The Development of Inquiry-Based STEM Instructional Modules on Students' Critical Thinking Skills in Geometry and the Application of Water Purification Processes

Hosiatus Sajawiyah[1]*, Wahyu Lestari[2], Athar Zaif Zairozie[3]
[123]Universitas Islam Zainul Hasan Genggong, Kraksaan, Probolinggo, 67282, Indonesia
hosiatussajawiyah12@gmail.com[1]*, why.lestari94@gmail.com[2], zaif.athar@gmail.com[3]
*corresponding author

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ABSTRACT

Students' critical thinking skills in mathematics are not yet optimally developed, particularly in geometry learning, which is often presented in an abstract manner with limited connection to real-life contexts. This study aimed to develop a STEM-integrated instructional module based on an inquiry-oriented learning framework for three-dimensional geometry using a water purification context to create more meaningful learning experiences. The study employed a development research design using the ADDIE framework, which consists of five phases: analysis, design, development, implementation, and evaluation. The participants were 20 ninth-grade students from a lower secondary school (SMP Mambaul Ulum). Data were collected through expert validation forms, student response questionnaires, and a critical thinking skills test to evaluate the module's validity, practicality, and effectiveness. The findings revealed that the developed module met the required criteria. It demonstrated a high level of validity, with a score of 82%. The practicality of the module improved from 65% in the initial trial to 75% after revision. Furthermore, its effectiveness was reflected in the improvement of students' critical thinking skills, with mastery levels increasing from 75% to 85%. Overall, the results indicate that the inquiry-based STEM module is both appropriate and effective as an instructional resource, as it supports learning that is closely connected to real-life contexts and enhances students' critical thinking skills in three-dimensional geometry.

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INTRODUCTION

Education serves as a primary factor in the development of human resources and acts as a driving force for a nation's progress. In this context, the learning process is a key element that serves to develop students' potential in terms of knowledge, skills, and attitudes (Musbikin, 2021). One of the subjects that significantly contributes to the development of thinking skills is mathematics. The study of mathematics is not only aimed at understanding concepts and procedures, but also at developing logical, systematic, analytical, and critical thinking skills in solving various problems (Harini, 2023).

A number of global studies indicate that the higher-order thinking skills of students in Indonesia, particularly in mathematics, remain relatively low. This can be observed based on the results of the international Programme for International Student Assessment (PISA) survey conducted by the Organisation for Economic Cooperation and Development (OECD) to assess reading, mathematics, and science literacy among 15-year-old students in various countries; data from 2022 shows that Indonesian students' mathematics literacy remains below the average of OECD member countries. This reflects that students' understanding of mathematical concepts still needs to be improved, as does their ability to apply these concepts to solve contextual problems (Risyani, et al. 2024). An illustration comparing 2022 PISA scores across several Southeast Asian countries, as shown in Figure 1.

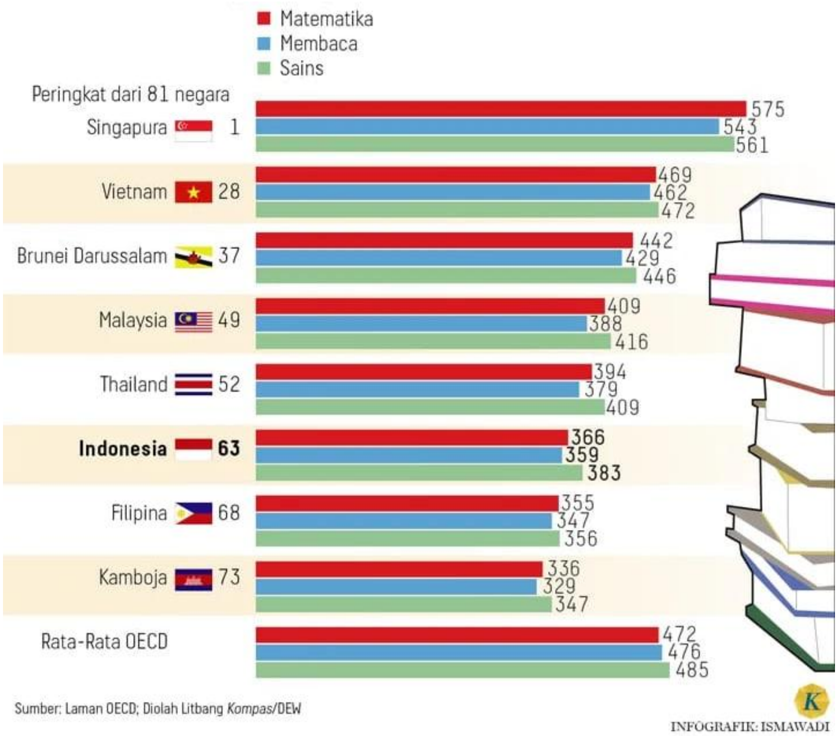

Figure 1. 2022 PISA Results for ASEAN Countries

In practice, mathematics instruction in schools still tends to be teacher-centered, with an emphasis on the theoretical presentation of material. Recent research findings suggest that such an instructional approach can lead to low levels of active student participation in learning activities. This situation has the potential to limit students' opportunities to explore ideas, ask questions, and develop their critical thinking skills to the fullest extent (Anwar, 2015). Learning conditions that do not encourage active student engagement limit students' ability to analyze problems in depth and to connect mathematical concepts to real-life contexts. This issue is particularly evident in solid geometry, which requires spatial visualization skills, logical reasoning, and an understanding of the relationship between abstract representations and concrete objects. A number of studies indicate that students' difficulties in understanding geometric concepts are not only caused by the complexity of the material but also by a lack of learning activities that tend to be exploratory and investigative in nature (Indah, et al., 2025).

Conceptually, geometry instruction is closely linked to the development of critical thinking skills. The process of understanding shapes, space, and the relationships between objects requires students to analyze, interpret, and draw logical conclusions. Thus, the development of critical thinking skills is essential in mathematics education, particularly in the topic of geometry. These skills include identifying problems, evaluating information, and formulating arguments and solutions in a systematic and rational manner (Maufiroh & Lestari, 2024). As an alternative solution, the Inquiry–STEM approach is considered effective in fostering the development of students' critical thinking skills. This approach integrates the scientific inquiry process with the interdisciplinary fields of Science, Technology, Engineering, and Mathematics, thereby training students to identify problems, formulate questions, conduct investigations, analyze data, and draw logical conclusions (Hasanah, et al., 2022).

In addition, using real-world contexts, such as the water purification process, can help students understand the connection between mathematical concepts and everyday life, particularly in the application of solid geometry (Saputri & Herman, 2022). For the Inquiry–STEM approach to be implemented effectively, there is a need for structured instructional materials that are aligned with the characteristics of the students. Learning modules are one option that can facilitate this process, as they include content, problem-based activities, and assessments that encourage active student engagement (Lestari, et al., 2025).

Although a number of studies have shown that STEM and inquiry-based approaches have the potential to develop critical thinking skills, most research still focuses on the implementation of learning models without being complemented by the development of specifically designed instructional materials. Furthermore, the use of contextual problems closely related to students' lives in mathematics instruction—particularly regarding three-dimensional shapes—remains relatively limited (Adelia, 2025). With the support of systematically and structurally organized modules, the learning process has the potential to be more focused and to facilitate active student engagement. Several studies indicate that instructional materials incorporating problem-based activities, step-by-step learning guides, and integrated assessments can help develop critical thinking skills through the processes of analysis, reflection, and logical conclusion-drawing. Therefore, research is needed to develop Inquiry–STEM-based mathematics learning modules with relevant contexts to support the optimal enhancement of students' critical thinking skills (Davidi, et al., 2021).

Several previous studies have shown that both the STEM approach and inquiry-based learning contribute to the development of students' critical thinking skills (Wahyu & Parmin, 2025; Zalsa, et al., 2025; Maulidyah, et al., 2024). However, most of these studies still focus on the implementation of learning models, without the development of instructional materials specifically designed to support their systematic application. However, most of these studies still focus on the implementation of learning models, without the development of instructional materials specifically designed to support their structured and sustainable application. On the other hand, the use of real-world problems closely related to students' daily lives in mathematics instruction remains limited, particularly in the area of solid geometry (Alfiyansyah & Salito, 2025).

Several previous studies have shown that the STEM approach contributes to improving the quality of the learning process while developing students' higher-order thinking skills. For example, Rodger W. Bybee emphasizes that STEM is an integrated learning approach that connects science, technology, engineering, and mathematics in real-life contexts to enhance students' understanding and thinking skills (Muttaqiin, 2023). In addition, Mark Sanders argues that the STEM approach promotes interdisciplinary integration, which provides students with opportunities to hone their problem-solving skills and critical thinking abilities through context-based learning. Nevertheless, the majority of existing studies still focus on the implementation of the learning approach without the development of instructional materials specifically designed to support its systematic application (Pertiwi, 2017).

Given these circumstances, there is a clear research gap: the lack of Inquiry–STEM-based mathematics learning modules that integrate three-dimensional geometric concepts with real-world contexts relevant to students. Therefore, this study focuses on developing Inquiry–STEM-based modules that use water purification as a context to connect mathematical concepts with their real-world applications. The main contribution of this study lies in the systematic integration of the Inquiry–STEM approach, the development of instructional materials in the form of modules, and the use of authentic contexts to support the improvement of students' critical thinking skills (Utari, et al., 2024).

Based on the above discussion, although various studies have examined the application of STEM and inquiry-based approaches in mathematics education, most studies still focus on the implementation of instructional models without being accompanied by the development of teaching materials that are specifically designed and integrated with real-world contexts. Furthermore, research specifically developing Inquiry–STEM-based modules on solid geometry by linking them to students' daily lives remains limited. Therefore, this study focuses on developing Inquiry–STEM-based learning modules on solid geometry using the context of water purification. This development aims to produce instructional materials that meet the criteria of being valid, practical, and effective (Lastri, 2023). At the same time, it represents a new contribution through the systematic integration of the Inquiry–STEM approach, module development, and the use of authentic contexts. Thus, the developed modules are expected not only to support learning activities but also to optimize students' critical thinking skills and help them connect mathematical concepts to real-world problems in a more meaningful way.

METHOD

This study employs a research and development (R&D) approach with the aim of producing an inquiry-based STEM learning module on the topic of solid geometry within the context of water purification that meets feasibility standards encompassing validity, practicality, and effectiveness in supporting the learning process and fostering the development of students' critical thinking skills. The development approach was chosen because it emphasizes the design and development of products, as well as the structured evaluation of learning products, so that they can be maximally utilized in mathematics learning (Emerentiana, et al., 2020).

This study employs the ADDIE development model, which comprises five stages: analysis, design, development, implementation, and evaluation. The sequence of these development stages is presented in a flowchart to clarify the research process. In the analysis stage, activities focused on identifying learning needs through a literature review and an examination of mathematics learning conditions in schools. This stage included an analysis of the curriculum, student characteristics, and the instructional materials to be studied, particularly regarding the topic of solid geometry (Rohaeni, 2020).

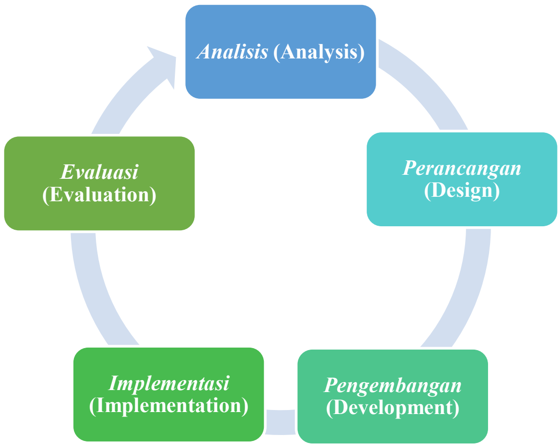

Figure 2. The Stages of the ADDIE Model

This stage also emphasizes the importance of efforts to enhance students' critical thinking skills in the mathematics learning process. Furthermore, during the design stage, a framework for the Inquiry–STEM-based learning module to be developed is formulated. This stage involves determining learning objectives, indicators of critical thinking skills, and designing learning activities that integrate the inquiry approach with concepts combining science, technology, engineering, and mathematics (STEM). The learning context selected for the module is a simple water purification process, so that students can relate the concept of solid geometry to real-world problems in their surroundings (Sunedi & Syaflin, 2024).

The development phase involved creating learning modules based on the previously designed framework; these modules then underwent a validation process by experts to assess their suitability. The validators in this study included mathematics education faculty members and mathematics teachers with expertise in mathematics instruction. The results of this validation served as the basis for refining the modules before entering the implementation phase, which included a pilot test with ninth-grade students to assess the practicality of the modules and student responses to the Inquiry–STEM-based learning activities presented within them. Subsequently, the previously developed design was used to create the modules, which then underwent a validation process by experts. Student feedback and their performance on critical thinking tests following the use of the instructional modules (Sun'an, et al., 2023). Theoretically, critical thinking is rooted in the philosophical tradition of rationalism and has developed within cognitive psychology. In the 1990s, education researcher Facione identified five key elements of critical thinking that are still frequently referenced today: Interpretation, Analysis, Evaluation, Inference, and Explanation. These five aspects also served as the foundation for the development of the California Critical Thinking Skills Test (CCTST), a widely used assessment tool in the international academic community (Facione, 1990). These five indicators are not merely conceptual; rather, they are concrete skills that can be taught and developed through classroom learning activities.

Table 1. Critical Thinking Indicators

Indicator	Sub-indicator	Description
Interpretation	Identifying important information	The ability to identify key data or information from a text, statement, graph, or image.
	Explaining the meaning of the information	The ability to break down or rephrase information obtained in one's own words to make it easier to understand.
Analysis	Identifying relationships between concepts	The ability to identify connections between ideas, concepts, or information provided.
	Distinguishing between facts and opinions	The ability to identify connections between ideas, concepts, or information provided. The ability to determine whether a piece of information is a verifiable fact or merely an opinion.
Inference	Drawing conclusions from the data	The ability to draw logical conclusions based on available evidence or information.
	Formulating a hypothesis or conjecture	The ability to predict possible answers or solutions based on available information.
Evaluation	Assessing the accuracy of information	The ability to assess whether the information or data being used is reliable and factually accurate.
	Evaluating the strength of an argument	The ability to determine whether the reasons or evidence provided are strong enough
Explanation	Explaining one's thoughts logically	The ability to present the results of an analysis or conclusions with clear and logical reasoning.
	Provide a reason for the answer	The ability to provide evidence or reasons to support the answers or opinions given.

This study involved 20 ninth-grade students at Mambaul Ulum Junior High School, located in Kaliacar Village. The research subjects consisted of students who had studied solid geometry. The research subjects were selected using purposive sampling, which involves selecting a sample based on specific criteria aligned with the research objectives. The criteria used included: (1) students had received the solid geometry material, (2) students had diverse academic abilities, and (3) students were willing to participate in the entire learning process using the developed module. The rationale for selecting these criteria was to ensure that the research subjects were relevant to the material under study and could provide a representative picture of the module's effectiveness in enhancing critical thinking skills. This study was conducted during the second semester of the 2025/2026 academic year, utilizing instruments such as a validation sheet, a student feedback questionnaire, and a test to measure critical thinking skills. The validation sheet was used to evaluate the suitability of the module based on the aspects of content appropriateness, presentation, language, and integration with the Inquiry–STEM approach. A more detailed explanation can be seen in the following Table 2.

Table 2. Data collection methods

Aspects Evaluated	Data	Instruments	Methods	Respondents
Validity of the module	Content validity, presentation, language, and graphic design of the module	Validation sheet	Survey	Subject matter expert, media expert, learning expert
The practicality of the module	The implementation of learning using modules	Implementation Observation Sheet	Observation	Observer
	Students' response to the use of the module	Student Feedback Survey	Survey	Student
The effectiveness of the module	Students' critical thinking test results	Test (critical thinking questions)	Test	Student
	Student activities during Inquiry–STEM learning	Student Activity Observation Sheet	Observation	Observer
	Student Responses to Inquiry-Based STEM Learning	Student Feedback Survey	Survey	Student

Next, the student feedback questionnaire was used as a reference to assess the extent to which the practical module could be applied in the learning process, including the ease of understanding the material, the clarity of activity instructions, student engagement during the learning process, and the visual appeal of the module. Meanwhile, the critical thinking skills test was used to measure students' mastery of critical thinking skills after using the module, with indicators including comprehension. These activities included identifying problems, analyzing information, evaluating solutions, and drawing conclusions (Pratama, et al., 2022).

The data for this study were obtained through expert evaluations, the distribution of student response questionnaires, and the administration of critical thinking skill assessments. The collected data were then analyzed using a quantitative descriptive approach to assess the extent to which the developed learning module is suitable for use. Validity testing was conducted based on the evaluators' assessments by calculating the percentage of scores on the validation sheets. The module was deemed valid if it achieved a minimum percentage of 61%. Furthermore, the practicality of the module was analyzed through student response questionnaires by calculating the percentage of scores regarding the use of the module in learning, where the module was categorized as practical if it obtained a minimum score of 61%. The effectiveness of the module in this study was assessed based on the results of measuring students' critical thinking skills after undergoing the learning process using the developed module. The assessment of effectiveness refers to the percentage of learning mastery, where the module is deemed effective if at least 61% of students achieve a score exceeding the Minimum Passing Criteria (KKM) set by the school, which is 60%.

The selection of these criteria is based on the consideration that this study focuses on the product development phase (development study), which aims to assess the initial feasibility and functionality of the module in a real-world learning context. Therefore, the use of classical mastery indicators is considered relevant as a practical measure to evaluate the extent to which the module can help the majority of students achieve the established competency standards. Furthermore, the 61% threshold refers to the classical mastery criterion commonly used in development research as a minimum indicator of a learning product's effectiveness. Further details regarding these criteria can be found in Table 3.

Table 3. Criteria for Validity, Practicality, and Effectiveness

No	Percentage	Evaluation Criteria	Notes
1	$81\% \leq V \leq 100\%$	Excellent	The product can be used as is
2	$61\% \leq V \leq 81\%$	Good	The product is usable but requires minor revisions
3	$41\% \leq V \leq 61\%$	Fair	The product is not recommended for use as it requires major revisions
4	$21\% \leq V \leq 41\%$	Poor	The product is unusable/invalid and requires a complete overhaul
5	$0\% \leq V \leq 21\%$	Very Poor	The product is unusable/invalid and requires a complete overhaul

RESULTS AND DISCUSSION

1. Analysis phase *(analisis)*

The analysis phase is the initial stage of the ADDIE development model, aimed at identifying learning needs and issues that arise during the process. During this phase, an assessment is conducted of the mathematics learning environment, student characteristics, and the need for instructional materials aligned with the content to be developed (Hidayat & Nizar, 2021). The results of this analysis indicate that the mathematics learning process, particularly regarding three-dimensional shapes, remains suboptimal, as it is heavily focused on theoretical instruction and has not yet been sufficiently linked to real-world problems in the students' environment. This situation has led to low levels of student understanding in applying mathematical concepts to daily life, and students' critical thinking skills have not yet developed to their full potential.

One of the problems frequently encountered in local communities is the lack of clean water, especially during the rainy season, which causes well water or water channels to become murky and unfit for use. These conditions highlight the need for simple solutions that communities can implement themselves, such as building water purification devices using materials easily found in the local environment, for example, gravel, charcoal, and coconut fiber. However, in practice, another problem often arises: the size of the container used in the water purification process is inappropriate, resulting in suboptimal amounts of clean water produced. This issue can be addressed through the concepts of solid geometry, particularly in determining the shape of the container and calculating the required volume so that the water purifier can function effectively (Fatma, 2026). Therefore, there is a need to develop Inquiry–STEM-based learning modules that link the concepts of solid geometry to the context of water purification, so that students' critical thinking skills can be optimally enhanced through a learning process integrated with real-life situations.

2. Design phase *(perancangan)*

The design phase aims to develop the learning modules to be used, based on the results of the needs assessment. During this phase, the module structure is designed to include learning objectives, content on solid geometry, and learning activities that integrate the Inquiry–STEM approach (Harianja & Anwar, 2021). The teaching module developed consists of several key components, including an introduction, learning objectives, learning materials, Inquiry–STEM-based learning activities, practice exercises, and learning reflections. The learning activities in the module are designed so that students can follow each stage of the inquiry process, which includes identifying problems, gathering information, analyzing data, and drawing conclusions. Through this series of activities, students are expected to have the opportunity to develop critical thinking skills in understanding the concepts of solid geometry.

The preliminary design of the instructional module can be seen in Figure 3, which shows the module's cover page and the first page of the learning module.

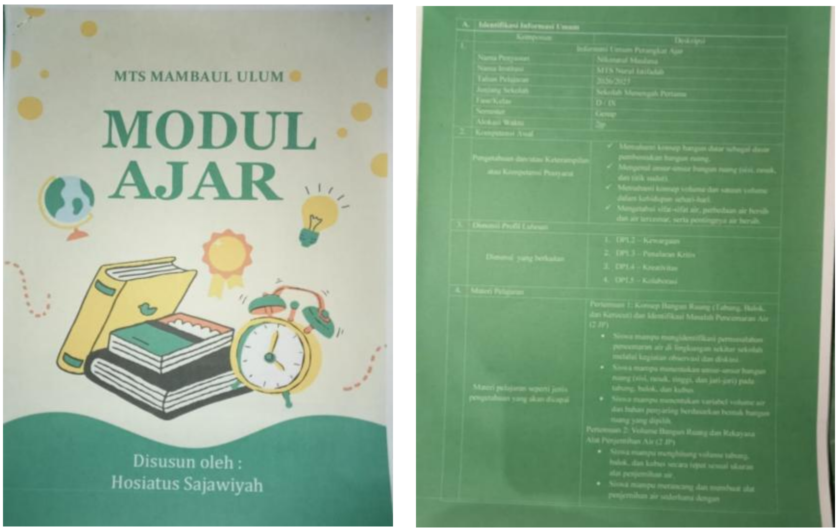

Figure 3. Module Cover and First Page

In addition, during the design phase, water purification experiments were also planned as a way to apply the concept of solid geometry in real life. The water purification process is carried out using several filtering materials such as gravel, coconut husks, charcoal, tissue, and cloth, which are arranged in layers within a container shaped like a three-dimensional figure. Through this activity, students not only understand mathematical concepts theoretically but are also able to apply them in real-life contexts to solve real-world problems in their surrounding environment (PB, et al., 2021). The design of the water purification device used in the lesson is shown in Figure 4.

Figure 4. Design of a Water Purification Device

In addition to developing learning modules, this phase also involves creating research tools used to collect data for the purpose of assessing the modules' feasibility, including expert evaluation forms, student feedback questionnaires, and assessment instruments used to measure critical thinking skills.

3. Development phase *(pegembangan)*

The development phase is the process of creating learning modules that are systematically organized in accordance with a pre-established design. The Inquiry–STEM-based learning module was developed for the topic of solid geometry within the context of water purification. The module is structured to support improved understanding of mathematical concepts while developing students' critical thinking skills through investigative learning activities (Kurnia, et al., 2019). The teaching module consists of several key components, including an introduction, learning objectives, content, Inquiry–STEM-based learning activities, a water purification experiment, practice questions, and a learning reflection. The learning activities in the module are designed to encourage students to identify problems. This process involves formulating hypotheses, conducting observations, analyzing data, and drawing conclusions (Atiqoh, et al., 2025).

After the instructional module was developed, the next step was to conduct validation by experts, involving mathematics education lecturers and mathematics teachers, using an assessment instrument in the form of a validation sheet that covered aspects of content appropriateness, instructional presentation, language use, and alignment with the Inquiry–STEM approach. The validation results showed that the teaching module received a score of 85% from the first validator and 79% from the second validator. Based on these two assessments, the teaching module was deemed to have a very high level of validity and was therefore deemed suitable for use in learning activities with several adjustments based on feedback from the validators, as shown in Table 4.

Table 4. Validity Results of the Teaching Module

Validator	Percentage of the score	Criteria
1	85%	This is entirely valid the teaching module can be used as is.
2	79%	The teaching module can be used, but it requires minor revisions
Total	82%	It is fully valid the teaching module can be used as is.

4. Implementation phase

The implementation phase is the process of applying the learning modules that have been developed in classroom learning activities (Siregar & Rhamayanti, 2025). Next, a pilot test of the module was conducted with 20 students from a ninth-grade class at Mambaul Ulum Junior High School in Kaliacar Village. During the learning process, students were divided into several teams to conduct an investigation into the water purification process. The activity began with a presentation of the problem regarding the murky water found in the surrounding environment. Next, students were asked to identify the problem, formulate a hypothesis, and design a simple water purification device using various materials, including gravel, coconut husks, charcoal, tissue paper, and cloth. After designing the water purification device, students observed the water filtration process, recorded their observations, and analyzed the data obtained. The learning activity concluded with a group discussion and the drawing of conclusions regarding the relationship between the concept of solid geometry and the design of the water purification device created. The results of the teaching module experiments during the implementation phase are shown in Figure 5. The implementation phase is the process of applying the developed learning module in classroom learning activities.

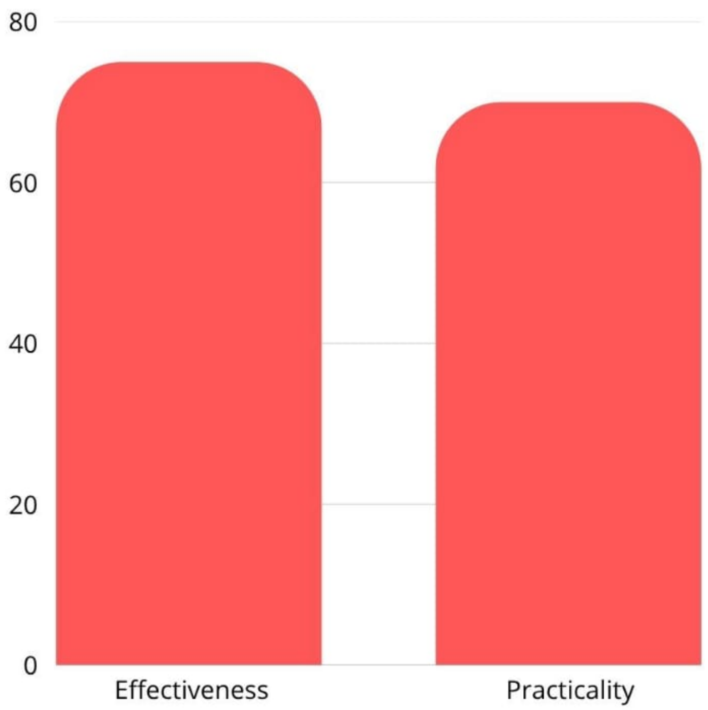

Figure 5. Results of the Trial Use of the Instructional Module

Based on the data analysis at this stage, the instructional module achieved a practicality rating of 65%, placing it in the “somewhat practical” category. Additionally, the results of the critical thinking assessment indicate that 75% of students achieved scores that exceeded the established Minimum Competency Criteria (KKM).

5. Evaluation phase *(evaluasi)*

The evaluation stage is the final phase of the ADDIE model, designed to assess the quality of the learning modules that have been developed. The evaluation process is conducted by examining three key aspects: the validity, practicality, and effectiveness of the Inquiry–STEM-based learning modules (Siregar & Rhamayanti, 2025). The evaluation results indicate that the developed teaching module meets the feasibility criteria. This is evident from the expert validation, which was categorized as highly valid; student feedback indicating that the module is easy to implement in the classroom; and the results of the critical thinking skills test, which show that the majority of students achieved scores above the Minimum Passing Score (MPS). A summary of the evaluation results regarding the use of the module in the classroom is presented in Figure 6.

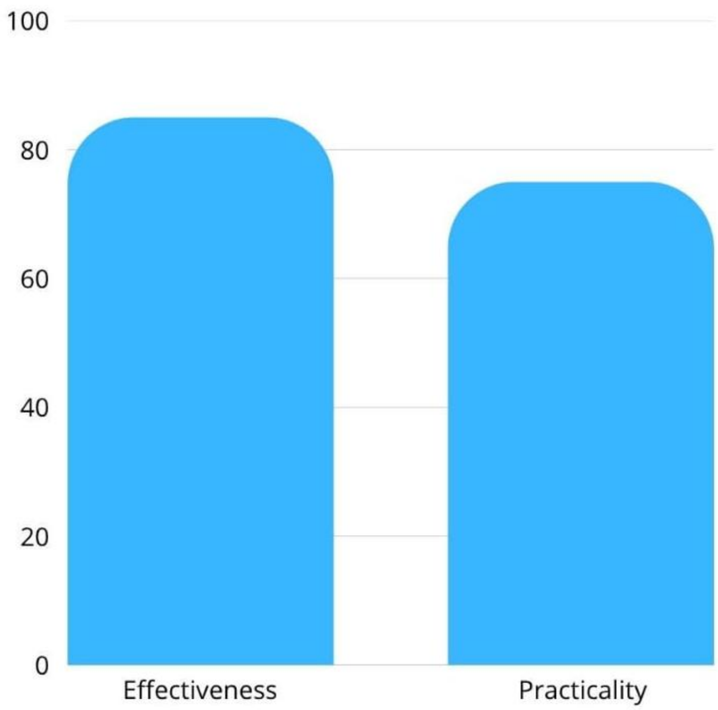

Figure 6. Results of the Evaluation of the Use of the Instructional Module

Based on the evaluation results, the practicality of the teaching module increased to 75%, while its effectiveness rose to 85%. The research findings indicate that the implementation of Inquiry–STEM-based learning modules can enhance students' critical thinking skills while facilitating their understanding of solid geometry concepts through contextual problems. These results are consistent with Hasanah's research, which shows that STEM-based learning can encourage students to conduct investigations, analyze information, and relate concepts to real-world situations. Through the integration of science, technology, engineering, and mathematics, students not only gain conceptual understanding—they not only understand the concepts—but are also able to apply those concepts to solve everyday problems (Hasanah, et al., 2022).

Furthermore, the findings of this study are consistent with those of Saputri &

Herman (2022), who found that the implementation of STEM-based learning in mathematics can increase student participation and help them understand the connections between concepts and other disciplines. Moreover, this improvement is evident not only in terms of engagement but also in students' critical thinking processes during the learning process (Saputri & Herman, 2022). In Inquiry-based STEM activities, students are encouraged to identify problems, formulate questions, gather and analyze information, and draw logical conclusions. This process trains students not only to act as recipients of information but also to actively evaluate and construct their own knowledge. Engagement in project-based activities or experiments, such as designing solutions based on real-world contexts, provides students with opportunities to test ideas, correct mistakes, and connect mathematical concepts to relevant situations. These positive changes in critical thinking skills occur because Inquiry–STEM-based learning provides a learning environment that demands higher-order thinking processes, such as analysis, evaluation, and reasoning (Santoso & Arif, 2021). As a result, students do not merely understand concepts procedurally, but are also able to apply and reflect on their understanding to solve problems in a more in-depth and systematic manner.

These results are also consistent with the study by Lestari, et al. (2025), which indicates that systematically designed learning modules can support students' independent learning while enhancing conceptual understanding. Furthermore, these modules, which include exploration and problem-solving activities, provide students with opportunities to develop critical thinking skills. Thus, the results of this study support previous findings that the integration of the Inquiry approach with STEM through learning modules has a positive effect on improving the quality of mathematics learning. This approach not only deepens conceptual understanding but also encourages students to hone their critical thinking skills through contextual and problem-solving-oriented learning (Lestari, et al., 2025).

CONCLUSION

This development study produced an Inquiry–STEM-based learning module on solid geometry with a water purification context, developed using the ADDIE model. The research results indicate that the module meets feasibility criteria, as assessed in terms of validity (82%, categorized as highly valid), practicality (increasing from 65% to 75%), and effectiveness. The module's effectiveness is demonstrated by an improvement in students' critical thinking skills, reflected in an increase in the learning achievement rate from 75% to 85% following the module's implementation. This improvement is particularly evident in the ability to analyze problems, connect geometric concepts to contextual situations, and formulate logical solutions.

Thus, the Inquiry–STEM-based module developed is not only deemed suitable for use but also contributes to the development of students' critical thinking skills through learning that integrates mathematical concepts with real-world contexts.

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