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Development of Interactive Mathematics E-Modules to Improve Elementary School Students' Learning Outcomes and Critical Thinking Skills

Nur Sofiah[1], Wiryanto[2], Neni Mariana[3]
[1, 2, 3] Program Studi Pendidikan Dasar, Pascasarjana Universitas Negeri Surabaya, Indonesia

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ABSTRACT

The study's background stems from the low mathematics learning outcomes and critical thinking skills of students, which are a result of limited supporting learning media. Therefore, this study intends to develop an interactive mathematics e-module aimed at improving learning outcomes and critical thinking skills of fifth-grade elementary school students on spatial geometry material. The research method used is the ADDIE (Analysis, Design, Development, Implementation, Evaluation) development model. We conducted this research in class V of Kyai Ibrahim Elementary School. The results of the study indicate that the interactive e-module developed is very feasible, with media expert validation of 95.3%, material expert validation of 91.7%, and learning device expert validation of 89%. The practicality of this e-module is supported by the results of teacher responses of 96% and student responses of 93%, which are categorized as very practical. The product's effectiveness is shown by the fact that 89% of students completed their learning in large classes during the implementation stage, and there was an improvement in learning results and critical thinking skills, with an N-Gain value of 0.72 (72.09%). Student activity during implementation also increased, with 89% categorized as very active. Thus, this interactive e-module has proven effective in improving learning outcomes and critical thinking skills among fifth-grade elementary school students.

Corresponding Author:

Nur Sofiah,
Program Studi Pendidikan Dasar, Pascasarjana Universitas Negeri Surabaya, Indonesia
Email: nursofiah.21008@mhs.unesa.ac.id

1. INTRODUCTION

The rapid technological advances of the 21st century pose challenges for education. One of the main challenges is adapting to technological advancements, particularly information and communication technology (Alenezi et al., 2023; Muthmainnah et al., 2023). Therefore, the education system must prepare future generations to be ready for all challenges. Critical thinking skills are one of the essentials for elementary school students to face the challenges of the 21st century (Veronica et al., 2022).

Critical thinking is the process of actively engaging in intellectual disciplines (Wiryanto et al., 2021). It is demonstrated by a person's ability to identify concepts, correctly apply and analyze, synthesize, and evaluate information obtained through observation, experience, reflection, reasoning, or communication. This helps a person form beliefs or make decisions (Paul & Elder, 2006). According to Azizah et al. (2018), critical thinking is a process in students' cognitive thinking through systematic and specific problem analysis, the ability to carefully distinguish facts, and the analysis of information to resolve dilemmas by planning appropriate strategies. Critical thinking skills are necessary to face all future challenges for the Gen Z generation, which is closely connected to technology. Moreover, today's technological sophistication brings major changes in almost every field.

To improve critical thinking skills, problem-solving strategies are used. Research by Miftichatun (Chanifah et al., 2019) suggests that applying problem-solving models can improve critical thinking skills. Similarly, Cahyadi et al. (2019) argues that critical thinking skills are acquired through the mathematics problem-solving test questions. Learning media is an important consideration for educators, in addition to selecting appropriate teaching materials and approaches. Over time, learning media has become a crucial tool for ensuring the smooth running and achievement of learning objectives. We expect the application of appropriate learning strategies and media to foster student interest and motivation. The strategies used can include methods or approaches, while learning media serves as a tool to facilitate understanding of the subject matter.

Developing logical, critical, systematic, and creative thinking skills is crucial in education because it provides students with the foundation for understanding, analyzing, and solving everyday problems. Developing these skills is crucial because it improves students' conceptual understanding. Critical thinking skills enable students to objectively evaluate information, understand the implications for different arguments, and identify weaknesses or deficiencies in an argument or approach. These abilities expand problem-solving possibilities and promote flexibility of thought. Logical, critical, systematic, and creative thinking skills are also highly useful in real life. Students are able to use these skills to make sound decisions, solve everyday problems, and think more effectively in complex situations. Therefore, developing these thinking skills is an integral part of a holistic and comprehensive education to prepare students to become competent and useful individuals in society. Such thinking is a prerequisite for developing science and technology (Azizah et al., 2018). However, many students still experience difficulties in developing these skills.

The fundamental effort to create quality human resources is education (Fadil et al., 2023). Quality education offers numerous benefits, including advancements in science and technology. In today's era, students must adapt to technological developments, so innovation and creativity are essential in education. Educators are key to educational success. It plays a crucial role in producing high-achieving, competitive students today (Wijaya et al., 2022). Innovation in the use of methods, approaches, and teaching materials determines student learning success (Lestari et al., 2023). Educators play a key role in implementing learning activities that are relevant to the times by presenting

more engaging teaching materials, models, strategies, or media, making learning less boring for students. Therefore, the development of learning media is essential in the learning process (Muliyana et al., 2022).

In implementing learning, teachers are required to be more innovative so that the learning process does not become boring for students (Amran et al., 2021). Up-to-date knowledge and information are essential for teachers to upgrade themselves. The role of teachers is no longer central or exclusive to students, but now teachers act as facilitators, demonstrators, motivators, and guides for the development of attitudes, behavior, and values. The role of teachers as facilitators of student learning is thus able to optimally foster student motivation and interest (Hapsari et al., 2021). Teachers should play a greater role as motivators for students, especially regarding learning methods and preparation for facing the real world (Iswantiningtyas, 2021). Teachers must also help students learn to handle all the issues in their surroundings (Mariana, 2019). The current paradigm shift influences teachers' teaching patterns so they can adapt to environmental conditions and current developments. Students are expected to be brave in expressing themselves and learn actively, such as through a dialogical approach. This type of instruction can encourage students to ask questions or debate in a fun discussion atmosphere (Raihani, 2020).

Learning from the 2020 COVID-19 pandemic, teachers were taught to understand and practice learning activities using various digital media. Learning through digital media aims to maintain the learning process (Anita et al., 2021). The obstacles that teachers face can become learning opportunities for improving their ability to adapt to learning needs. Teachers who are able to utilize IT (information technology) will adapt more quickly than those who are technologically illiterate.

Teachers who implement less innovative learning and rely solely on lecture methods will undoubtedly impact student learning outcomes and motivation (Suttrisno & Prastiwi, 2023). Trinaldi et al. (2022) argue that the use of teaching materials is crucial in learning activities. Teaching materials facilitate teachers in explaining topics to students, enabling them to learn independently in greater depth and complexity (Kosasi, 2021). Teaching materials, both media and modules, must evolve with technological advancements (Taher & Desyandri, 2022). Therefore, technological advancements require teachers to maximize their innovations to create diverse teaching modules. Furthermore, Purnasari and Sadewo (2021) explain that technology can also enhance learning activities, stimulating learning outcomes. This is because the internet allows students to explore their existing knowledge. The use of digital-based learning modules by teachers can improve the quality of education. According to Dewi and Lestari (2020), digital-based modules make learning more effective and efficient, resulting in meaningful learning. To improve learning outcomes, it is necessary to use appropriate learning media that align with learning objectives. Furthermore, they must be engaging for students, particularly in mathematics (Supriyono, 2018).

Mathematics is a subject that encompasses numbers, algebra, geometry, probability, statistics, and uncertainty. This subject involves logical reasoning and critical thinking in solving problems and understanding the world around us (Ekawati et al., 2020).

Mathematics can also be interpreted as a language, containing defined terms and meaningful symbols. Learning mathematics enables students to develop effective communication skills about mathematics itself and real-life situations. The main objectives of mathematics learning are (1) developing intellectual skills, (2) developing problem-solving skills, (3) improving learning outcomes, (4) fostering communication habits, and (5) fostering positive student character (Ministry of Education and Culture). Mathematics learning in the independent curriculum teaches students to think critically and logically and to view mathematics as a process of exploration and experimentation. The goal is for students to have a strong understanding of mathematics and be able to apply it in everyday life (Daimah, 2023). Therefore, educators must be able to make mathematics learning more interactive and creative to foster critical thinking skills and improve student learning outcomes.

Observations indicate that elementary school students' numeracy skills are still weaker than their literacy skills. At Kyai Ibrahim Elementary School, geometry had the lowest percentage of correct answers among students, with only 30.91% answering correctly, while the percentages for numbers and data and uncertainty were 31.98% and 36.64%, respectively. The evidence indicates that geometry is a component of mathematics that is poorly understood by students due to its abstract nature, particularly regarding geometric shapes (Nurjanah & Juliana, 2020). Furthermore, compared to other subjects, the average math score at Kyai Ibrahim Elementary School was the lowest. To visualize these shapes, the right media are therefore required. Innovation in the textbooks used in learning is needed.

Observations showed that 20 out of 26 fifth-grade students (77%) experienced difficulty solving geometric shape problems. This demonstrates that the formative value of the geometric shapes material has not met expectations. Data obtained showed that 77% of students scored below the learning objective achievement criteria.

Based on this description, innovation is needed to improve critical thinking skills and student learning outcomes, namely by creating student-centered learning (Dewi & Fauziati, 2021). Real-life or contextual problems present students with opportunities to foster independence and critical thinking, enabling them to solve their problems. Therefore, to meet students' needs, particularly in mathematics, modules based on realistic, contextual, and sustainable learning approaches and strategies are necessary.

Based on these problems, it is apparent that real-world conditions conflict with the expected ideal conditions. Students' mastery of the material is lacking. Therefore, alternative solutions to this problem focus on improving the presentation of teaching materials, the availability of learning media, and the applied learning approaches. It is appropriate that mathematics teaching materials are developed according to student characteristics. The development of teaching materials must be based on contextual problems in the students' environment to enhance students' critical thinking skills. Furthermore, engaging and up-to-date teaching materials can increase students' motivation to learn, making it easier for them to understand the lessons presented. Ultimately, these factors can improve student learning outcomes.

Regarding the development of teaching materials, Wahyuningtyas and Shinta (2017) stated that developing modular teaching materials can significantly contribute to the learning process by enabling quality learning. Their implementation can be tailored to learning activities, is more independently planned, has measurable completion, and the results (output) are clear. Research has proven that modules enhance the quality of learning, thereby improving learning outcomes (Mariana et al., 2018; Mariana et al., 2023). Learning modules contribute to improving student learning outcomes (Kurniawan et al., 2018).

The development of technology-based teaching materials, such as e-modules, is a crucial innovation in today's education. The benefits of using e-modules in learning include easy access, cost-effectiveness, interactive and multimedia features, adaptability to needs, and encouragement of independent learning (Febrianti et al., 2024). Thus, e-modules are an effective tool for supporting independent learning, fostering critical thinking skills, and facilitating the achievement of learning objectives more efficiently and effectively. E-modules are equipped with user instructions for independent study (Turnip et al., 2021).

E-modules are computer-based modules that display not only text but also images, graphics, audio, animation, and video (Nugraha et al., 2021). Slightly different from Husni et al. (2023), e-modules are part of the teaching materials, presenting subject matter that students can study independently. Nopiani revealed the advantages of e-modules, including the ability to add images, video, audio, and animation to enhance student engagement, while remaining budget-friendly and accessible (Nopiani et al., 2021).

Advances in science and technology provide valuable resources for developing interactive and student-centered mathematics e-modules. Facilitating mathematics learning using readily available and accessible technology can enhance students' critical thinking skills through engaging and enjoyable learning. To foster critical thinking skills, teachers must develop learning strategies, including innovations, to motivate students to learn mathematics (Wiryanto et al., 2021).

The chosen learning strategy or approach naturally aims to foster student motivation, leading to improved learning outcomes. The chosen learning approach should foster students' ability to express opinions, hone their reasoning skills, and be contextual and measurable. Furthermore, it should foster active communication between students and teachers and ensure the material is presented in a continuous and interconnected manner.

An interactive e-module is a medium that generates active interaction for its users from the information or content presented. In this case, interactive media refers to a computer program or website that allows users to perform certain actions, such as clicking buttons, filling out forms, or playing games. This study aims to create an interactive mathematics e-module to help fifth-grade elementary school students learn better and think critically about spatial geometry topics. It is hoped that with this interactive e-module, students' learning outcomes and critical thinking skills in learning mathematics will increase, especially the material on spatial shapes, namely cubes and cuboids.

2. METHOD

This research is a research and development study using the ADDIE development model, which consists of five stages: analysis, design, development, implementation, and evaluation. The analysis stage was conducted to identify the needs and challenges faced by fifth-grade students at Kyai Ibrahim Elementary School in understanding the material on spatial geometry, particularly in terms of learning outcomes and critical thinking skills. The design stage involved designing an interactive multimedia-based e-module tailored to the characteristics of elementary school students. Interactive features like videos, animations, and quizzes complemented the spatial geometry (cubes and cuboids) focus of the developed material.

During the development stage, the designed e-module was validated by media experts, material experts, and learning device experts to assess the product's feasibility. Validation used a Likert-based assessment instrument. After achieving favorable validation results, the e-module was piloted in two stages: a limited group trial and a large group trial. The limited group trial was conducted with six fifth-grade students to assess the module's initial practicality, while the implementation trial was conducted in two classes: an experimental class (using the interactive e-module) and a control class (using conventional learning).

Data analysis techniques in this study include validity, practicality, effectiveness, and improving learning outcomes. Validity comes from the evaluator's ratings; practicality is based on feedback from teachers and students through surveys, and effectiveness is determined by how well students learn and improve their critical thinking skills. Quantitative data were analyzed using normality tests, homogeneity tests, and t-tests to compare the pretest and posttest results between the experimental and control groups. The increase in learning outcomes and critical thinking was measured using the N-Gain formula with a high category if the g value > 0.60.

Table 1. Data Analysis

Data Type	Instruments	Analysis Techniques
Module Validity	Media, materials, and equipment expert validation sheets	Feasibility Percentage
Practicality	Teacher and student questionnaires	Usability Percentage Score
Effectiveness	Pretest and posttest questions	Learning Completion and T-Test
Student Activities	Observation sheets	Activity Percentage
Improved Learning Outcomes and Critical Thinking	Pretest-posttest	N-Gain Test

3. RESULTS AND DISCUSSION

Results

Final Product Development

The final product of this research is a multimedia-based interactive mathematics e-module designed for the subject of spatial figures (cubes and cuboids) for fifth-grade elementary school students. This module was developed through the ADDIE model stages and integrates visual elements (3D images and learning videos) and audio elements (narration), as well as interactive quizzes and digital worksheets. Expert validation shows that this product is suitable for use, with validation scores from media experts of 95.3%, material experts of 91.7%, and learning device experts of 89%. All of these aspects strengthen the module's reliability in supporting contextual and engaging mathematics learning.

Learning Outcomes and Critical Thinking Skills

The effectiveness of the E-Module was tested by comparing the pretest and posttest results between the experimental class (using the E-Module) and the control class (without the E-Module). The average pretest score for the experimental class was 50.1%, while the posttest score increased to 86.7%, with an N-Gain of 0.72 (high category). In contrast, the control class only showed an increase from 50.1% to 68.6% with an N-Gain of 0.37 (moderate category). This result means that the use of the E-Module has been proven to significantly improve students' learning outcomes and critical thinking skills. The following is a summary of the improvement data in Table 2.

Table 2. Learning Outcomes and Critical Thinking Skills

Class	Pretest (%)	Posttest (%)	N-Gain	Category
Experiment	50,1	86,7	0,72	High
Control	50,1	68,6	0,37	Medium

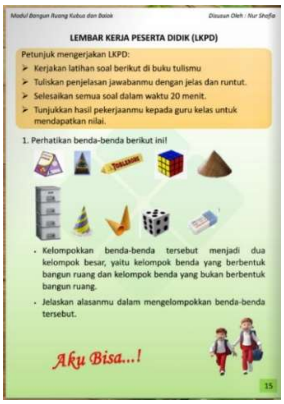
Student Activities

Student activity during the implementation process also saw a significant increase. Students in the experimental class showed 89% engagement (very active), compared to only 56% in the control class (moderately active). This indicates that the interactive module is able to encourage active student participation in learning. This success aligns with Piaget's constructivist theory, which states that meaningful learning occurs when students are actively involved in the process of constructing knowledge. The interactive visual features in the module also helped students understand abstract geometric concepts, reinforcing the theory of spatial visualization in mathematics learning.

Overall, the interactive mathematics e-module not only improved students' understanding of spatial concepts but also strengthened their critical thinking skills through structured exploratory and reflective questions within the module. These results confirm the hypothesis that the use of the interactive e-module can have a significant positive impact on students' learning outcomes and higher-order thinking skills. The

following displays the pre- and revised versions of the interactive mathematics e-module, presented in Table 3.

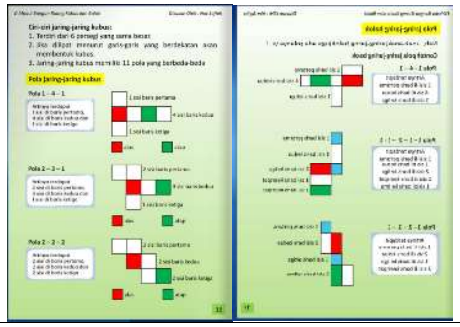
Table 3. E-Module Revision

Before Revision	After Revision
Web address: https://bejewelled-salamander-17d8a1.netlify.app/	Web address: https://E-Modul-bangun-kubus-balok.netlify.app/
LKPD Form: There are no interactive links yet 	LKPD Form: LKPD is supplemented with a link by clicking Klik Latihan Soal to be directed to an interactive question form. 

The following is a display before and after the revised interactive mathematics E-Module, presented in Table 4.

Table 4. Results of E-Module Revision

Before Revision	After Revision
Learning objectives: 	Learning objectives: 
Multiplication operation form: Write the multiplication operation with the letter x.	Multiplication operation form: Writing multiplication operations with the multiplication symbol

Before Revision	After Revision
Volume Kubus = r x r x r = 4 x 4 x 4 = 64 cm^3	Volume Kubus = $r \times r \times r$ = $4 \times 4 \times 4$ = 64 cm^3
There is no material on nets of cubes and cuboids yet	Material on nets of cubes and cuboids: 

Discussion

This section interprets the research findings, connects them with relevant theories, and compares them with previous research so that the resulting interactive mathematics E-Module is valid, practical, and effective. In addition, it describes the practical implications of developing an interactive mathematics e-module for improving student learning outcomes and critical thinking skills in fifth-grade elementary school students. At the process and development stage of the interactive mathematics E-Module, a series of stages are presented to produce a valid, practical, and effective E-Module.

The purpose of this e-module is to produce a learning medium that meets current student learning needs. Media and technology experts determined the e-module's feasibility through a validation process. To achieve validity criteria, the minimum score percentage on the validation sheet across several assessment aspects must demonstrate an average score of at least 61%. In Chapter IV, Table 4.4, the average score obtained by the media and technology expert validator was 95.3%, representing a very feasible criterion. Teachers can utilize a valid e-module in the learning process. This aligns with Zulkifli's (2018) opinion that the module can be implemented comprehensively and build students' critical thinking skills. Furthermore, according to Suryanti (2020), the e-module can help students solve problems in everyday life.

The interactive mathematics e-module designs its material to enhance students' learning outcomes and critical thinking skills. The feasibility of the material presented in the e-module received a score of 91.7%. This percentage falls within the very appropriate criteria. Critical thinking skills are assessed through pretest and posttest questions because critical thinking skills encompass the ability to conceptualize, apply, analyze, synthesize, and evaluate (Rizki, 2023). Moreover, Muthmainnah et al. (2023) emphasizes the capacity to methodically assess and resolve issues.

The learning tools were validated and declared suitable for use in learning, with a score of 89%, falling within the very appropriate criteria. The components of the learning tools include learning objectives, learning steps, and learning assessments. The lesson plan used consists of two sessions. The first session begins with a pretest and material delivery, while the second session continues with material delivery and is followed by a posttest. The student worksheet includes learning objectives and steps for students to take, involving various activities such as observation, creation, problem-solving, listening, and practice.

Furthermore, the teacher practicality assessment aimed to determine their opinions and suggestions regarding the interactive mathematics e-module. The 5th grade teacher's assessment in the limited group trial resulted in a score of 94.2%, categorized as very practical. Of the 13 assessment indicators, three received a score of 3, and twelve received a score of 4. Meanwhile, the 5th grade teacher's score in the experimental class was 96.2%, categorized as very practical. Of the 13 indicators, 2 received a score of 3 and 11 received a score of 4. Based on the assessments of both teachers, it can be concluded that this interactive mathematics e-module is practical and supports a systematic learning process to achieve learning objectives (Monitha, 2022).

The e-module's student practicality assessment sought to gauge the ease with which students grasped the material on geometric shapes through its use. The practicality assessment was conducted in the limited group trial and the implementation phase in the experimental class. The student practicality validation consisted of 15 indicators assessed by students in the limited group and the experimental class. From a limited group of 6 students, the assessment results were 94%. The experimental group of 29 students produced a percentage of 93%. As stated by Daryanto (2014), modules must be systematic so that they are practical to use.

The effectiveness of the interactive mathematics E-Module was measured by an effectiveness test to determine how effective the use of the E-Module was in the learning process. Based on the results of the pretest and posttest scores at the implementation stage, the control class that was not treated with the interactive mathematics E-Module had a completeness of 28% (less than 75%), while the experimental class that was treated with the interactive mathematics E-Module had a completeness of 86% (more than 75%).

Data analysis results showed a significant improvement in student learning outcomes after using the interactive mathematics e-module. This was evident in the higher average post-test scores for the experimental class compared to the pre-test scores. Furthermore, the average post-test scores for the experimental class were higher than those for the control class using the conventional learning model. The average post-test score for the experimental class was 86.7%, the pre-test score was 50.1%, and the post-test score for the control class was 68.6%.

The better learning results in the experimental class show that the interactive mathematics e-module helped fifth-grade elementary school students understand geometric concepts. The interactive features within the e-module, explanatory features for cube and cuboid images, practice problems with immediate feedback, and available

instructional videos increased student engagement in the learning process. This engagement encouraged students to actively explore the material and construct their knowledge. This is in line with constructivism theory (MacLeod et al., 2022). The material on geometric shapes in mathematics lessons is part of geometry, where the shapes are abstract and therefore need to be visualized. With this interactive mathematics E-Module, abstract concepts such as showing the edges, sides, or planes have been visualized in an intriguing, easy-to-use, and understandable way, as well as nets and volumes of cubes and cuboids. This visualization aims to help students represent more concretely the material on geometric shapes of cubes and cuboids. The interactive mathematics E-Module allows students to learn according to their own pace and learning style. This finding is in line with Prastowo (2011), who also showed the use of interactive media in improving mathematics learning outcomes, especially on geometric shapes.

Furthermore, there was a significant improvement in students' critical thinking skills after using the interactive mathematics e-module. The experimental group's average post-test critical thinking skill score was higher than the pre-test average and the control group's score. The N-Gain for the experimental group was 0.72, or 72.09%, in the high category, and for the control group, it was 0.37, or 36.78%, in the moderate category. These results indicate that the interactive e-module can improve critical thinking skills.

This improvement in critical thinking skills can be explained by aspects of the interactive mathematics e-module design, namely: The learning material presented in the e-module is contextual and relevant to students' daily lives. The e-module designs its exercises to enhance students' analytical and evaluation skills. Additionally, some questions focus on problem-solving, pattern identification, and evaluation. The questions presented in the interactive e-module encourage students to make connections between concepts and solve problems. Sinaga and Setiawan (2022) highlights the effectiveness of interactive multimedia in enhancing the critical thinking abilities of elementary school students. This aligns with Arni et al.'s (2024) findings that interactive media can be used as a tool to improve critical thinking skills in elementary school students.

Despite the positive results of this study, it is important to acknowledge its limitations. This study's sample size was insufficient to make a generalization to the entire fifth-grade student population. The use of the interactive e-module in this study was relatively short-term. If we want to use it long-term, we need to conduct further research. The research sample may have certain characteristics that do not represent the entire population of fifth-grade students. The measurement of critical thinking skills in this study used a specific instrument. The use of a different instrument may produce different results. The questions used to measure critical thinking skills were not specifically grouped.

4. CONCLUSION

The conclusion of this study shows that the interactive mathematics E-Module developed for fifth-grade elementary school spatial geometry material is proven valid, practical, and effective. This module successfully improves students' learning outcomes and critical thinking skills with an N-Gain score of 0.72 (high category) and a student activity level of 89%. Therefore, it is recommended that elementary school teachers utilize this E-Module as an alternative teaching material for more interactive mathematics learning and that future researchers develop similar modules with a wider scope of material and levels.

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