



Developing a Problem-Solving E-Module to Enhance Senior High School Students' Critical Thinking Skills

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ABSTRACT

Purpose: This study aims to develop and evaluate a problem-solving-based e-module on Sequences and Series to address the low critical thinking skills of senior high school students caused by the lack of interactive learning materials. **Methods:** Employing a Research and Development (R&D) design with the ADDIE model, the study involved 25 students from SMAN 13 Takalar. Data collected through validation sheets, practicality questionnaires, and pre-test and post-test instruments were analyzed using Aiken's V formula and Normalized Gain (N-Gain). **Findings:** The results demonstrated that the developed e-module is highly valid (average 1.00) and categorized as very practical by both practitioners and classroom observations. Furthermore, the e-module proved effective, as evidenced by an average N-Gain of 0.76, placing students' critical thinking improvement in the "high" category. **Limitations:** However, this study is limited by a small sample size at a single institution, a reliance on purely written cognitive assessments that overlook digital literacy and intrinsic motivation, and the use of a one-group pretest-posttest design without a control group. **Research Implications:** These findings suggest that integrating structured problem-solving steps into digital modules provides a significant pedagogical tool for teachers to foster higher-order thinking skills. **Originality:** This research contributes by specifically integrating Polya's framework with Facione's cognitive indicators within a culturally contextualized digital e-module.



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INTRODUCTION

In the current era of digital education, the development of e-modules has emerged as an innovative strategy to enhance pedagogical quality. Specifically, instructional e-modules offer several transformative advantages: (1) fostering interactive learning through visual aids and video-based problem-solving, which simplifies complex concepts. Furthermore, e-modules encourage students to analyze problems to discover, comprehend, and apply mathematical concepts in problem-solving contexts, while bridging theoretical knowledge with real-world applications (Islahiyah et al., 2021; Ayu et al., 2026; Jumrah et al., 2025; Salma, 2025). (2) Optimizing learning activities tailored to individual student competencies, thereby directing their focus toward problem identification and the exploration of alternative solutions (Zuhaida & Pujiastuti, 2025; Islahiyah et al., 2021; Fadzil, 2025). (3) Providing structured learning activities that significantly improve instructional efficiency and effectiveness (Damayanti, 2025; Pitorini, 2023).

More specifically, (Maharani et al., 2025) assert that the integration of e-modules in the classroom can stimulate critical thinking skills, subsequently leading to improved learning outcomes. Comprehensively, (sugiyono, 2017; Islahiyah et al., 2021) emphasizes that an effective e-module must satisfy three fundamental criteria: validity, practicality, and effectiveness. These criteria are interconnected, ensuring that the e-module is not only technically functional but also pedagogically sound in helping students achieve learning objectives. Consequently, an e-module should not be viewed merely as a digital reproduction of printed material, but rather as an interactive and dynamic learning instrument designed to facilitate autonomous learning.

To operationalize this instructional e-module, the Polya problem-solving approach was selected as the developmental foundation. Polya's model stimulates the development of students' cognitive abilities by fostering creative and comprehensive thinking (Schoenfeld, 1987). Furthermore, it encourages students to adopt "out-of-the-box" perspectives, as the learning process involves intensive mental engagement where students analyze problems from diverse viewpoints to derive effective solutions (Ayu et al., 2026). According to (Nada & Yulia, 2023), students'

cognitive flexibility plays a crucial role in successfully solving complex mathematical problems. Therefore, this e-module is designed by integrating Polya's problem-solving steps so that students do not rely solely on mechanical procedural solutions but can systematically develop their own heuristic strategies. These developed problem-solving skills will, in turn, support mastery of the five essential critical thinking indicators that are the learning achievement targets.

The utilization of e-modules as instructional materials offers various significant benefits that address the limitations of conventional learning. First, e-modules enhance learning flexibility and accessibility (Magdalena et al., 2020). This flexibility serves as a cornerstone for implementing differentiated instruction, enabling students to progress through learning trajectories that align with their individual needs and competencies (Febrianti & Dafit, 2023). Second, as evidenced by (Mayer, 2024), e-modules integrated with multimedia features, such as videos, images, and animations, and designed with an engaging visual interface (e.g., utilizing platforms like Canva), yield a significant positive impact on facilitating students' conceptual understanding.

Previous research has extensively explored the development of instructional materials in the form of e-modules based on problem-solving approaches to facilitate the attainment of learning objectives. Anggraini & Pramudita, (2021) suggest that the systematic implementation of e-modules within a problem-solving framework serves as a viable alternative to foster more active and efficient mathematical problem-solving skills among students, while simultaneously streamlining the learning process. Specifically, a study by (Anggraini & Pramudita, 2021) demonstrated that Android-based mathematics e-modules utilizing a problem-solving approach are highly feasible and effective for classroom instruction. Furthermore, studies conducted by (Islahiyah et al., 2021; Rukiyah et al., 2023), and (Hasanah et al., 2024) consistently demonstrate that the integration of e-modules with a problem-solving approach effectively enhances students' ability to resolve complex mathematical problems.

The integration of problem-solving approaches is fundamentally aimed at elevating students' higher-order cognitive skills, particularly critical thinking. According to (Murtafiah et al., 2023; Tahir et al., 2019), critical thinking is a reflective and reasonable thinking process focused on deciding what to believe or do. This is further operationalized by (facione, 1990), who identifies core cognitive indicators such as interpretation, analysis, evaluation, inference, and explanation. Mastering these skills is essential for students to transition from merely memorizing formulas to systematically resolving complex mathematical phenomena, particularly in demanding topics like Sequences and Series.

Despite its importance, students often encounter significant challenges in applying critical reasoning. Preliminary observations and diagnostic tests conducted on tenth-grade students at SMA Negeri 13 Takalar revealed substantial deficiencies in critical thinking, particularly in their structural inability to translate word problems into accurate mathematical models (interpretation and analysis) and their failure to assess the logical validity of their computational results (evaluation). Consequently, an analysis of students' mathematics learning outcomes for the even semester of the 2024/2025 academic year showed an average score of only 51.72, well below the 70% Minimum Mastery Criterion (KKM). This low performance is largely attributed to the lack of interactive instructional materials aligned with current learning objectives, an overreliance on conventional teacher-centered methods, and insufficient problem-solving-oriented media.

Previous studies on problem-solving-based e-modules have consistently demonstrated overall benefits in improving students' general mathematical abilities. However, a critical research gap remains unaddressed: existing developments predominantly treat critical thinking as a single baseline score, completely lacking a granular, indicator-based measurement utilizing frameworks like Facione's specific cognitive sub-skills. This generalized approach makes it highly difficult for educators to diagnose precise cascading failures in student reasoning, such as how low interpretation structurally impairs analysis and inference in abstract topics like Sequences and Series. Furthermore, contemporary digital modules frequently overlook the integration of localized context, which is vital to bridge abstract mathematical concepts with students' cultural realities.

To resolve these limitations, this study establishes its urgency and novelty by developing an instructional e-module for Sequences and Series based on a problem-solving approach. Moving beyond general efficacy testing, this Research and Development (R&D) study uniquely provides a detailed, indicator-based critical thinking analysis under Facione's framework, while evaluated through the ADDIE model to ensure its validity, practicality, and effectiveness in high school mathematics instruction.

METHOD

This study is a Research and Development (R&D) project aimed at producing a valid, practical, and effective learning product. The research follows the ADDIE development model, which consists of five integrated phases: Analysis,

Design, Development, Implementation, and Evaluation. The ADDIE model was selected due to its systematic, clear, and goal-oriented procedures that align with the principles of instructional media development.

The research was conducted at SMA Negeri 13 Takalar from January 9 to January 30, 2026. The subjects involved in this study consisted of two main groups: product validators and the target users. The product validators included two experts from Universitas Muhammadiyah Makassar, a media expert and a subject matter expert, to assess the quality of the e-module. The target users (research subjects) were 25 students of Class X at SMA Negeri 13 Takalar, determined through purposeful selection to address identified structural weaknesses in critical thinking skills. The selection of a one-group pretest-posttest design and a limited sample size of 25 students was deliberately intended for the formative evaluation stage of this Research and Development (R&D) study. This restricted scale focuses on diagnosing specific cognitive trajectories and gathering initial empirical evidence of the e-module's feasibility within the target environment, rather than establishing broad statistical generalization. To compensate for the absence of a control group, a detailed, indicator-based qualitative analysis of students' critical thinking shifts was employed to ensure the depth and rigor of the effectiveness claims.

Data collection was performed using several instruments: validation sheets for experts, practicality questionnaires for teachers and students, and pre-test and post-test instruments to measure critical thinking skills. The critical thinking test was designed as an essay based on Facione's cognitive indicators interpretation, analysis, evaluation, inference, explanation, and self-regulation integrated with Polya's problem-solving steps (Schoenfeld, 1987). The research design utilized for measuring effectiveness was the One-Group Pretest-Posttest Design, comparing students' initial abilities before using the e-module with their final abilities after five learning sessions.

Data analysis techniques were categorized into three parts. First, validity was analyzed using the Aiken's V formula to measure the index of agreement between expert validators (Lewis R. Aiken, 1980). Second, practicality was determined by calculating the percentage of teacher and student response scores (Branch, 2009). Third, the effectiveness was evaluated using the Normalized Gain (N-gain) formula to calculate the improvement between pre-test and post-test scores (Hake, 1999). The product was declared high quality once it met the criteria for being valid, practical, and effective in enhancing critical thinking skills.

RESULTS

The development of the e-module using a problem-solving approach was evaluated through three main criteria: validity, practicality, and effectiveness. The following sections describe the empirical findings from the developmental process.

a. Validity Results

The validity of the e-module was assessed by a panel of experts focusing on content and media quality. The data obtained was analyzed using the Aiken's V formula to ensure the product met the established pedagogical and technical standards.

Table 1. Average Assessment of E-Module Aspects Based on the Problem-Solving Approach with the Aiken's V Index

Assessment Aspects	Scor Rater		ΣS	n(c-1)	V	Ket.
	S1	S2				
Layout (Media Appearance)	24	24	48	48	1,00	High
Content	15	15	30	30	1,00	High
Benefits	12	12	24	24	1,00	High
Language Suitability	9	9	18	18	1,00	High
Average			30	30	1,00	Valid

Table 1 above shows that the layout aspect (media display) obtained a validity index with an average of 1.00, categorized as valid. The content feasibility aspect obtained a validity index with an average of 1.00, categorized as valid. The benefits aspect obtained a validity index with an average of 1.00, categorized as valid. Meanwhile, the language feasibility aspect obtained a validity index with an average of 1.00, categorized as valid. The validators' assessment of the Problem-Solving Approach-Based E-Module reached the same conclusion: without revision, it was declared suitable for use in the limited trial phase.

b. Practicality Results

Practitioner assessment of the Problem-Solving Approach-Based E-Module developed in the learning process at school. The practitioner assessment questionnaire was completed by five mathematics teachers at SMA Negeri 13

Takalar. The scores obtained by the five practitioners who provided assessments of the Problem-Solving Approach-Based E-Module developed can be seen in [Table 2](#) below.

Table 2. Practitioner Assessment Scores for the Development of Problem-Solving-Based E-Modules

Assessment Aspects	Practitioner Score					PRS	Criteria
	P1	P2	P3	P4	P5		
Content Suitability	76	76	76	58	76	95,26	Very Practical
Presentation Suitability	60	60	60	45	60	95	Very Practical
Language Suitability	28	26	26	21	28	92,14	Very Practical
Graphics Suitability	100	100	91	88	98	95,4	Very Practical
						94,45	Very Practical

Based on [Table 2](#) above, practitioners gave very good assessments for the four assessment aspects of the Problem-solving Approach-Based E-Module that was developed. The cumulative practitioner response score on the aspect of content feasibility obtained a percentage of 95.26% with a very practical category, on the aspect of presentation feasibility obtained a percentage of 95% in the very practical category, on the aspect of language feasibility obtained a percentage of 92.14% in the very practical category, and on the aspect of graphic feasibility obtained a percentage of 95.4% in the very practical category. From the results of the scores obtained from the five practitioners, the average percentage score was 94.45% with a very practical category.

Table 3. Implementation Observation Assessment Score Problem-solving-based e-module

Assessment Aspect	Meeting					Percentage Score (PRS)	Criteria
	1	2	3	4	5		
Use of e-module components	20	19	20	20	17	96.0	Very Practical
Problem-solving syntax (Polya)	15	15	16	16	15	96.3	Very Practical
Critical thinking stimulation (Facione)	23	21	24	22	24	95.0	Very Practical
Completeness and closing section of the e-module	20	19	19	20	20	98.0	Very Practical
Average	19.5	18.5	19.75	19.5	19	96.32	Very Practical

Based on [Table 3](#), teacher observations on the implementation of learning through the use of problem-solving-based e-modules during five meetings showed a cumulative score of 96.0% for the Use of e-module components, categorized as very practical. The Problem-Solving Syntax (Polya) aspect scored 96.3%, categorized as very practical. The Stimulation of Critical Thinking (Facione) aspect scored 95.0%, categorized as practical. The Completeness and Conclusion of the e-module scored 98.0%, categorized as very practical. Based on the overall scores for each meeting, the average score was 96.32%, categorized as very practical.

c. Effectiveness Results

The effectiveness of the e-module in enhancing critical thinking skills was measured by comparing pre-test and post-test scores using the Normalized Gain (N-Gain) formula.

Table 4. Results of Analysis of Students' Critical Thinking Ability Test Scores

Parameter	Pre-test		Post-test	
	Skor	Nilai	Skor	Nilai
Skor Ideal Maksimum	24	100	24	100
Skor Ideal Minimum	0	0	0	0
Skor Empiris Maksimum	16	67	22	92
Skor Empiris Minimum	2	8	18	75

[Table 4](#), shows the improvement in students' critical thinking skills, based on the pretest and posttest scores of 25 students. The maximum empirical score for the pretest was 16 with a score of 67, and the minimum empirical score was 2 with a score of 8. Meanwhile, the maximum empirical score for the posttest was 22 with a score of 92, and the minimum empirical score was 18 with a score of 75. To obtain the effectiveness of the e-module based on the problem solving approach, the students' critical thinking ability test was analyzed using N-Gain which can be seen in [Table 5](#) below.

Table 5. N-Gain Scores for Students' Critical Thinking Skills Grade 10 of SMAN 13 Takalar

Parameter	Category	Number of Students	Percentage (%)
$g > 0,7$	Height	19	76
$0,3 \leq g < 0,7$	Medium	6	24
$g < 0,3$	Low	0	0
Quantity		25	100

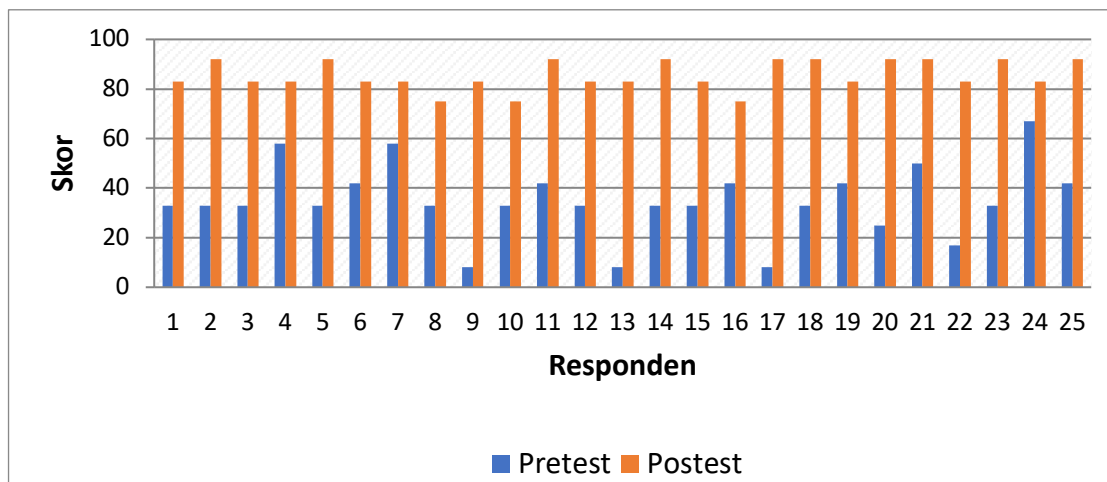


Figure 1. Pretest and posttest scores of students' critical thinking skills

Table 6. Results of Analysis of Each Indicator of Students' Critical Thinking Ability

Indicator	Rerata Skor <i>Pretest</i>	Persentase (%)	Rerata Skor <i>Posttest</i>	Persentase (%)
Interpretation	3,28	82	4	100
Analysis	1,76	44	3,6	90
Inference	1,36	34	3,76	94
Explanation	0,88	22	3,76	94
Evaluation	1,12	28	2,88	72
Self-regulation	0,08	2	2,56	64

Based on the data presented in Table 6, a deeper qualitative analysis reveals a profound hierarchical relationship among the critical thinking indicators. Specifically, a consistent cognitive pattern emerged from the student evaluations: low interpretation directly leads to flawed inferences. When comparing subjects based on their test responses, a distinct divergence is evident. Lower-performing subjects who failed to accurately interpret the initial context of the Sequences and Series problem, such as misidentifying the initial term or the common difference inevitably constructed incorrect mathematical models during the analysis stage. Consequently, because their foundational modeling was compromised, their final mathematical conclusions (inference) were structurally flawed, regardless of their calculation skills. Conversely, higher-performing subjects demonstrated that taking the time to master the interpretation stage directly safeguarded the validity of their subsequent analysis and inference.

This cascading failure in critical thinking occurs not due to a lack of basic arithmetic skills, but because students have been deeply conditioned by conventional learning methods to blindly plug numbers into memorized formulas without understanding the underlying logic. When faced with contextual problems, they lack the self-regulation to pause and evaluate their assumptions. The developed e-module addresses the root cause of this issue. By systematically guiding students through problem-solving stages, the e-module forces them to conceptually deconstruct the problem first, thereby breaking the detrimental habit of mechanical calculation and effectively preventing the pattern of low interpretation leading to wrong inference.

DISCUSSION

A. Validation of E-Module Content Based on Problem Solving Approach

The content validity results were analyzed using the Aiken's V index test, which examines the content validity coefficient of the validated instrument. The e-module is considered valid if the content validity coefficient is greater

than 0.4. The validity results of the problem-solving-based e-module demonstrated a high level of feasibility across all assessment aspects: layout (media display) with a percentage of 100%, content feasibility with a percentage of 100%, usability feasibility with a percentage of 100%, and language feasibility with a percentage of 100%. The average results of the assessments of the two validators showed an average content validity coefficient of 1.00 with all having a valid category. Therefore, it can be stated that the e-module based on the problem-solving approach is valid and can be used without revision. The e-module based on the problem-solving approach is suitable for use in SMA Negeri 13 Takalar as an alternative learning resource that can be used by educators. This is in line with research (Dwi Agustina et al., 2023); (Islahiyah et al., 2021); (Hasanah et al., 2024); (Rukiyah et al., 2023); (Pujiono et al., 2024) which revealed that the e-module was declared valid based on product assessment by experts, so that the product is suitable for use in the learning process. Specifically, the clear step-by-step guidance in the problem-solving model accommodates a logical flow of mathematical concepts, which experts consistently rate highly for feasibility and instructional design quality.

B. Practitioner Assessment of E-Modules Based on the Problem Solving Approach

The average percentage obtained for the practitioner assessment sheet (teacher response) from all validity aspects was 100%. And the implementation observation sheet obtained an average percentage from all validity aspects of 96.33%. Overall, the practitioner assessment questionnaire sheet (teacher response) and the implementation observation sheet each have an Aiken's V index with an average coefficient of 1.00 with a valid category and 0.94 with a valid category. This can be stated that the practitioner questionnaire sheet (teacher response) and the implementation observation sheet can be used with minor revisions. So the practitioner assessment questionnaire sheet (teacher response) and the implementation observation sheet that have been validated can be used to measure the practicality of the problem-solving approach-based e-module. This is in line with the research of (Khotimah, 2024) and (Pramesti, 2024) who developed an e-module based on a practical problem-solving approach for use in mathematics learning because it is easy to understand and of course easy to use. The current study extends their findings by demonstrating that a problem-solving-based e-module is not only user-friendly but also provides a systematic framework that assists educators in effectively monitoring students' non-algorithmic strategies during mathematics learning.

C. Effectiveness of E-Modules Based on Problem Solving Approach

Students' critical thinking skills are measured by five specific indicators: interpretation, analysis, explanation, evaluation, and inference. The test consisted of a single essay question on sequences and series. The results of the students' critical thinking skills test before using the Problem-Solving-Based E-Module showed that their initial skills were still in the low category, with a maximum empirical score of 16 for the pretest, with a score of 67, and a minimum empirical score of 2 for the posttest, with a maximum empirical score of 22 for the posttest, with a score of 92, and a minimum empirical score of 18 for the posttest, with a score of 75. The content validity of the critical thinking test items in this study yielded a mean (V) of 1.00, categorized as valid. The expert validation analysis of the critical thinking test instrument was deemed valid and suitable for use in research with minor revisions.

The scores were analyzed using the N-Gain formula. The analysis showed an average N-Gain of 0.76, categorized as high. A total of 19 people or 76% of students were in the range of N-Gain parameters > 0.7 with the High category, 6 people or 24% of students were in the range of N-Gain parameters > 0.3 with the Medium category, and no students were in the low category.

The empirical efficacy of the developed e-module is demonstrated by the significant shifting in students' mathematical critical thinking skills, evidenced by an average Normalized Gain (N-Gain) score of 0.76, placing the improvement in the "high" category. Mechanistically, this substantial growth is structurally anchored in the systematic integration of Polya's problem-solving steps as the operational foundation of the e-module. Guided through the sequential syntax, students are systematically trained to dissect abstract concepts in Sequences and Series. In the initial stage of understanding the problem, students are prompted to isolate critical information and relevant variables, which directly stimulates Facione's core indicators of interpretation and analysis. Subsequently, during the planning and executing stages, students are scaffolded to connect prior mathematical schemas with the newfound problem structures, thereby sharpening their inference and explanation competencies. Finally, the "looking back" phase establishes a metacognitive space for students to self-evaluate their logical pathways and verify the precision of their final constraints. This structured routine gradually shifts student behavior from mechanical formula memorization to a logical, comprehensive reasoning framework.

However, to ensure a critical and unbiased interpretation, these positive outcomes must be evaluated against potential biases and alternative explanations. While the high N-gain suggests robust efficacy, the observed improvement might be partially attributed to the "Hawthorne effect," where students exhibit heightened engagement simply due to the novelty of using an interactive digital treatment and the awareness of being research subjects. Furthermore, alternative pedagogical factors played a critical role; the intensive scaffolding provided by the classroom

teacher across the five structured interventions might have synergized with the module's content to accelerate learning gains, meaning the module cannot be viewed as an entirely isolated catalyst. Additionally, individual baselines in digital literacy and external independent study habits remained uncontrolled variables that could positively skew the efficacy claims.

A rigorous indicator-based analysis further reveals a pedagogical anomaly: the lowest post-test achievements were consistently observed within the Evaluation and Self-Regulation indicators. From a hierarchical standpoint, these dimensions represent the highest echelons of metacognition. This lower performance roots deeply from cultural resistance inherited from conventional schooling paradigms, where students have been historically conditioned to terminate their cognitive processing immediately upon reaching a final numerical answer. Consequently, students frequently lack the intrinsic instinct to execute contextual verification (Evaluation) or independently recalibrate their deductive trajectories (Self-Regulation). Moving students away from a product-centered mentality toward proactive metacognitive awareness undeniably demands a pedagogical duration far exceeding a brief five-meeting intervention. Repositioning instructional media from passive digital literature to a proactive cognitive catalyst remains a longitudinal adaptive process for high school learners.

While this Research and Development (R&D) study provides valuable pedagogical insights, several limitations must be acknowledged for future improvements. First, regarding the number of subjects, the field implementation was restricted to a relatively small sample size of 25 students at SMAN 13 Takalar. This limited scale constrains the broad generalizability of the findings. Second, concerning the research instruments, the assessment relied heavily on written cognitive measurements based on Facione's critical thinking indicators. This approach may not have fully captured other influencing variables in digital learning, such as students' intrinsic motivation or their prior digital literacy skills. Finally, in terms of the research design, this development phase utilized a limited trial design without a rigorous control group comparison. Therefore, future studies are highly recommended to involve a larger and more diverse demographic, integrate broader assessment instruments, and employ a quasi-experimental design to further validate the broader impact of this culturally contextualized e-module

CONCLUSION

Based on the research and development of a problem-solving-based e-module to improve critical thinking skills for tenth-grade students at SMA Negeri 13 Takalar, it can be concluded that the developed e-module met the criteria of validity, practicality, and effectiveness. The expert validation results using the Aiken's V index showed that the e-module media validation and material validation both obtained an average score of 1.00. The validation of the learning implementation observation sheet obtained a score of 0.94, while the teaching module validation obtained a score of 1.00. In addition, the practitioner-teacher response questionnaire and student response questionnaire also achieved an average content validity score of 1.00. These results indicate that the developed e-module was valid and suitable for use in the learning process. The practicality of the e-module was demonstrated through the cumulative practitioner response score, which reached an average of 94.45%, categorized as very practical, while the implementation observation score reached an average of 81.30%, also categorized as very practical. This shows that the practitioners gave positive responses toward the developed e-module. Furthermore, the effectiveness of the e-module was determined through N-gain analysis, which revealed that 19 students, or 76%, achieved a high level of improvement in critical thinking skills, while 6 students, or 24%, achieved a moderate level of improvement, and no students were categorized in the low improvement category.

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AUTHOR CONTRIBUTION STATEMENT

Conceptualized the study, developed the e-module, and conducted the data collection and analysis. N and AMF supervision on the research methodology and critically reviewed the manuscript.

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