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DEVELOPMENT OF A BIOTECHNOLOGY E-MODULE INTEGRATED WITH THE PROBLEM-BASED LEARNING MODEL INCORPORATING SOCIOSCIENTIFIC ISSUES TO TRAIN STUDENTS' CRITICAL THINKING SKILLS

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Abstract

Critical thinking skills (CTS) are essential competencies in science education for preparing students to respond to complex socioscientific challenges in the 21st century. Nevertheless, empirical evidence and classroom practices indicate that Indonesian students' CTS remain at a low level, particularly in biotechnology learning, which often requires higher-order reasoning. This condition is exacerbated by the dominant use of textbook-centered instruction and the limited availability of digital teaching materials that systematically integrate real-world socioscientific issues (SSI). Therefore, the development of innovative, context-based instructional materials is urgently needed. This study aimed to examine the validity, practicality, and effectiveness of a science e-module integrating the Problem Based Learning (PBL) model and SSI to enhance students' CTS in biotechnology. A Research and Development approach using the ADDIE model was employed, involving 32 ninth-grade students at a Public Junior High School 11 Magelang. Data were collected through expert validation sheets, student response questionnaires, and CTS pretest–posttest instruments. The results showed that the e-module was valid (Aiken's V = 0.92), practical (81%), and effective in improving students' CTS, as indicated by a significant Wilcoxon Signed-Rank Test result (p = 0.000) with a moderate N-Gain of 0.47. These findings suggest that integrating PBL and SSI in a digital e-module effectively supports the development of students' critical thinking skills in science learning.

Keywords**:** *science e-module, PBL, socioscientific issues, critical thinking skills, biotechnology.*

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Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

INTRODUCTION

Critical thinking ability is an essential 21st-century competence that must be developed through science education [1]. This skill plays a crucial role in enabling students to analyze information, evaluate evidence, and make rational decisions regarding increasingly complex scientific and social issues. However, Indonesian students' mastery of critical thinking skills remains relatively low. The 2022 Programme for International Student Assessment (PISA) results indicate that the higher-order thinking skills of 15-year-old students are at levels 2 to 3, which are still below international standards [2]. These findings are reinforced by national studies reporting low levels of critical thinking achievement among junior high school students, including in biotechnology topics [3].

A similar condition was also identified in science learning at SMP Negeri 11 Magelang City. The results of preliminary observations indicate that students' critical thinking skill indicators, particularly in the aspects of interpretation, analysis, and self-regulation, have not developed optimally, with achievement percentages of 0%, 7%, and 38%, respectively. This finding suggests that the ongoing learning process has not fully facilitated students to think critically and reflectively. Therefore, innovative and sustainable efforts are required in designing science instruction that can systematically train students' critical thinking skills.

The use of technology in science education has been proven to enhance the quality of the learning process and support the development of students' critical thinking skills [4]. One form of instructional material with strong potential for this purpose is the e-module, as it allows content to be delivered in a self-directed, interactive, and flexible manner [5]. However, in practice, many schools in Indonesia still rely heavily on textbooks as the primary learning resource, including at SMP Negeri 11 Magelang City. This reliance limits students' independent exploration of concepts and inadequately supports contextual learning and instruction oriented toward the development of higher-order thinking skills [6].

The selection of instructional materials must be accompanied by the implementation of an appropriate learning model. The Problem-Based Learning (PBL) model has been widely reported to be effective in enhancing critical thinking skills because it positions students at the center of learning and uses authentic problems as triggers for the thinking process [7]. Nevertheless, the effectiveness of PBL is highly dependent on the quality of the problem context and the learning media employed. PBL that is not supported by contextual and relevant instructional materials may lose its potential to foster deep critical thinking skills.

In the context of science learning, particularly biotechnology, the problems employed in PBL should ideally be linked to socioscientific issues. A socioscientific issue–based approach enables students to connect scientific concepts with social, ethical, and environmental realities, thereby promoting evidence-based decision-making and critical reasoning [8]. Socioscientific issues frequently arise in biotechnology topics, such as genetic engineering, genetically

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

modified organisms (GMOs), vaccines, and cloning, which often generate moral, legal, and social dilemmas within society [9].

Based on the foregoing discussion, it is necessary to develop a science e-module that not only adopts the syntax of the Problem-Based Learning model but also explicitly incorporates contextual socioscientific issues within biotechnology concepts. This study aims to develop and examine the validity, practicality, and effectiveness of a PBL-integrated science e-module incorporating socioscientific issues in training junior high school students' critical thinking skills.

METHOD

This study employed a Research and Development (R&D) approach using the ADDIE model (Analyze, Design, Development, Implementation, and Evaluation), which aims to produce educational products that are valid, effective, and practical [10]. The population of this study consisted of all ninth-grade students at SMP Negeri 11 Magelang City in the 2024/2025 academic year. The sample was selected using purposive sampling, namely the deliberate selection of participants based on specific considerations, such as students' readiness to engage in learning using the e-module and recommendations from the subject teacher [11].

This study employed a one-group pretest–posttest design, in which students' abilities were measured before and after the treatment was administered to the same group [10]. Class IX A was designated as the main sample, consisting of 32 students. The research and development procedures were carried out in accordance with the stages of the ADDIE model, as illustrated in Figure 1.

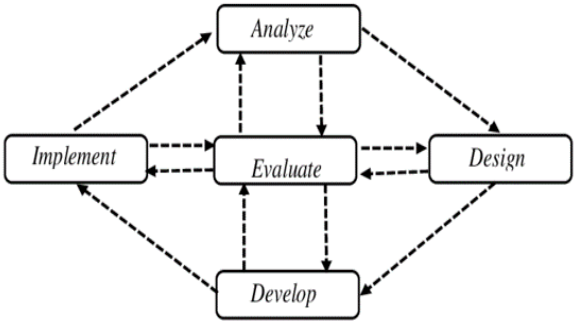

Figure 1. ADDIE Stages

Analyze Stage

The analysis stage focused on identifying the initial needs prior to the development of the e-module. The analysis activities included: (1) analyzing the characteristics of students through interviews with teachers and reviewing the context of science learning at SMP Negeri 11 Magelang; (2) analyzing teachers' and students' needs for alternative instructional materials based on Problem-Based Learning (PBL) and socioscientific issues through questionnaire distribution; (3) conducting a curriculum analysis by

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

examining the Learning Outcomes (CP), Learning Objectives (TP), and science understanding elements in accordance with the Merdeka Curriculum; (4) analyzing the PBL model syntax to be integrated into the e-module activity flow; and (5) analyzing the content of socioscientific issues selected based on criteria of authenticity, relevance, and educational value in local, national, and global contexts.

Evaluation at this stage was conducted through the distribution of a needs assessment questionnaire to 32 students and one subject teacher, as well as an initial diagnostic analysis of critical thinking skills using six multiple-choice questions.

Design Stage

The design stage was carried out by developing an initial framework for the e-module, which included biotechnology content, PBL syntax, and socioscientific issue components. Additionally, the e-module format was designed, covering layout, the use of QR codes, and supporting hyperlinks. At this stage, research instruments were also prepared, including an expert validation sheet, pretest–posttest questions for critical thinking skills, and a practicality questionnaire. The initial e-module design was then consulted with the supervising lecturer to obtain feedback before proceeding to the development stage, serving simultaneously as an evaluation of the design phase.

Development Stage

The development stage involved the initial production of the e-module based on the final framework from the design stage. Content was prepared using Microsoft Word, while the visual design was developed using Canva. The initial e-module prototype was then reviewed internally with the supervising lecturer as a form of formative evaluation.

After revisions were made, the e-module and research instruments were validated by experts. Content validity was assessed based on material feasibility, presentation, language, and graphics using a validation sheet, and then analyzed using Aiken's V index with the following formula:

$$V = \frac{\Sigma s}{n\,(c-1)}$$

$$S = r - l_0$$

where Σs is the total score from the validators, n is the number of validators, and c is the scoring range. An item is considered valid if $V \geq 0.8$. This approach is used to ensure that the level of agreement among evaluators does not occur by chance [12]. Feedback from the validators was used as the basis for revising the e-module before proceeding to the limited trial phase and also served as an evaluation effort in the development stage.

Implementation Stage

The e-module that had been declared valid was subsequently implemented in a limited trial with 32 students of Class IX A at SMP Negeri 11 Magelang City. The practicality of using the e-module was analyzed using a student response questionnaire with a five-point Likert scale [10]. The practicality score was calculated using the following formula:

$$P = \frac{Score}{Maximum\ score} \times 100\%$$

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

The practicality percentage score was then classified based on the following criteria: very practical (81–100%), practical (61–80%), moderately practical (41–60%), less practical (21–40%), and not practical (0–20%) [13].

At this stage, the effectiveness of the e-module in training students' critical thinking skills was also tested using a pretest and posttest consisting of 20 multiple-choice questions. Effectiveness analysis was conducted using the nonparametric Wilcoxon Signed Rank Test and the calculation of the N-Gain score to determine the improvement in students' critical thinking abilities. The N-Gain score was calculated using the following formula:

$$\text{N-Gain} = \frac{Posttest\ score - Pretest\ score}{Maximum\ score - Pretest\ score}$$

The calculated N-Gain scores were then interpreted based on improvement criteria, namely high ($g \geq 0.7$), moderate ($0.3 \leq g < 0.7$), and low ($g < 0.3$) [11]. Evaluation at the implementation stage was conducted by assessing the effectiveness of the e-module in training students' critical thinking skills as well as its practicality, using the mathematical formulations described above.

RESULT AND DISCUSSION

Analyze Stage

Interviews with the science teacher indicated that students' critical thinking skills remain relatively low, particularly in responding to contextual scientific issues. This condition is attributed to the predominance of conventional teaching methods, which have not systematically trained critical thinking skills. The teacher also expressed the need for instructional materials that are interactive and integrated with the Problem-Based Learning (PBL) syntax and socioscientific issues (SSI).

Student needs analysis was conducted through a questionnaire, which revealed that the majority of students were not familiar with contemporary biotechnology issues and had difficulty connecting science concepts to real-world problems. A total of 59% of students indicated a need for instructional materials that present real cases and are easy to understand. These findings highlight the urgency of developing a PBL-based science e-module incorporating socioscientific issues to support meaningful learning.

Design Stage

At the design stage, the e-module was developed based on ninth-grade biotechnology content, referring to the Learning Outcomes (CP), Learning Objectives (TP), and the Pancasila Student Profile elements in the Merdeka Curriculum. The e-module was designed in an interactive digital format (PDF), with attention to readability and students' self-directed learning. The visual design used Radley font at 13 pt and included illustrations, QR codes, and hyperlinks to support material exploration.

In addition to developing the e-module, the research instruments were also designed, including an expert validation sheet, a blueprint of critical thinking skill questions based on six Facione indicators, and a student response questionnaire. The initial e-module prototype was developed using Microsoft Word and Canva, and then

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

reviewed and revised based on feedback from the supervising lecturer.

Development Stage

The development stage was carried out by preparing the product, which was subsequently validated by five experts. The validation covered four aspects: content feasibility, presentation, language, and graphics.

Table 1. Recapitulation of the e-module validation results

Assessment Aspects	Aiken's V Index	Category
Content Feasibility	0,90	Valid
Presentation Feasibility	0,93	Valid
Language Feasibility	0,92	Valid
Graphics Feasibility	0,95	Valid
Total	**0,92**	**Valid**

Table 1 shows that all aspects fall into the valid category, with an average score of 0.92. The graphics aspect received the highest score (0.95), followed by presentation (0.93), language (0.92), and content (0.90). These scores indicate that the e-module has met substantial feasibility criteria and is suitable for implementation in learning [14].

In the content feasibility aspect, the validators provided feedback emphasizing the importance of including credible sources or references in the scientific facts feature. Adding these references aligns with the principles of scientific literacy, which can train students to think critically about evidence-based information [15].

The presentation aspect received a validity score of 0.93 and was considered consistent with the PBL syntax, thereby promoting active student engagement and facilitating self-directed learning [16]. Nevertheless, the validators recommended that the PBL stages be explicitly stated in the e-module and accompanied by indicators of the critical thinking skills targeted in each activity. Additionally, during the product presentation stage, it was suggested that students produce tangible artifacts as concrete representations of biotechnology topics and socioscientific issues. The validators also emphasized the need to improve the flow in the investigation and analysis stages, as well as to strengthen reflective discussions of socioscientific issues during the evaluation phase.

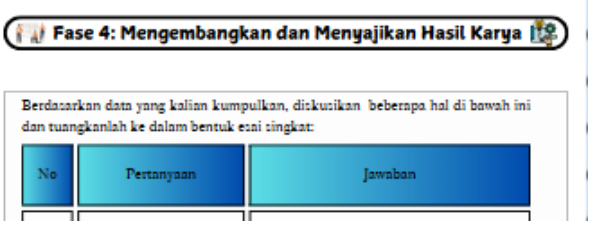

Figure 2. Emphasis on learning artifacts within the "presenting and developing work" syntax

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

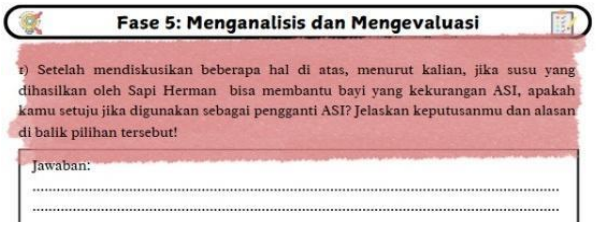

Figure 3. Explicit discussion activities within the "analyzing and evaluating" syntax

The language aspect received a validity score of 0.92. The language used in the e-module was considered communicative, appropriate for the cognitive level of junior high school students, and unambiguous. Clear and accurate language plays an important role in enhancing students' understanding of the learning material [17]. Nevertheless, several improvements were made concerning the application of the Enhanced Spelling System (EYD), consistency in the use of capital letters and punctuation, and correction of writing errors.

The graphics aspect received the highest validity score of 0.95, indicating that the e-module's visual design was very well crafted through proportional layout, harmonious color selection, and illustrations that support content comprehension. The integration of visual and verbal elements in instructional materials has been shown to enhance the effectiveness of students' information processing [18]. Validator feedback for this aspect primarily focused on simplifying the wording of activity titles and improving the neatness and consistency of the glossary format. All validator suggestions were used as the basis for revisions to comprehensively enhance the quality of the e-module.

Implementation Stage

After the development stage, the e-module was trialed through classroom implementation. Evaluation at this stage was conducted by assessing the practicality and effectiveness of the e-module. The practicality of the e-module was measured using a student questionnaire covering the aspects of presentation, content, and language.

Table 2. Recapitulation of the e-module practicality scores

Aspect	Percentage	Category
Presentation	81%	Very Practical
Content	77%	Practical
Language	85%	Very Practical
Total	**81%**	**Very Practical**

The assessment results in Table 2 show a total practicality score of 81%, categorized as very practical, with the language aspect receiving the highest percentage (85%), followed by presentation (81%) and content (77%). These results indicate that the e-module has satisfactorily met the practicality criteria.

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

The language used is communicative, easy to understand, and appropriate for students' cognitive abilities [19]. In addition, an attractive visual design and systematic layout further support students' comfort and engagement in learning [20]. Nevertheless, the content aspect still requires improvement, particularly in simplifying the material and strengthening its connection to students' everyday context.

Students also recommended adding interactive elements, such as videos, infographics, digital student worksheets (e-LKPD), and online platform–based discussion forums [21]. This aligns with the social constructivist approach, which emphasizes the importance of collaboration and reflection in meaningful learning [22].

Table 3. n-gain Score

Data	N-Gain	Category
Pretest - Posttest	0,47	Moderate

The effectiveness of the e-module was tested on 32 students of Class IX A at SMP Negeri 11 Magelang City. The Wilcoxon Signed-Rank Test results in Table 3 indicate a significant difference between pretest and posttest scores ($p = 0.000$), suggesting that the use of the e-module had a significant effect on improving students' critical thinking skills. N-Gain analysis showed a score of 0.47 in the moderate category, indicating a fairly meaningful improvement in critical thinking ability [23].

The implementation of the PBL-based e-module incorporating socioscientific issues promoted active student engagement in solving contextual problems, thereby contributing to the development of critical thinking skills, particularly in constructing arguments and evaluating evidence-based information [24]. Nevertheless, the moderate N-Gain achievement indicates the need for further reinforcement of learning, influenced by the complexity of the material, time constraints, and students' adaptation to the problem-based approach [25].

Overall, the N-Gain score of 0.47 indicates that the e-module is moderately effective in improving students' critical thinking skills. However, further development is still needed by strengthening reflective activities, providing teacher guidance, and integrating interactive features to support students' self-regulation in learning [26].

CONCLUSION

The science e-module developed in this study, integrated with the Problem-Based Learning (PBL) model and incorporating socioscientific issues, has met the criteria for validity, practicality, and effectiveness in training students' critical thinking skills on biotechnology concepts. Expert validation results showed an Aiken's V value of 0.92, indicating that the e-module is suitable for use in terms of content substance, presentation, language, and graphics.

In terms of effectiveness, the implementation of the e-module was

Jurnal Pendidikan Matematika dan IPA
Vol. 17, No. 2 (2026) h. 235-244

shown to significantly improve students' critical thinking skills, as evidenced by the Wilcoxon Signed-Rank Test results ($p = 0.000$) with a moderate N-Gain value (0.47). The most notable improvements occurred in the indicators of explanation, evaluation, and analysis, while the self-regulation indicator showed relatively lower gains. These findings suggest that integrating PBL and socioscientific issues in the e-module is effective in promoting problem-based critical thinking, but still requires reinforcement in metacognitive aspects.

In terms of practicality, student responses indicated that the e-module is easy to use, engaging, and supportive of self-directed learning, with a practicality score of 81%. This confirms that the e-module is not only theoretically feasible but also applicable in the context of school-based science learning.

Implication-wise, the results of this study indicate that the PBL-based e-module incorporating socioscientific issues can serve as an innovative alternative instructional material to support science learning oriented toward the development of critical thinking skills. Further development is recommended to strengthen reflective and self-regulation features, integrate socioscientific issues based on local wisdom, and utilize interactive digital technology to enhance student engagement and learning effectiveness.

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Vol. 17, No. 2 (2026) h. 235-244

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