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Development of an Interactive E-Module Using a PBL Approach to Static Electricity Materials to Improve Students' Critical Thinking Skills

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Abstract: This research is a type of research and development (R&D) using the 4D model: define, design, develop, and disseminate. The goal of this research and development is to find out the content validity, practitioners' responses, and the effectiveness of using an interactive e-module with a Problem-Based Learning (PBL) approach in physics learning to improve students' critical thinking skills. The content validity of the e-module was evaluated by experts and tested using Aiken's V. Its practicality was evaluated by 10 physics teachers from South Sulawesi. The e-module was tested on 19 students in class XII B at MAN Kabupaten Kepulauan Selayar. The instruments used in this study included a validation sheet for the e-module, a validation sheet for the practitioners' response questionnaire, and a critical thinking test validation sheet. Each instrument was validated by experts. The practitioners' questionnaire and the critical thinking test were also used in the study. The results showed that the PBL-based interactive e-module in physics learning was valid according to the experts, highly practical according to the practitioners' responses, and effective in improving students' critical thinking skills, with an N-gain percentage of 57,71%. Based on the results, the developed e-module is considered valid, practical, and effective in improving students' critical thinking skills.

Keywords: Critical thinking skills; E-modul physics; PBL Approach

Introduction

Entering the third decade of the 21^{st} century, advances in science and technology have brought significant changes to various aspects of life, including education (Wagner, 2010). This transformation requires the education system to no longer focus solely on knowledge transfer but also on developing skills relevant to the needs of the times (Trilling & Fadel, 2009). Modern education is geared toward equipping students with adaptive skills to face complex and dynamic global challenges (Partnership for 21^{st} Century Skills, 2009). In this digital era, the success of such adaptive learning is heavily dependent on students' ability to become self-regulated learners who can manage their own cognitive processes (Zimmerman, 2002). Therefore, school learning needs to be designed to systematically integrate various 21^{st}-century skills into the learning process (Zubaidah, 2016). In the context of science education, (Astari et al., 2025) emphasize that implementing innovative approaches is essential to fostering students' higher-order thinking skills, which are fundamental to navigating modern scientific challenges.

One of the key skills that must be developed is critical thinking, which serves as the foundation for decision-making and problem-solving. Critical thinking falls into the category of Higher Order Thinking Skills (HOTS), which require complex cognitive processes (Anderson et al., 2022). This skill involves the ability to analyze information in depth to understand a problem (Brookhart, 2010). Furthermore, critical thinking skills also include evaluating various available alternative solutions (Facione, 2013). Therefore, developing these

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skills is crucial in 21st-century learning (Paul & Elder, 2000).

Critical thinking can be conceptually understood as a reflective and rational thought process in determining what to believe or do (Fisher, 2008). This ability involves the systematic interpretation of received information (Facione, 2013). Furthermore, critical thinking also includes the ability to draw conclusions based on relevant evidence (Ennis, 1985). This process requires the ability to logically connect various pieces of information (Facione, 2013). Therefore, critical thinking is not only related to understanding concepts, but also the ability to use them in different contexts (Paul & Elder, 2000).

In the context of science learning, particularly physics, critical thinking skills play a crucial role due to the abstract and complex nature of the material (Redish, 2003). Learning physics requires students to be able to relate concepts to everyday phenomena (Hake, 1998). Moreover, there is a strong correlation between a student's mathematical readiness and their ability to achieve conceptual learning gains in physics, emphasizing that critical thinking in this field requires integrated analytical preparation (Meltzer, 2002).

Furthermore, students are also required to be able to analyze the relationships between variables in a physical phenomenon (Docktor & Mestre, 2014). This ability is key to understanding concepts in depth, rather than simply memorizing formulas (Redish, 2003). Therefore, physics instruction needs to be designed to actively encourage students' critical thinking (Arends, 2008).

However, conditions in the field indicate that students' critical thinking skills have not yet developed optimally. One contributing factor is teacher-centered learning, which results in students being less actively involved (Brookhart, 2010). Furthermore, the use of less interactive teaching materials makes it difficult for students to understand concepts in depth (Prastowo, 2019). This impacts students' low ability to analyze and evaluate problems (Munir, 2012). These conditions indicate the need for innovation in the learning process to improve the quality of learning (Arends, 2008). In line with this, Doyan et al. (2020) state that the development of structured physics learning tools using a problem-based approach is essential for strengthening students' mastery of fundamental concepts.

This problem was also found at MAN Kepulauan Selayar, based on initial observations, which showed that students still had difficulty understanding physics concepts comprehensively. Students tended to memorize formulas without understanding the true meaning of the concepts. Furthermore, students also experienced difficulty solving problems requiring high-level reasoning. The lecture-based learning method, which is still dominated by lectures, resulted in students being less active in the learning process (Hijriani & Hatibe, 2021). This resulted in low critical thinking skills. In line with this, Syamsinar et al. (2023) state that critical thinking skills have a significant impact on students' physics learning outcomes, where strong analytical abilities are directly proportional to academic achievement. This situation indicates the need for innovation in learning that can increase active student involvement and optimally develop critical thinking skills.

Learning difficulties are increasingly apparent in static electricity, which has abstract concepts and cannot be directly observed. The concept of Coulomb force requires an understanding of the relationship between charge and distance, which is not easily visualized. Furthermore, the concept of electric fields also requires good representation skills to be understood. Students' inability to understand these concepts leads to misconceptions (Docktor & Mestre, 2014). This condition impacts low critical thinking skills in solving physics problems.

To address these issues, learning innovations are needed that integrate technology into the learning process. One potential solution is the use of interactive e-modules as digital teaching materials. Supporting this, Cynthia et al. (2023) emphasize that the development of interactive physics e-modules is an effective strategy to foster independent learning and significantly enhance students' critical thinking skills. The use of multimedia in learning can help students understand abstract concepts more concretely. Thus, interactive e-modules have the potential to improve the quality of learning (Lastri, 2023).

To be more effective in improving critical thinking skills, interactive e-modules need to be combined with appropriate learning approaches (Arends, 2008). Problem-Based Learning (PBL) is a learning model that can be used to train critical thinking skills (Hmelo-Silver, 2004). This model emphasizes the use of real-world problems as learning contexts (Savery, 2016). Through PBL, students are encouraged to actively seek information and find solutions (Arends, 2008). In line with this, Harjono et al. (2025) emphasize that the use of innovative learning media is crucial in enhancing teachers' ability to effectively implement Problem-Based Learning (PBL) in the classroom.

In this study, an interactive e-module was developed using the Canva platform, which allows for visual and engaging presentation of material. Canva can be used to create systematic and easily understood teaching materials for students (Andriyani et al., 2024). In line with this, (Yersi et al., 2025) emphasize that the development of contextual e-modules in physics learning is highly effective in facilitating students' cognitive processes to achieve higher-level critical thinking skills. Furthermore, this e-module was integrated with an interactive PhET simulation that can visualize abstract concepts in physics (Wieman et al., 2008). The PhET simulation allows students to explore concepts independently (Perkins et al., 2006). Therefore, the integration of Canva and PhET is expected to improve students' conceptual understanding

Previous research has shown that the use of PBL-based e-modules is effective in improving students' critical thinking skills (Rasyid & Wiyatmo, 2024). Supporting this, Wati et al. (2022) state that the development of problem-based learning tools assisted by multimedia is highly effective in improving students' critical thinking skills**.** Furthermore, Fadila et al. (2025) demonstrate that PBL-based e-modules effectively support students in mastering complex physics concepts through a structured and interactive learning flow. However, research integrating Canva and PhET in a single PBL-based e-module is still limited. Furthermore, research in the context of MAN Kepulauan Selayar has not been widely conducted. This suggests an opportunity for further research.

The contribution of this research lies in the development of an interactive e-module based on Problem Based Learning that integrates Canva and PhET simulations to concretely visualize the concept of static electricity. This e-module is designed according to the characteristics of students at MAN Kepulauan Selayar. This development is expected to significantly improve students' critical thinking skills. In addition, this research also provides alternative solutions for more innovative physics learning. Thus, this research has practical and theoretical value in educational development (Arends, 2008). This contribution is realized through the application of empirically tested learning tools in the learning process. One of the main aspects that proves the success of this tool is through the fulfillment of effectiveness indicators. The effectiveness indicators in this study are seen from the e-module's ability to encourage students to carry out high-level cognitive processes, such as analyzing authentic problems and critically evaluating electrical phenomena through the integration of PBL steps (Yovita et al., 2023).

This research is important because it can provide solutions to students' low critical thinking skills. It also supports the implementation of 21^{st} -century learning in schools. Furthermore, the results are expected to serve as a reference for teachers in developing innovative teaching materials. With the PBL-based interactive e-module, physics learning is expected to become more engaging and meaningful. Therefore, this research has high urgency in improving the quality of learning.

Based on this description, this study aims to develop an interactive e-module based on Problem-Based Learning on static electricity to improve students' critical thinking skills.

Method

This research is a type of Research and Development (R&D) that aims to produce an interactive e-module using a Problem Based Learning (PBL) approach in science (physics) learning to improve students' critical thinking skills. The development procedure follows the 4D model, which includes define, design, develop, and disseminate (Thiagarajan, 1974). The stages of the 4D development model can be seen in the following picture.

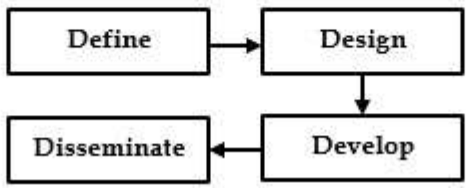

Figure 1. The stages of the 4D development model

In the define stage, there are four types of analysis: initial needs analysis, student analysis, concept analysis, and learning objectives analysis.

Initial Needs Analysis

This analysis was conducted to identify the primary issues in science learning, specifically physics, at MAN Kepulauan Selayar and to understand the importance of developing relevant teaching materials. Based on observations in Grade XII, it was found that the learning process is still dominated by the teacher (teacher-centered) and is mostly one-way, leading to student passivity. Students rarely ask questions and face difficulties in the aspects of data interpretation, concept analysis, and making inferences or drawing conclusions from the physics phenomena studied. This issue is exacerbated by limited laboratory facilities and a lack of practicum materials at the school, which prevents students from proving theories through direct experimentation. Consequently, students struggle to understand the material deeply and are unable to relate physics concepts to everyday life. The reliance on printed textbooks as the primary source is also a constraint, as the material is presented in long texts without providing space for students to explore or conduct independent investigations. Furthermore, the available exercises focus more on rote memorization rather than sharpening higher-order thinking skills. In addition, the learning process at MAN Kepulauan Selayar has not yet optimally utilized technology-based media. In today's digital era, instructional innovations are required to overcome the limitations of practicum tools while increasing student engagement. As a solution, it is necessary to develop an interactive e-module designed using Canva. This e-module will not only present material visually but also integrate PhET simulation links as a virtual laboratory to replace limited conventional practicums. Through this approach, it is expected that students' motivation, activeness, and critical thinking skills—specifically in interpretation, analysis, and inference—can be significantly improved.

Student Analysis

Student analysis is conducted to determine the extent of students' abilities before developing the e-module. The e-module is designed to be relevant to the actual needs of students in the classroom. Several aspects considered include general characteristics, cognitive abilities, and students' learning styles. Based on observations, Grade XII students at MAN Kepulauan Selayar are, on average, 17 to 18 years old. According to Jean Piaget's theory, adolescents at this age should be in the mature formal operational stage, where they are expected to think abstractly, solve complex problems systematically, and perform scientific reasoning.

However, in reality, a gap was found between theory and field conditions. Most students still face difficulties in processing information deeply, particularly in the aspects of interpretation, analysis, and inference. Students are not yet accustomed to constructing logical arguments independently. Regarding learning styles, the majority of students have visual and kinesthetic tendencies. They understand abstract physics concepts more quickly when visualized attractively and involving explorative activities. Therefore, the use of an interactive e-module based on Canva that integrates PhET simulations is an appropriate solution to facilitate these learning styles while stimulating their critical thinking skills. The results of the observation on students' learning styles are as follows.

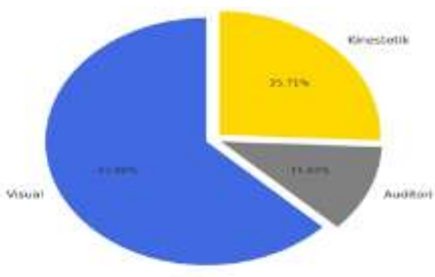

Figure 2. Learning styles of grade XII students at MAN Kepulauan Selayar

Based on the data from the diagram in Figure 2, it was found that most students have a tendency toward visual learning style (62.86%), followed by kinesthetic learning style (25.71%), and only a small number have auditory learning style (11.43%). Based on this analysis, students need learning materials that not only provide information but also help them interact actively and think critically through reflective questions, virtual experiments, or problem-based activities.

Concept Analysis

Concept analysis aims to map and determine the main parts of the physics material to be taught. The material analyzed in this research is Static Electricity for grade XII. Through concept analysis, the researcher explores the material more deeply, identifying electrical phenomena relevant to real life—such as the working principles of lightning rods or photocopiers—since students are typically more interested in material connected to their daily experiences. The scope of the analyzed material includes Coulomb's Law, electric fields, electric potential, electric potential energy, and the principles of capacitors. This material will be presented through learning activities within an interactive e-module designed using Canva. By performing a thorough concept analysis, students can understand the connection between abstract theories (such as charge interactions) and real practice with the help of PhET simulations. The development of this e-module is expected to be effective in achieving learning objectives and improving students' critical thinking skills—specifically in the aspects of interpretation, analysis, and inference—through activities exploring static electricity phenomena.

Learning Objectives Analysis

Learning objectives analysis is conducted by establishing learning goals for each activity based on the Learning Achievement (CP) set by the government and the Learning Objectives Flow (ATP) found in the Merdeka Curriculum. The formulated learning objectives serve as a guide in designing and developing the product—an interactive e-module on Static Electricity—to improve students' critical thinking skills, specifically in interpretation, analysis, and inference.

The design stage includes activities to plan the e-module product, focusing on the learning process to reach the expected goals. The steps in this stage include: preparing research instruments, organizing the material, and designing the e-module layout. The Canva application is used for designing the e-module. The product is developed by integrating material that aligns with real-life situations, making it relevant to the students' daily lives and enhancing their engagement.

The development stage includes product validation to determine the feasibility of the developed e-module. This is done by providing validation sheets to a team of experts (validators), followed by conducting limited and field trials. The trial design used is the "One Group Pre-test and Post-test Design." In this design, the assessment is conducted twice: before the experiment (O_1), known as the pre-test, and after the intervention using the e-module (O_2), known as the post-test. This trial design is described as follows.

$$O_1 \quad X \quad O_2$$

Figure 3. Research trial design

Explanation:
X : treatment (independent variable)
O_1 : pre-test score (initial test before treatment)
O_2 : post-test score (final test after treatment)

The disseminate stage aims to analyze the results of the product trial in the field and to make improvements if there are suggestions or feedback from practitioners. The improved or revised product, in this case the e-module, will be given to the teacher as a way of distributing it to the school and will be published in a journal for wider reach.

Data Analysis

Data Analysis of Validation Results

The analysis used to find out the level of relevance by experts used the content validity coefficient (Aiken's V). Aiken's V formula is used to calculate the content validity coefficient based on the expert's rating of each item (Azwar, 2019).

$$V = \frac{\sum s}{[n(c-1)]} \quad (1)$$

Explanation:
V : index of expert agreement on item validity
S : s = r - l0
O_2 : post-test score (final test aftertreatment)
S : the difference between the score given by each expert and the lowest score in the rating scale
I_0 : score given by the rater (expert)
n : number of experts
c : the highest score in the rating scale

The Aiken test requirement, after calculation, is that if V ≥ 0.4, then the expert agreement index is considered valid.

Practicality Analysis

The practitioners' assessment of the e-module was carried out using a questionnaire filled out by Physics teachers in South Sulawesi (Sulsel), with a rating scale from 1 to 4. The coding rules for the responses are clearly explained based on the criteria in Table 1 below (Sugiyono, 2019).

Table 1. Coding of practitioner response

Category	Positive Statement Score	Negative Statement Score
Strongly Agree	4	1
Agree	3	2
Disagree	2	3
Strongly Disagree	1	4

The steps of the analysis are calculating the ideal score statement or item, calculating the total score for each statement or item and calculating the percentage of the total score for each item using the formula.

$$\text{Percentage} = \frac{\text{Total score of each item}}{\text{Total ideal (maximum) score}} \times 100\% \quad (2)$$

The percentage of practitioner responses for each statement will be analyzed using the scoring criteria in Table 2.

Table 2. Practitioner Assessment Score Categories (Sahida, 2018)

Category	Criteria
75 ≤ x ≤ 100	Very Practical
50 ≤ x < 75	Practical
25 ≤ x <50	Less Practical
0 ≤ x < 25	Not Practical

Effectiveness Analysis

The effectiveness of interactive e-modules with the PBL approach can be determined by testing students' critical thinking skills. To measure the improvement in students' critical thinking skills before and after using the e-module, the normalized average gain formula is used. The N-Gain test is conducted using the following formula (Sundayana, 2014).

$$g = \frac{Posttest\ Score - Pretest\ Score}{Maximum\ Score - Pretest\ Score} \quad (3)$$

The N-Gain calculations are then interpreted using the categories in Table 3.

Table 3. Normalized N-Gain Criteria (Salam et al., 2023)

Normalized N-Gain	Category
$0,70 < g \leq 100$	High
$0.30 < g \leq 0.70$	Medium
$0.00 < g \leq 0.30$	Low
$g = 0.00$	No Change
$-1.00 \leq g \leq 0.00$	Decrease

The effectiveness of using the e-module is based on the interpretation of the N-gain score obtained, which is then converted into a percentage (%) as shown in Table 4 (Puspita & Setyaningsih, 2022).

Table 4. Interpretation of standard gain effectiveness

Interval	Category
$g \leq 55$	Ineffective
$g \geq 56$	Effective

Table 4 categorizes effectiveness based on the N-gain percentage, which measures the improvement in learning outcomes before and after using the E-module. The Ineffective category is given if the N-gain percentage is ≤ 55, indicating that the improvement in learning outcomes is very minimal or nonexistent. Furthermore, if the N-gain percentage exceeds ≥ 56, the value is considered Effective, meaning that the improvement in learning outcomes has met or even exceeded the expected target.

Result and Discussion

Development of Interactive E-modules with a PBL Approach to Improve Students' Critical Thinking Skills Theoretically

The development of digital teaching materials is a fundamental element in educational transformation to meet the demands of 21st-century skills, which emphasize higher-order thinking skills. This innovation is rooted in the theory of social constructivism, where learning occurs optimally when students are encouraged to construct their own knowledge through interactions with meaningful real-world problems. In the context of physics learning, technology integration in the form of interactive e-modules based on Problem-Based Learning (PBL) is a strategic solution for bridging abstract concepts. Research shows that the development of a physics e-module based on Problem Based Learning (PBL) as an independent teaching material can significantly improve students' critical thinking skills, where the digital format facilitates a more systematic and structured investigation process compared to conventional learning resources (Azriyanti & Syafriani, 2023).

The development of this interactive e-module began with an in-depth analysis phase that covered aspects of needs, student characteristics, and learning materials at MAN Kepulauan Selayar. The analysis results showed that students' low critical thinking skills were caused by limited learning resources that were still conventional and students' difficulties in interpreting and analyzing abstract physical phenomena. Therefore, static electricity material was chosen as the main focus because of its complex characteristics that require a Problem Based Learning (PBL) approach to stimulate inference and independent problem-solving skills through interactive digital exploration.

The results of this analysis serve as the primary basis for continuing development to the interactive e-module design stage. The e-module structure in this study is systematically designed to stimulate critical thinking skills through the presentation of contextual problems, interactive simulation features, and independent reflection spaces that require students to interpret and analyze data in depth. According to Dwyer et al. (2013), the integration of technology in digital learning media is very effective in improving critical thinking frameworks because it allows for the visualization of arguments and the process of evaluating information in real time. Through a structured e-module design with a problem-based approach, students are guided to develop inference skills to draw logical conclusions about the physics phenomena being studied.

Interactive e-modules were chosen as the primary medium due to their superiority in presenting dynamic multimedia content and their ability to facilitate independent cognitive processes. E-modules are efficient learning media because they allow students to interact directly with simulations and contextual problems flexibly, which in turn accelerates the understanding of complex physics concepts (Serevina et al., 2018). Furthermore, the integration of critical thinking indicators into e-modules is crucial so that students are not merely passive recipients of information, but are able to evaluate, analyze, and synthesize the problems they face (Ennis, 1985). With this interactive approach, e-modules serve as a strategic tool in transforming students' thinking to be more analytical and systematic.

In this study, students' critical thinking skills were measured using an assessment instrument consisting of a pretest with 25 questions and a posttest with 25 multiple-choice questions. Consistent with Zubaidah (2016), students' critical thinking skills can be accurately identified through a test instrument specifically designed to measure indicators of interpretation, analysis, and inference. The assessment instrument plays a crucial role as a valid measuring tool to collect data on the extent of improvement in students' cognitive abilities after being given treatment (Arikunto, 2013). After the design phase, the interactive e-module and all assessment instruments were validated by experts to ensure their suitability, readability, and fe asibility before being implemented in learning at MAN Kepulauan Selayar.

Validation Results of Interactive E-module Content with PBL Approach with Aiken's V Index

The validity assessment of the developed Google Sites physics teaching materials was carried out by three experts who provided assessments and input on four aspects of feasibility, including the content feasibility aspect containing 13 statement items, the presentation feasibility aspect containing 9 statement items, the language feasibility aspect consisting of 9 statement items, and the graphic feasibility aspect consisting of 12 statement items, with a total of 43 statement items. The test scores obtained for the analysis of the validity coefficient of the expert agreement index with the Aiken's V index are presented in Table 6.

Table 6. Analysis test of interactive E-modules with PBL approach with Aiken's V index:

Aspect	Validity score	V	Category
Content	10.33	0.84	Valid
Presentation	7.17	0.84	Valid
Graphic	9.92	0.86	Valid
Language	7.0	0.82	Valid
Average		0.84	Valid

Based on the data in Table 6, the validity test results for the content and presentation feasibility aspects obtained the same index, namely 0.84, for the language feasibility aspect obtained an index of 0.82, while for the graphic feasibility assessment aspect obtained an index of 0.86. Overall, the average index value of the four aspects analyzed was 0.84, which means that the analyzed V index is ≥0.4 indicating that the expert agreement index is valid. This indicates that the interactive E-module with the PBL approach is worthy of being continued for limited trials.

Table 6 shows that all assessment aspects are in the valid category. This indicates that the developed interactive e-module has met the eligibility criteria in terms of content, presentation, graphical display, and language use appropriate to the characteristics of the students. Therefore, this e-module is suitable for use as a teaching material in physics learning, particularly for static electricity. These results align with Andriyani et al. (2024)research, which states that interactive e-modules have a high level of eligibility in supporting students' independent learning.

The integration of the Problem-Based Learning (PBL) approach into interactive e-modules also contributes to the quality of the developed teaching materials. PBL can encourage students to actively engage in the learning process through contextual problem-solving. This is supported by research by Hmelo-Silver (2004), which states that PBL increases student engagement and critical thinking skills. Furthermore, research by Anita and Wiyatmo (2024) also shows that PBL-based e-modules are effective in improving critical thinking skills at a high level.

The use of Canva-based interactive media combined with PhET simulations also contributes to visualizing abstract physics concepts. Interactive simulations allow students to understand concepts such as the Coulomb force and electric fields more concretely. This aligns with research by Wieman et al. (2008), which states that PhET simulations can improve conceptual understanding through interactive exploration. This finding is further supported by research by Lastri (2023), which states that the use of interactive digital media can improve the quality of learning and students' conceptual understanding.

Validation Results of the Teacher/Practitioner Assessment Questionnaire for Interactive E-modules with a PBL Approach

Expert validation data on the teacher assessment questionnaire instrument from 26 statement items were then analyzed using Aiken's V expert agreement index. The results of the validity analysis test of the teacher assessment questionnaire instrument obtained an expert agreement index of 0.78 which is in the valid category. Based on this, the teacher/practitioner assessment questionnaire for the interactive E-module with the PBL Approach is declared suitable for use in the field without revision.

Critical Thinking Skills Test Validation Results

The instrument was validated by three experts to determine the validity of each statement. Each statement consisted of 25 questions, each covering three indicators: a focus on interpretation, analysis, and inference. The results of the validity analysis of the critical thinking skills test instrument for the are shown in Table 7.

Table 7. analysis test of Critical Thinking skills with Aiken's V index

Indicator	Total Validity Item Score	V	Category
Interpretation	8.78	0.80	Valid
Analysis	6.56	0.94	Valid
Inference	6.33	0.90	Valid
Average	21.67	0.88	Valid

Expert assessments of the pretest and posttest instruments for measuring students' thinking skills found them suitable for use in the field with minor revisions. Expert suggestions and input included improvements to the sentence structure used in each ambiguous statement. The revised instrument is ready to be implemented to measure the critical thinking skills of grade XII students at MAN Kepulauan Selayar.

Development of Interactive E-modules with a PBL Approach to Empirically Improve Students' Critical Thinking Skills

The empirical approach includes the stages of product implementation in the classroom and field evaluation to test the effectiveness of the designed media. Implementation was carried out on trial subjects involving physics teachers and 12th grade students at MAN Kepulauan Selayar. At this stage, interactive e-modules with a Problem Based Learning (PBL) approach were used directly in learning activities to assess the practical application of the product and observe students' responses to the static electricity material presented. This stage provides an initial overview of the quality of the developed e-modules, particularly in stimulating students' critical thinking skills, facilitating independent problem analysis processes, and developing interpretation and inference abilities through the available interactive features.

The results of the practitioner assessment and student responses to the interactive E-module with the PBL approach developed are presented in the following paragraphs.

Practitioner Assessment of Interactive E-modules with PBL Approach

The practicality assessment of the PBL-based interactive physics e-module was obtained through a questionnaire completed by physics teachers at MAN Kepulauan Selayar. The questionnaire was designed to evaluate the suitability of the content with PBL syntax, ease of display navigation, language accuracy, and the quality of the graphics and interactive features of the developed e-module. Based on the results of the data analysis, the average percentage of practitioners' assessment scores reached 92.45%. This percentage is included in the very practical category, indicating that this interactive e-module is suitable for use in physics learning in grade XII.

The assessment from practitioners reflects the extent to which the developed product can be effectively implemented to train students' critical thinking skills. The data obtained indicates that the developed interactive e-module is not only easy for teachers to operate but also highly relevant to learning needs in the field, particularly in addressing the limitations of learning resources and practical tools for static electricity. With these highly practical qualities, this e-module is expected to be an effective independent learning tool for students.

Effectiveness of Interactive E-modules with PBL Approach

The effectiveness of the developed interactive physics e-module based on Problem Based Learning (PBL) can be seen from the results of measuring the improvement of students' critical thinking skills. The measurement of critical thinking skills of class XII students of MAN Kepulauan Selayar was carried out using a test instrument consisting of a total of 50 questions, divided into 25 questions in the pre-test before treatment and 25 questions in the post-test given after learning using the interactive e-module. This instrument is designed to measure indicators of interpretation, analysis, and inference of students on static electricity material. The results of the analysis of students' critical thinking skills test scores during the pre-test are presented in the following table as initial data before product implementation. The results of the analysis of students' critical thinking skills test scores during the pre-test can be seen in Table 8.

Table 8. Results of the analysis of critical thinking skills test scores

Parameter	Critical Thinking Skills	
	Pretest	Posttest
Number of Respondents	19	19
Maximum Ideal Score	25	25
Minimum Ideal Score	0	0
Maximum Empirical Score	19	23
Minimum Empirical Score	7	12
Average Score	11.8	19.4

Source: processed primary data (2026)

Based on Table 8, we can see an increase in students' critical thinking skills, as seen from the pre-test and post-test scores of 19 students. The average score before treatment was 11.8, while after learning using interactive e-modules with a PBL approach, the average score obtained through the post-test was 18.5. Furthermore, to determine the effectiveness of the interactive e-module with a PBL approach, an analysis of the improvement in critical thinking skills was conducted using the N-gain Score equation. The results of the N-gain analysis can be seen in Table 9.

Further more, to obtain the effectiveness of using interactive E-modules with a PBL approach, it is obtained from the calculation of students' Critical Thinking Skills tests using the N-gain formula. The following results of the N gain Score analysis can be seen in Table 10.

Table 9. N-gain Score Analysis of Critical Thinking Skills Test Improvement

Range	Category	Frequency	Percentage %
$0.70 < g \leq 100$	High	6	31.57
$0.30 < g \leq 0.70$	Medium	13	68,43
$0.00 < g \leq 0.30$	Low	0	0
$g = 0.00$	No Change	0	0
Total		19	100

Table 10. Percentage of effectiveness of using interactive e-modules with the PBL approach

Interval	Category	Number Of Student	Percentage (%)
$g \leq 55$	Not Effective	8	42.1
$g \geq 56$	Effective	11	57.9

Based on the data presented in Table 10, the effectiveness of using interactive e-modules with a PBL approach shows variation among students. Through the analysis conducted, it was seen that there were 8 students in the ineffective category with a percentage of 42.1%, and 11 students in the effective category with a percentage of 57.9%. The effectiveness of the e-modules was categorized based on criteria adapted from (Hake, 1998; Puspita & Setyaningsih, 2022), where an average N-gain score ≥ 56% is considered effective. From this percentage, it can be concluded that the developed product, with an average N-gain score of 57.71%, is effective in improving students' critical thinking skills at MAN Kepulauan Selayar, especially in Grade XII. By the findings of Laili (2023), which show that the use of interactive E-Modules based on Problem Based Learning (PBL) has a significant positive impact on improving students' critical thinking skills, as evidenced by the achievement of N-gain scores in the effective category in the implementation of physics learning.

Through observations conducted during the learning process in class XII of MAN Kepulauan Selayar, students demonstrated significant active involvement in solving problems presented in the e-module. The material structure, which refers to PBL syntax, guides students in interpreting data, analyzing static electricity concepts, and drawing inferences independently or in groups. The implementation of PBL-based e-modules that integrate interactive media provides opportunities for students to explore dynamic physical phenomena anytime and anywhere, thus facilitating the improvement of critical thinking skills through representative simulations (Serevina et al., 2018).

The developed interactive e-module also makes it easier for educators to present various abstract static electricity phenomena in a single, integrated digital platform without having to switch applications. Teachers can easily guide students to explore the text, learning videos, and PhET simulations embedded in the e-module to strengthen conceptual understanding. This aligns with the view that interactive digital learning media is highly effective in visualizing arguments and facilitating real-time information evaluation, thus effectively addressing space and laboratory equipment constraints (Dwyer et al., 2013).

Conclusion

Based on the research results and discussions that have been described, it is concluded that theoretically the development of an interactive physics e-module based on Problem Based Learning (PBL) is conceptualized based on the principles of social constructivism learning and digital instructional design that focuses on strengthening critical thinking skills. Through product validation by experts, a valid category was obtained with an average Aiken V value of 0.84, which indicates that the e-module is suitable for use as a learning medium. Empirical development at MAN Kepulauan Selayar also shows a high level of practicality with a percentage of teacher responses of 92.45% which is in the very practical category. Furthermore, the effectiveness test shows that the use of this e-module is able to improve students' cognitive abilities with an N-Gain of 0.58 in the effective category. Based on these results, the interactive e-module based on PBL is considered theoretically valid, empirically practical, and effective in improving students' critical thinking skills on static electricity material.

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Author Contributions

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Conflicts of Interest

The authors declare no conflict of interest.

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