Applicable of the e-module based on input from experts, teachers, and students, while the quantitative approach was used to test the effectiveness of the e-module on students' learning interestand critical thinking skills through descriptive and inferential statistical analysis. The combination of these two approaches aimed to obtain more accurate, objective, and comprehensive research results. The variables of this study are learning interestand critical thinking. Table 3 presents a grid of critical thinking questions, as well as a grid of observation sheets of students' learning interests in table 4.

Table 3. Critical Thinking Question Grid

Critical Thinking Indicators (FRISCO)	Question Indicators	Question Number
Focus: Analyze and identify key issues.	- Analyze predictions of nyale emergence and whether spawning will be single or split. - Analyze readings and identify issues arising.	1 & 5
Reason: Provide supporting reasons related to the main issue.	- Link the relationship between the full moon phase and the appearance of nyale, as well as the habitat and the existence of nyale worms. - Link the relationship between this issue (no. 5) and the interests of the community and the government.	2 & 6
Inference: Making conclusions based on reasons to support the conclusions made.	- Concluding what factors affect the survival of nyale worms. - Concluding things about the conditions/situations that occur based on the reading.	4 & 7
Situation: Revealing important factors that need to be considered in making conclusions/decisions.	Analyzing the impact of environmental changes that could threaten the sustainability of the population and the role of nyale worms in the coral reef ecosystem.	3
Overview: Check and double-check ehighlything from start to finish (as generated in FRIS).	Based on the answers to the previous questions, students can recommend steps/efforts that can be taken to ensure the sustainability of the population and the role of nyale worms in the coral reef ecosystem, as well as which parties need to	8

	be involved in efforts to preserve the population and role of nyale worms in the coral reef ecosystem.

(Sources: Jamaluddin et al. 2023; Jasman et al. 2025; Ratu et al. 2025)

Table 4. Learning Interest Indicator Grid

Learning Interest Indicator	Indicator Description
Enjoyment of learning	Students' enjoyment, happiness, and enthusiasm in participating in the learning process.
Interest in subject matter	Students' interest in the content of the lesson or topic being studied.
Active involvement in the learning process	Students' enthusiasm in asking questions, discussing, answering, and participating in learning tasks/activities.
Attention and concentration while learning	Students demonstrate focus and are not easily distracted during the learning process.

(Sources: Fitriantini, D., & Winata, M. 2021; Lilis K. G. 2025; Ananda Putri, et al. 2023)

4. RESULT AND DISCUSSION

4.1 Produk Trial and Final Results

The presentation of the results was systematically arranged according to the ADDIE model development stages, providing a comprehensive overview of the feasibility, Applicable, and effectiveness of the product in increasing students' learning interest and critical thinking skills. Table 5 below shows the results of the e-module assessment by media experts, subject matter experts, and practitioners.

Table 5. Results of E-Module PBL Assessment in the Flipped Classroom Mode

Benchmark	Assessment Aspects	Score (%)	Category	Suggestions & Feedback
Media Expert	Design	91	Highly Appropriate	Make the layout more attractive, include video sources, separate the experimental and control teaching modules, and include PBL syntax in the student worksheet.
	Appearance	88	Highly Appropriate	
	Operational	85	Highly Appropriate	
Subject Matter Expert	Display	79	Appropriate	Adding scientific explanations about the taxonomy and ecology of nyale worms.
	Content	80	Appropriate	
	Material	83	Highly Appropriate	
Biology Teacher	Materials/Content	94	Highly Applicable	Corrected several typos, replaced the material on food webs with images, used easy-to-understand language, and avoided wordy sentences.
	Topics	83	Applicable	
	Media	100	Highly Applicable	
	Learning	96	Highly Applicable	
Students (small scale trial)	Display	88	Highly Applicable	Adjust the spacing and paragraphs so they are not too close together, and use language that is easy to understand.
	Language	88	Highly Applicable	
	Content	89	Highly Applicable	
	Material	94	Highly Applicable	

Based on Table 5, it is stated that the results of the feasibility and Applicable assessment of the e-module show that media experts gave an average score of 88% (highly feasible category) with suggestions for improvement in appearance, inclusion of video sources, separation of teaching modules, and addition of PBL syntax in LKPD. Subject matter experts gave an average score of 80.7% (feasible category) with input to add scientific explanations about the taxonomy and ecology of nyale worms. Biology teachers' assessment of Applicable obtained an average of 93% (highly Applicable category) with suggestions for improvement in language, images, and writing. Meanwhile, student assessments in limited trials showed an average of 89.75% (highly Applicable category) with suggestions to adjust spacing and use easy-to-understand language. Overall, the e-module was deemed feasible, highly Applicable, and ready for implementation with some refinements.

Critical thinking ability instruments were also tested for empirical validity and reliability. Validity is a measure that indicates the level of validity or validity of an instrument (Sukmadinata, 2017). Item validity testing was carried out by correlating the data results into Product Moment correlations using SPSS 25. If the sig value (2-tailed) > 0.05, then H0 is accepted, meaning that the item is declared invalid. If the sig value (2-

tailed) < 0.05, then H0 is rejected, meaning that the item is declared valid. The results of the item validity test showed that all items were valid (sig. < 0.05).

A research instrument is considered reliable if it can provide relatively the same results when re-measured on different objects at different times, or in other words, it can provide consistent results (Payadnya & Jayantika, 2018). According to Ghozali (2018), a question is considered reliable if the Cronbach's Alpha value is > 0.6. The item reliability test with Cronbach's Alpha produced a value of 0.867 (highly high category), indicating strong internal consistency. Thus, this instrument is Appropriate for accurately measuring students' critical thinking skills. Student learning interest data was analyzed from learning interest data before and after learning from a learning interest questionnaire containing 27 statements. This questionnaire was given to students in the experimental and control classes. The questionnaire was administered before and after learning. A descriptive statistical analysis of the learning interest results in both classes can be seen in Table 6 below.

Table 6. Descriptive Statistics Results for Learning Interest

Class	N	Average Score		N-Gain Score
		Pre-Test	Post-Test	
Experiment	31	43,0	74,8	0,6
Control	32	42,8	64,5	0,4

Table 6 shows a comparison of student learning interest results in the experimental class and the control class. The average learning interest of both classes was not much different. The average learning interest before learning in the experimental class was 43 and in the control class was 42.8. These two values indicate that learning interest before the learning process in both classes was similar. Furthermore, the average learning interest after learning in the experimental class was 74.8 and in the control class was 64.5. The N-Gain results for learning interest in the experimental class and control class were both moderate, but when viewed more specifically, the N-Gain Score for the experimental class was higher than that for the control class (0,6 > 0,4). This N-Gain value supports the statement that the use of e-modules in the flipped classroom mode has an effect on increasing students' interest in learning. Data on students' critical thinking skills were analyzed from the pretest and posttest scores of 8 questions in both the experimental and control classes. A descriptive statistical analysis of the critical thinking skills test results in both classes can be seen in Table 7 below

Table 7. Descriptive Statistics Results for Critical Thinking Skills

Class	N	Average Score		N-Gain Score
		Pre-Test	Post-Test	
Experiment	31	28,8	75,5	0,7
Control	32	24,8	55,7	0,4

Table 7 shows a comparison of the scores of the two experimental classes on the critical thinking test with the scores of the control group. The pretest averages of the two classes were not significantly different. The average for the experimental class was 28.8 and for the control class was 24.8. The difference in the pretest average scores between the experimental and control classes was only 4. This means that the students' critical thinking skills at the beginning of the meeting were the same. The increase in students' critical thinking skills after learning in the experimental class was higher than in the control class. The difference between the pretest and posttest scores in the experimental class was 46.7 and in the control class was 30.9. The N-Gain Score results in the experimental and control classes were both in the moderate category, but when viewed more specifically, the N-Gain Score in the experimental class was higher than the N-Gain Score in the control class (0,7 > 0,4). Thus, it can be concluded that learning about the role of nyale worms in the coral reef ecosystem using the flipped classroom e-module was able to improve students' critical thinking skills.

This study aims to examine the effectiveness of the PBL e-module in a flipped classroom mode on students' critical thinking skills and learning interest. In a large-scale trial, the experimental class used the flipped classroom PBL e-module, while the control class used a printed non-flipped classroom module. Critical thinking skills were measured through pre-tests and post-tests, while learning interest was measured using questionnaires before and after learning. The data were then analyzed using the MANOVA test to see the effect of the learning treatment on both variables. Before conducting the MANOVA test, several prerequisite tests had to be fulfilled, namely the multivariate normality test, the linearity test, the homogeneity of variance–covariance matrices test, and the multicollinearity test. The multivariate normality test was assessed using the Mahalanobis Distance and Chi-Square (qi) values in SPSS, which produced a result of 0.984, a value close to 1, indicating that the data on learning interest and critical thinking skills in both the experimental and control classes were simultaneously normally distributed. The linearity test showed a significance value for Deviation from Linearity of 0.980, which is greater than 0.05, confirming that there is a linear relationship between the independent and dependent

variables. The homogeneity assumption was tested using Box's M test, yielding a significance value of 0.175 (> 0.05), which indicates that the variance–covariance matrices of the experimental and control groups were equal. Furthermore, the multicollinearity test showed a tolerance value of 0.831 (> 0.10) and a VIF value of 1.203 (< 10.00), demonstrating that there was no multicollinearity among the variables. The MANOVA test table can be seen in Table 8 below.

Table 8. MANOVA Test Results

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.995	6121.167[b]	2.000	60.000	.000
	Wilks' Lambda	.005	6121.167[b]	2.000	60.000	.000
	Hotelling's Trace	204.039	6121.167[b]	2.000	60.000	.000
	Roy's Largest Root	204.039	6121.167[b]	2.000	60.000	.000
Kelas	Pillai's Trace	.685	65.102[b]	2.000	60.000	.000
	Wilks' Lambda	.315	65.102[b]	2.000	60.000	.000
	Hotelling's Trace	2.170	65.102[b]	2.000	60.000	.000
	Roy's Largest Root	2.170	65.102[b]	2.000	60.000	.000

a. *Design*: Intercept + Kelas

b. Exact statistic

The decision criteria in the MANOVA test use an alpha value of 0.05, meaning that if the sig. value is < 0.05, then Ha is accepted. The sig. values in both classes show sig. < 0.05, so it can be concluded that there is a simultaneous difference in critical thinking skills and learning interest between the experimental class that uses the flipped classroom e-module and the control class that uses the non-flipped classroom printed module. The next stage of the MANOVA test is to look at the results of the Test of Between-Subjects Effects to determine the extent to which the use of the flipped classroom e-module affects the research variables, namely the learning interest and critical thinking skills of phase E students, which can be seen in Table 9 below.

Table 8. Results of the Test of Between-Subjects Effects

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Critical Thinking	6150.717[a]	1	6150.717	79.279	.000
	Learning Interest	1562.563[b]	1	1562.563	38.868	.000
Intercept	Critical Thinking	270791.860	1	270791.860	3490.358	.000
	Learning Interest	306802.690	1	306802.690	7631.614	.000
Kelas	Critical Thinking	6150.717	1	6150.717	79.279	.000
	Learning Interest	1562.563	1	1562.563	38.868	.000

a. R Squared = .565 (Adjusted R Squared = .558)

b. R Squared = .389 (Adjusted R Squared = .379)

The test results in Table 9 show sig. values for critical thinking skills and learning interest of 0.000 < 0.05, so H0 is rejected and Ha is accepted. This means that there is a significant difference in critical thinking skills and learning interest between students in the experimental class who used the PBL e-module in a flipped classroom mode and students in the control class who used a printed module in a non-flipped classroom mode on the material of the role of nyale worms in coral reef ecosystems.

4.2 Discussion

The product developed in this study is an e-module in the Problem-Based Learning (PBL) model on ecosystem material, specifically the role of nyale worms in coral reef ecosystems, using the flipped classroom mode. The e-module was developed in the form of a website called "NWJ: Nyale Worm Journey" https://nwjmodule.com/index.php, which can be accessed by registering using a smartphone or laptop connected to the internet. The idea for development arose from the problem of low critical thinking skills and learning interestamong students due to monotonous learning media. This e-module highlights the local potential of nyale worms on the island of Lombok to link biological theory with real phenomena, so that learning becomes meaningful, fosters awareness of cultural and environmental preservation, and trains critical thinking skills. The

content is essential, interesting, relevant, contextual, and continuous, covering Phase E ecosystem material such as the definition and components of ecosystems, energy flow, interactions between organisms, ecological roles, ecosystem balance and disturbances, as well as specific material on the role of nyale worms, including their characteristics (morphology and spawning), the Mandalika Beach coral reef ecosystem (biotic and abiotic components, energy flow, ecological roles), and threat factors and conservation efforts. Key features include a discussion forum for interaction outside of school hours and live worksheet-based exercises with immediate feedback. The flipped classroom model provides theoretical knowledge, problem orientation through videos, and reinforcement of understanding outside the classroom prior to learning. The PBL syntax is applied starting from problem orientation, student organization, investigation guidance, development and presentation of discussion results, to analysis and evaluation of problem solving, which includes individual and group activities. This innovation is in line with the Merdeka Curriculum, which emphasizes PBL, and is supported by the findings of Arifah et al (2021) that PBL is effective in increasing learning interest and critical thinking skills. It is hoped that this e-module will have a similar impact on students.

The findings of this study indicate that the integration of a Problem-Based Learning (PBL) e-module within a flipped classroom model significantly improves students' critical thinking skills and learning interest. The larger effect size observed in critical thinking compared to learning interest suggests that the intervention was particularly effective in promoting higher-order cognitive processes. This result confirms that structured problem exposure, contextual exploration, and guided reflection collectively stimulate deeper analytical engagement. The improvement in critical thinking can be theoretically interpreted using FRISCO framework (Focus, Reason, Inference, Situation, Clarity, Overview). The increase in the average critical thinking score in the experimental class (46.7) was higher than that in the control class (30.9). The answers given by students in the experimental class were closer to the correct answers, especially for questions 1, 3, 4, 5, and 8. This indicates that the experimental class showed a significant improvement in critical thinking indicators, especially in terms of focus, drawing conclusions, and identifying important factors in drawing conclusions. The problem scenarios embedded in the nyale worm ecological context required students to identify core issues (Focus), justify arguments logically (Reason), and draw evidence-based conclusions (Inference). The inclusion of real ecological phenomena strengthened students' ability to consider environmental variables and contextual factors (Situation). Meanwhile, structured discussions and presentations enhanced clarity in articulating arguments (Clarity), and reflective activities within the flipped classroom component supported metacognitive evaluation of reasoning processes (Overview). Thus, the instructional design did not merely improve test scores but systematically engaged all dimensions of critical thinking. This was achieved through a combination of PBL e-modules and the flipped classroom model.

The findings of this study reinforce the results of Erwanto (2020) study, which states that Problem-Based Learning (PBL) can significantly improve students' critical thinking skills because learning is centered on authentic problem solving that requires students to identify problems, analyze information, construct evidence-based arguments, and draw logical conclusions. In Erwanto's study, the improvement in critical thinking occurred mainly because students were actively involved in the investigation and discussion process, so that they were no longer passive recipients of information. The results of this study not only confirm these findings but also expand upon them through the integration of PBL with a flipped classroom based on contextual e-modules on nyale worms. While Erwanto's study focused on the application of PBL in conventional learning, this study adds a stage of independent learning prior to face-to-face sessions, which allows students to be better cognitively prepared when entering the discussion and problem-solving stages. Judging from the FRISCO indicators (Focus, Reason, Inference, Situation, Clarity, Overview), the PBL stages as described by Erwanto mainly contribute to the aspects of Focus, Reason, and Inference, while the integration of the flipped classroom in this study also strengthens the aspects of Clarity and Overview through presentation, reflection, and evaluation of thinking activities. Thus, this study not only supports Erwanto's (2020) findings but also contributes something new by strengthening all critical thinking indicators more comprehensively in the context of biology learning based on local phenomena.

Learning interest can influence student learning outcomes, which, in addition to originating from the students themselves, can also be shaped through the teacher's approach in creating engaging learning experiences (Idamayanti et al., 2022; Suriyanti, 2021; Yunitasari & Hanifah, 2020). Therefore, it is important for educational institutions to not only consider individual factors but also create a supportive learning environment, taking into account external aspects that influence learning interest. Indicators of learning interest include enjoyment of learning, interest in subject matter, active involvement in the learning process, and attention and concentration while learning (Aswan, 2022; Fitria et al. 2024; Fauza, Effendi, & Lony, 2023).
The increase in students' learning interest was influenced by the attractiveness of interactive e-module content, which presented problem orientation videos, quizzes, and contextual topics about the role of nyale worms in the coral reef ecosystem on Lombok Island. The average learning interest score for students in the experimental

class was 74.8, while that for the control class was 64.5. Based on these results, there was an increase in student learning interest in both classes. However, the increase in learning interest in the experimental class was higher than that in the control class. In terms of learning interest, during the field trial, students were highly enthusiastic about operating the e-module. Each student focused on learning and watching the videos contained in the e-module. Students also asked many questions when learning about the role of nyale worms in coral reef ecosystems, and participated actively in discussions while working on the worksheets. Local potential makes it easier for students to relate the material to real life, generating a sense of enjoyment and interest in biology, in line with Ilmia et al. (2022), who state that monotonous learning hinders understanding, while engaging media increases motivation, and Lipikuni et al. (2023), who found that interactive online media increases enthusiasm.

The results of this study indicate that the use of PBL and e-module-based flipped classrooms can increase students' interest in learning. These findings are in line with the research by Umam et al. (2019) and Cevikbas and Argün (2017), which states that flipped classrooms make students more active and interested because they learn independently before class discussions. Similarly, both previous studies and this study show an increase in learning interestthrough student-centered learning. The difference is that this study not only uses the flipped classroom, but also combines it with PBL and contextual material about nyale worms in the form of a digital e-module. This makes students interested not only because of the learning method, but also because the material studied is close to their environment. Thus, this study contributes by combining active learning models and local contexts to increase learning interest in a more meaningful way. Learning interestis positively correlated with critical thinking skills (Khairunnisa et al., 2021), where highly interested students are more active in discussions and analytical thinking activities. Thus, the PBL flipped classroom e-module effectively integrates increased learning interest and critical thinking, while also serving as an alternative medium for teachers to present interesting features and content for higher-quality biology learning and the achievement of learning objectives.

5. RESEARCH LIMITATIONS

First, the study was conducted on a limited sample, only in one school (MAN 2 Mataram), so the results cannot necessarily be generalized to a wider population. Second, the measurement of learning interest used a self-report questionnaire that depended on the subjective perceptions of students. Third, the learning arrangement requires students to be prepared for independent learning, effective time management, and consistency from teachers in implementing each stage of PBL and the flipped classroom. Differences in the level of student independence and time constraints in class can affect the optimization of the discussion and reflection process, thereby potentially affecting the research results.

6. CONCLUSION

Based on the findings of research on the development of a flipped classroom PBL e-module on the role of nyale worms in coral reef ecosystems, which aims to optimize critical thinking skills and learning interest among phase E students, it can be concluded that the PBL e-module on the role of nyale worms in coral reef ecosystems is feasible and Applicable for use in teaching phase E students about ecosystems. and is effective in increasing the learning interest and critical thinking skills of phase E students on ecosystem material, especially material on the role of nyale worms in coral reef ecosystems.

7. SUGGESTIONS FOR FUTURE RESEARCH

Future studies should involve larger and more diverse samples to improve generalizability. Longer implementation periods are also recommended to examine long-term effects. Further research may include additional variables such as digital literacy, prior knowledge, or learning motivation. Expanding the use of contextual e-modules in different topics and applying mixed-method designs would also provide deeper insights into students' critical thinking and learning interest development.

ACKNOWLEDGMENTS

Appreciation is extended to Universitas Negeri Yogyakarta, particularly the Master's Program in Biology Education, Faculty of Mathematics and Natural Sciences, for academic support. The author also thanks the thesis supervisor for valuable guidance throughout the research process. Sincere thanks are addressed to MAN 2 Mataram, the biology teachers, and the participating students for their contribution to this study. Gratitude is also extended to the validators and all parties who supported this research.

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