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Problem-based learning in improving critical mathematical thinking skills: Independent curriculum teaching module

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Abstract

Background: Students' limited abilities in critical mathematical thinking present a persistent obstacle in mathematics education. To address this issue, this study focuses on developing a teaching module aligned with the Independent Curriculum, incorporating the Problem-Based Learning (PBL) approach.

Aim: This research aims to design and validate a teaching module tailored to enhance students' critical thinking skills in solving mathematical problems.

Method: Employing the Plomp development model, the study was conducted through three phases: preliminary analysis, development or prototyping, and evaluation. Data collection involved expert validation, with analysis performed using a validity index.

Result: The independent curriculum teaching module received an average validity score of 3.57, categorized as highly valid, confirming its feasibility and alignment with instructional criteria.

Conclusion: The findings demonstrate that the developed module fulfills all validity criteria, making it suitable for use in mathematics education to support the development of critical thinking skills. Further studies are encouraged to investigate its influence on students' learning outcomes.

INTRODUCTION

Mathematics extends its influence far beyond numbers and equations, standing as a critical pillar for the advancement of science and technology. In mathematics education, students are not only exposed to abstract concepts but are also encouraged to develop systematic, logical, and critical thinking skills, which help them effectively convey ideas and solve mathematical problems (Ainin et al., 2020). According to the Ministry of National Education, fostering critical mathematical thinking skills is a primary objective in the junior high and high school curricula (Putri et al., 2020). Critical thinking, described as the process of guiding individuals to make logical and reasoned decisions (Ennis, 1993), is a core competency that supports the development of other essential skills, such as problem-solving and analytical reasoning (Darhim et al., 2020). With strong critical thinking abilities, students are better prepared to tackle both straightforward and intricate challenges, equipping them to excel academically and address practical problems in real-world contexts (Setiana & Purwoko, 2020). As such, critical thinking forms a fundamental foundation for success in both educational and everyday domains.

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One approach to assess students' critical mathematical thinking skills is by providing them with mathematical story problems that are directly connected to their everyday experiences (Sari et al., 2024). Among the various mathematical topics, probability stands out as a material that effectively highlights students' ability to think critically when solving story problems (Tarmizi & Bayat, 2012). As noted by Sari et al. (2024), the study of probability demands critical thinking skills, including the capacity to analyze situations, identify pertinent information, and make decisions grounded in the outcomes of problem analysis. This aligns with previous findings suggesting that mathematical concepts integrated into real-life contexts significantly enhance students' engagement and critical thinking abilities (Malaluan & Andrade, 2023). This approach not only strengthens students' conceptual understanding but also enables them to apply mathematics effectively in solving real-world problems.

Based on the results of a mathematical critical thinking skills test involving 94 students from three Islamic Senior High Schools (MAN) in Padang, it was found that 45 students were categorized as not critical, 20 as less critical, 12 as moderately critical, 8 as critical, and only 9 as highly critical. Overall, the number of students categorized as critical or highly critical was significantly lower than those in the other categories. This indicates that students' critical thinking skills are generally low. Interviews with mathematics teachers from the three schools also revealed that most students struggle with solving mathematical word problems. Teachers explained that students often face difficulties in understanding the core of the given problem, identifying the known information, and formulating problem-solving strategies. As a result, students frequently fail to solve word problems correctly. These challenges are also reflected in mathematics test results, where many students make errors on word problem questions.

One instructional approach that can be employed to address these issues is Problem-Based Learning (PBL). PBL is a student-centered teaching method (Ali, 2019; Huang & Liao, 2024) that encourages learners to solve real-world problems relevant to their daily lives (Suparman et al., 2023). This approach not only enhances student engagement in the learning process but also helps them develop critical thinking skills through systematic stages, such as problem identification, information analysis, and solution evaluation. Previous studies have demonstrated that PBL is effective in improving students' mathematical critical thinking skills, particularly on topics that require in-depth analysis (Apriyani et al., 2019; Primayanti et al., 2018). By utilizing this approach, students are trained to understand concepts contextually, relate them to real-life situations, and solve problems logically and systematically (Winarso & Haqq, 2020). Consequently, students not only gain a conceptual understanding but are also able to apply it in various relevant contexts. This aligns with the objectives of the independent curriculum, which provides flexibility in developing context-based instructional materials to support more meaningful learning experiences.

The independent curriculum, a new policy introduced by the Ministry of Education, Culture, Research, and Technology, provides educators with the flexibility to develop instructional materials that are relevant, contextual, and aligned with students' needs (Syahril et al., 2023). This curriculum is designed to support student-centered learning,

where students are encouraged to actively engage in the learning process through exploration, analysis, and problem-solving (Efendi & Suastra, 2023). One of the key features of the independent curriculum is its emphasis on strengthening students' competencies to address real-world challenges by integrating locally and globally contextualized learning (Mustafiyanti et al., 2023). This competency enhancement also offers students the opportunity to become independent, active, and adaptive learners, equipped to navigate various social and technological dynamics in the future.

Supporting the implementation of the independent curriculum, this study develops a learning module based on the Problem-Based Learning (PBL) approach. The module is designed to enhance critical thinking skills, enabling students to solve problems using precise and accurate steps (Tosuncuoglu, 2018; Faiziyah & Priyambodho, 2022). This module also facilitates students in breaking down problems (Anggraini et al., 2020), evaluating solutions (Cailloux & Meinard, 2020), and making decisions grounded in relevant facts (Tomesko et al., 2022). The approach encourages systematic thinking and independent problem-solving, shifting the learning process from merely mastering content to fostering critical thinking skills applicable in various life contexts.

Previous studies have highlighted the importance of developing students' mathematical critical thinking skills to solve everyday problems, as demonstrated by Basri et al. (2019), Darmawan & Warmi (2022), Suanto et al. (2022), Susilo (2022), Istiqomarie et al. (2023), Karim & Nurlaelah (2023), Permatasari & Nurhanurawati (2021), and Rizki et al. (2023). To the best of the researcher's knowledge, there has been no development of problem-based learning modules within the context of the independent curriculum to date. This study provides a fresh perspective by designing a problem-based learning module specifically tailored to support the implementation of the independent curriculum. The integration of the PBL approach with the independent curriculum creates an innovative learning model that is not only aligned with current educational needs in Indonesia but also provides a practical solution to enhance students' abilities. Accordingly, this study aims to develop a problem-based learning module designed to improve students' mathematical critical thinking skills.

METHODS

Design:

This research is a development research that aims to produce a mathematics teaching module on the topic of probability to improve students' critical mathematical thinking skills. This research uses a development procedure by Plomp which consists of three stages, namely the preliminary stage, the development or prototype making stage and the assessment stage. The stages of the development procedure can be seen in Table 1.

Table 1. Product Development Procedures

Stage	Criteria	Activity Description
Preliminary Research	More emphasis on content validity.	Problem analysis and literature study. The result of this stage is the initial design form of the prototype.
Prototyping Phase	Focus on consistency (construct validity) and practicality.	Development of a prototype that will be tested and revised based on formative evaluation.
Assessment Phase	Efficiency / Effectiveness.	Assess whether the product is effective.

Source: Translation and modification (Plomp & Nienke Nieveen, 2013)

Based on Table 1, the procedures carried out at each stage can be seen, starting from the preliminary stage, continuing to the prototype making stage and ending at the assessment stage. However, due to the limitations that the researcher has, this study is limited to the Prototyping Phase in the form of a valid teaching module to be used in improving students' critical mathematical thinking skills.

Participants:

This research was conducted with the aim of producing a mathematics teaching module for the independent curriculum based on Problem Based Learning to improve the critical thinking skills of students in mathematics. The teaching module that had been designed was validated by several experts consisting of three mathematics lecturers to validate the content aspect, one language lecturer to validate the language aspect, and one educational technology lecturer to validate the display or graphic aspect of the teaching module.

Instruments:

The instrument used in this study was a validation sheet that had been validated to see the validity of the designed teaching module. The instrument was then given to the validators who participated as validators of the developed teaching module. The designed teaching module is an independent curriculum teaching module that focuses on opportunity material to improve students' mathematical thinking skills.

Data Analysis:

The teaching module designed and used in this study is the independent curriculum teaching module based on Problem Based Learning. Before being tested on students, the teaching module was validated by several validators. The validation results by the validators were then adjusted to the validation criteria by Muliyardi (2006) as seen in Table 2 below.

Table 2. Validity Criteria

Percentage	Criteria
$3{,}4 \leq R \leq 4{,}0$	Very Valid
$2{,}8 \leq R < 3{,}4$	Valid
$2{,}2 \leq R < 2{,}8$	Quite Valid
$1{,}6 \leq R < 2{,}2$	Less Valid
$1{,}0 \leq R < 1{,}6$	Not valid

Based on the validity criteria in Table 2, a good teaching module is used if it has been declared valid by obtaining an average of ≥ 2.8 and is in the valid or very valid criteria. This means that if the results of the teaching module validation obtain an average of < 2.8, it is stated that it does not meet the valid criteria, so improvements are needed to the teaching module.

RESULTS AND DISCUSSION

Result

This research was conducted through several stages, namely the preliminary stage, product development stage and assessment stage. In the preliminary stage, the results obtained that students' critical mathematical thinking skills were still lacking, students also had difficulty in solving problems in the form of story problems so it was concluded that an effective module or teaching material was needed to help students improve their critical mathematical thinking skills and also make it easier for students to solve various story problems given.

Based on the findings in the preliminary stage, a mathematics teaching module was designed with the topic of opportunity to improve students' critical mathematical thinking skills. The teaching module was designed based on Problem Based Learning by implementing the independent curriculum. The teaching module has several components, namely general information about the teaching module, initial components, Pancasila profile, learning outcomes, learning objectives, teaching materials and assessment of student learning outcomes. The teaching module focuses on the topic of opportunity for grade X SMA students with various contextual problems presented in the form of story problems. One of the contextual problems designed can be seen in the following picture.

Figure 1. Contextual Issues

The finished product is then checked again to prevent any typos or errors in the teaching materials. Furthermore, the teaching module is given to the validator for validation. Validation is carried out by several experts to assess the level of validity of each aspect listed in the Problem Based Learning-based teaching module. The validation results by the validators can be seen in Table 3 below.

Table 3. Validation Results of Problem Based Learning Teaching Module

Aspects Assessed	Validity Index	Category
Presentation	3.56	Very Valid
Content Suitability	3.47	Very Valid
Language	4.00	Very Valid
Graphics	3.25	Valid
Average Validity Index	**3.57**	**Very Valid**

Based on Table 3 above, it shows that the aspects assessed in the teaching module consist of presentation aspects, content feasibility aspects, language aspects and graphic aspects. The presentation and content feasibility aspects, and language of the teaching module meet the very valid category, then the graphic or display aspect of the teaching module meets the valid category. Overall, the level of validity of the designed teaching module obtained a validity index of 3.57 and met the very valid category for use in learning.

Discussion

The results of this research demonstrate that the developed teaching module has been validated and deemed effective for use in learning environments. This validation confirms that the module aligns with the required standards to support the learning process, particularly in fostering students' critical mathematical thinking abilities. The module aims to address deficiencies in existing teaching resources by offering a structured and targeted approach to developing these essential skills. Its implementation in classrooms is expected to greatly assist students in overcoming difficulties associated with understanding and solving complex mathematical problems.

The adoption of this validated teaching module is expected to substantially enhance students' critical thinking capabilities in mathematics. By involving students in activities that emphasize exploration, reasoning, and problem-solving, the module seeks to encourage deeper comprehension and cognitive engagement. According to Darmayanti et al. (2022), improving critical thinking skills enables students to better address challenges in identifying and analyzing information. This improvement is especially critical in mathematics, a subject that often presents abstract concepts requiring connections to real-world contexts.

Previous research has underscored the importance of critical thinking in empowering students to reason effectively and approach problems with confidence (Ardiansyah et al., 2022). Strengthening their ability to evaluate and interpret information enables students to identify key ideas, question assumptions, and construct well-grounded arguments. The module’s design is centered on cultivating these competencies in a structured and supportive learning environment, thereby equipping students to successfully navigate both academic and real-life challenges.

One of the core benefits of fostering critical thinking is the ability to critically evaluate and verify the accuracy of information. Monteleone et al. (2023) argue that individuals with well-developed critical thinking skills can process intricate information

and draw logical conclusions. This ability is increasingly essential in today's data-driven world, where students must assess not only the content they receive but also its relevance, credibility, and implications. By incorporating tasks designed to enhance these evaluative skills, the module serves as a valuable tool for both mathematical problem-solving and broader decision-making processes.

The validation and application of this teaching module signify a notable advancement in mathematics education, particularly in embedding critical thinking as a core objective. By enabling students to reason logically and critically evaluate information, the module contributes significantly to their cognitive growth and their readiness to address complex problems. This aligns with modern educational priorities, which emphasize the importance of 21st-century skills such as critical thinking and problem-solving. Ultimately, this module represents a forward-thinking and practical solution that can be adapted and scaled to meet the diverse needs of learners in various educational contexts.

Implication

The resulting teaching module is a mathematics teaching module with an independent curriculum on the topic of probability with valid categories for use in learning, especially on the topic of probability. Furthermore, it can also be a reference for further researchers to develop similar teaching modules that can improve students' mathematical abilities through various other studies.

Limitation and Suggestion for Further Research

Based on the conditions that the researcher experienced directly at the research location, the researcher had difficulty in determining the time for data collection and implementation of the preliminary stage, so that the determination of the implementation time was adjusted according to the direction of the school. Furthermore, the teaching module produced from this study only focuses on students' critical mathematical thinking skills with the topic of probability, so that for further researchers it is expected to be able to develop research on other mathematical abilities as well as on different mathematical materials.

CONCLUSIONS

This study successfully developed an independent curriculum teaching module utilizing a problem-based learning approach. Validation results indicate that the module meets the criteria for validity in mathematics instruction, achieving an average validity score of 3.57, which falls under the "highly valid" category. The module is specifically designed to enhance students' mathematical critical thinking skills by providing a contextual learning experience rooted in real-world problems.

AUTHOR CONTRIBUTIONS STATEMENT

HJ : Conceptualization, module design, implementation, and data curation.
EJZ : Supervision, guidance, module validation, and review.

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