How to Cite (APA Style):
Cahyaningsih, U. & Nahdi, D. S. (2025). Development of an interactive e-module based on PBL to Enhance elementary students' critical thinking. *Jurnal Ilmiah Pendidikan Dasar*, *12* (2), 251-270. http://dx.doi.org/10.30659/pendas.12.2.251-270

JURNAL ILMIAH PENDIDIKAN DASAR
p-ISSN: 2354-9580
e-ISSN: 2685-211X

Development of an interactive e-module based on pbl to enhance elementary students' critical thinking

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Submitted: June 11th, 2025 **DOI: 10.30659/pendas.12.2.251-270**
Revised: July 30th, 2025
Accepted: July 31st, 2025

Keywords:
e-modul; problem based learning; critical thinking skill

Abstract

The development of critical thinking skills at the elementary school level is a foundational component in preparing students to navigate complex, real-world problems that demand analytical reasoning, evaluative judgment, and effective problem-solving. This study investigates the efficacy of an interactive e-module grounded in Problem-Based Learning (PBL) principles in enhancing the critical thinking abilities of fourth-grade students, with a particular focus on mathematics and science instruction. A quasi-experimental design was implemented, comprising an experimental group that utilized the PBL-based e-module and a control group that received conventional instruction. Data collection methods encompassed pre- and post-tests measuring critical thinking performance, observational protocols documenting student interaction with the module, student perception questionnaires, and semi-structured interviews with both students and teachers to elicit qualitative insights. The findings indicate that students in the experimental group exhibited significantly greater gains in critical thinking skills, as evidenced by a substantial improvement between pre- and post-test scores. Moreover, these students engaged more actively in collaborative discussions and problem-solving tasks relative to their peers in the control group. The results underscore the effectiveness of PBL-based e-modules as pedagogical tools for fostering critical thinking at the elementary level. The study's implications point to the transformative potential of integrating PBL frameworks into digital learning environments to enhance educational quality and student engagement in primary education settings.

INTRODUCTION

Background of the Study

Education in the 21st century demands the development of critical thinking skills among students as part of their preparation to face global challenges (Mulyawati et al., 2024). One effective way to enhance critical thinking skills is through the integration of technology in learning, particularly by developing e-modules designed to engage students in problem-solving activities that are relevant to their everyday lives (Anjarsari et al., 2023). The use of technology-based e-modules provides students with opportunities to learn independently, flexibly, and interactively, which can enhance their understanding of the material and encourage them to think more critically (Ardiansya et al., 2024).

Problem-Based Learning (PBL) is widely recognized as an effective approach for developing critical thinking skills. PBL presents students with unstructured problems to solve, allowing them to activate prior knowledge and engage in analytical and evaluative thinking (Fitriana et al., 2024). In the context of elementary education, the implementation of PBL can be carried out through the development of e-modules that present context-based problems requiring critical thinking and creative solutions (Izzah et al., 2023).

Specifically, at the elementary education level, critical thinking skills are essential, as they not only support students' academic understanding but also prepare them to face more complex problems in the future(Susilawati & Supriyatno, 2023). According to research conducted by Mulyawati, interactive digital modules that integrate Problem-Based Learning (PBL) can help students develop critical thinking skills, as they are given the opportunity to analyze problems in depth and formulate solutions based on their existing knowledge (Mulyawati et al., 2024).

With the advancement of information and communication technology, the use of e-modules in learning has become a practical solution that enables students to access learning materials anytime and anywhere. These e-modules not only provide textual content but are also equipped with multimedia elements such as videos, images, and animations, which can make the learning materials more engaging and easier to understand (Anjarsari et al., 2023). PBL-based e-modules offer a more student-centered approach, in which learners can study and solve problems collaboratively by utilizing the digital resources provided within the module (Ardiansya et al., 2024).

At the same time, a common issue in elementary school mathematics learning is the lack of deep conceptual understanding, particularly in topics that require problem-solving, such as speed and volume flow rate. This challenge can be addressed through the use of PBL-based e-modules specifically designed to help students understand and apply mathematical concepts in contexts that are more relevant to their everyday lives (Izzah et al., 2023). In a study conducted by Anjarsari, it was found that the use of e-modules with a Problem-Based Learning (PBL) approach was effective in enhancing students' conceptual understanding and critical thinking skills in mathematics (Anjarsari et al., 2023).

Although many studies have demonstrated the benefits of using PBL-based e-modules, a major challenge lies in motivating students to be more actively engaged in this technology-based learning approach. Therefore, it is essential to design e-modules that not only present instructional content but also include elements that encourage students to interact with the material and think critically, such as reflective questions, videos, and simulations aligned with their cognitive developmental stage (Fitriana et al., 2024).

In the context of elementary education, the implementation of the PBL model through e-modules is becoming increasingly relevant, given the challenges of enhancing students' critical thinking skills in the digital era. This relevance stems from the need to provide learning materials that go beyond rote memorization and instead stimulate analytical and evaluative thinking (Susilawati & Supriyatno, 2023). PBL-based e-modules offer a comprehensive and effective approach to fostering critical thinking skills, particularly when combined with instructional strategies that motivate students to collaborate and solve problems creatively.

Accordingly, this study aims to develop and evaluate the effectiveness of a PBL-based e-module in enhancing elementary school students' critical thinking skills, particularly in subjects that require deep conceptual understanding such as mathematics and science. It is expected that the use of this e-module will support students in solving problems in a more interactive and comprehensive manner, as well as prepare them to face the increasingly complex challenges of the real world (Ardiansya et al., 2024).

The Problem of The Study

Critical thinking skills are essential for students to solve problems and make sound decisions. In the context of elementary education—particularly in the teaching of mathematics and science—critical thinking is crucial for understanding and

applying more complex concepts. However, many elementary school students still struggle to develop these skills, especially in topics that require deep conceptual understanding, such as fractions and other mathematical applications. Therefore, this study focuses on enhancing students' critical thinking skills through the use of Problem-Based Learning (PBL)-based e-modules

As noted by Chasanah, the implementation of PBL-based e-modules can serve as an effective solution in helping students overcome their difficulties in understanding mathematical concepts (Chasanah & Fitrianawati, 2023). By using a problem-based approach, students are encouraged to directly identify problems, formulate solutions, and think critically in resolving them. This provides them with the opportunity to think more deeply and creatively when solving tasks that not only test their knowledge but also their analytical abilities.

Additionally, Fajari stated that critical thinking skills play a significant role in improving students' overall academic achievement (Fajari & Chumdari, 2021). Students with well-developed critical thinking skills are more capable of connecting learned concepts and applying them in more complex situations. However, this study also indicates that many students at the elementary level have not yet achieved optimal critical thinking skills, which affects their ability to solve problems and develop deep conceptual understanding.

The research problem in this study is: How can the implementation of PBL-based e-modules enhance elementary school students' critical thinking skills, particularly in mathematics and science learning? This issue arises from findings indicating that, despite the application of various instructional approaches, students' critical thinking skills at the elementary level still require significant improvement. Therefore, this study aims to explore the effectiveness of using PBL-based e-modules in enhancing students' critical thinking skills and to identify the extent of their impact on students' understanding of concept-driven and problem-solving-oriented subjects.

This study will examine whether the implementation of PBL-based e-modules can serve as an effective tool to address this issue by facilitating students' understanding of the material through more contextual and comprehensive problem-solving (Ardiansya et al., 2024). Based on the findings of a study conducted by Izzah, this approach has shown positive results in addressing students' difficulties in understanding mathematical content and solving related problems (Izzah et al., 2023).

Accordingly, the main focus of this research problem is to investigate how PBL-based e-modules can help enhance elementary school students' critical thinking skills and improve their understanding of more complex mathematical and scientific concepts, which have long been major challenges in elementary education.

Research's State of the Art

Problem-Based Learning (PBL)

Problem-Based Learning (PBL) is an instructional approach that focuses on solving real-world problems. In PBL, students are presented with unstructured problems that require them to think critically, evaluate information, and find creative solutions. This approach emphasizes the development of critical thinking skills, as students are encouraged to connect their knowledge with relevant and authentic situations. Mulyawati explains that the use of e-modules integrating PBL can support the development of students' critical thinking skills, as they are engaged in problems that demand in-depth analysis and the application of knowledge (Mulyawati et al., 2024).

According to Fitriana, PBL can be effectively implemented not only in the context of elementary education but also at the secondary school level (Fitriana et al., 2024). In that study, the use of PBL-based e-modules in vocational high schools was proven to enhance students' critical thinking skills in solving practical problems. The implementation of PBL across various educational levels demonstrates its effectiveness in fostering deeper critical thinking skills, particularly in subjects that require analysis and evaluation, such as mathematics and science.

One effective application of PBL is in science education. Widiarta stated that the combination of PBL with interactive simulations can enhance elementary school students' critical thinking skills (Widiarta et al., 2023). By using tools such as PhET Interactive Simulations, students can more easily understand difficult scientific concepts while simultaneously developing their critical thinking skills through interactive problem-solving

Critical Thinking Skills

Critical thinking skills refer to the ability to analyze, evaluate, and draw conclusions from information in a systematic and logical manner. Fajari stated that critical thinking skills have a significant impact on students' ability to process information and solve problems effectively (Fajari & Chumdari, 2021). This study reveals that students with stronger critical thinking skills are more capable of

connecting the knowledge they acquire with their life experiences and applying it to real-world situations

Ardiansya emphasized that PBL is one of the most effective methods for enhancing students' critical thinking skills (Ardiansya et al., 2024). In PBL instruction, students are not only presented with theoretical content but also with challenging problems that require deep and creative thinking. This is highly relevant in the learning of mathematics and science, which demand strong critical thinking skills to solve complex problems.

Furthermore, Susanto highlighted that PBL-based science learning enables students to develop their critical thinking skills within a scientific context by solving real-world problems related to science topics (Susanto et al., 2022). Wulanjani also indicated that PBL supported by e-modules not only enhances students' critical thinking skills but also improves their communication skills, which are essential for expressing their ideas and solutions (Wulanjani et al., 2024).

E-Module Based on Problem-Based Learning (PBL)

PBL-based e-modules are instructional tools that integrate problem-based learning approaches with digital technology to enhance students' critical thinking skills. The development of PBL-based e-modules enables students to work independently, think analytically, and creatively seek solutions to the problems presented in the module. These e-modules also incorporate various multimedia elements, such as videos, simulations, and images, to make learning more interactive and engaging.

Research by Saralee shows that the use of applications such as Articulate Storyline in the development of PBL-based e-modules can enhance student engagement in learning. These e-modules not only deliver instructional content but also allow students to directly interact with the presented problems, encouraging them to think more critically and deeply (Saralee et al., 2024a). Additionally, Firdaus stated that PBL-based e-modules can be implemented to improve critical thinking skills among fifth-grade elementary students, particularly in solving problems related to mathematics and science (Firdaus et al., 2024). These e-modules help students think more critically as they are presented with problems that require in-depth problem-solving and evaluation based on the knowledge they have acquired.

One of the key advantages of PBL-based e-modules is their flexibility, allowing students to learn anytime and anywhere. Nurissamawati stated that e-modules designed to teach data processing can help students develop their critical thinking

skills within a technological context (Nurissamawati et al., 2024). Pertiwi further supports this by demonstrating that PBL-based e-modules within the context of STEM education are effective in enhancing critical thinking skills through virtual experiments, which allow students to apply theory in practice (Pertiwi et al., 2024).

In Pitorini's study, it was shown that combining PBL with Socratic dialogue in e-modules can further enhance students' critical thinking skills, as they are encouraged to think more deeply and to question their own understanding (Ekaputri Pitorini, n.d.). This study demonstrates that structured reflective dialogue can enrich the learning experience and enhance students' critical thinking skills.

Novelty, Research Gap, & Objective

Elementary education plays a crucial role in developing students' critical thinking skills, particularly for understanding and applying more complex concepts in subjects such as mathematics and science. Although critical thinking has been widely recognized as an essential skill for students, its effective implementation at the elementary level remains a significant challenge. Various instructional approaches have been applied in primary education, yet not all are capable of effectively optimizing students' critical thinking, especially in mathematics and science. One promising approach is Problem-Based Learning (PBL), which has been shown to enhance critical thinking skills; however, its application at the elementary level is still limited and underexplored. Therefore, this study aims to address this research gap by developing and evaluating a PBL-based e-module designed to improve critical thinking skills among elementary school students.

The novelty of this study lies in the implementation of a PBL-based e-module that integrates interactive technology to enhance critical thinking skills at the elementary school level, particularly in mathematics and science education. While numerous studies have developed PBL-based e-modules for secondary and higher education, their application among elementary school students remains limited and underexplored (Chasanah & Fitrianawati, 2023). This study seeks to fill that gap by designing an e-module that is more aligned with the cognitive development of elementary school students and includes content relevant to their daily lives, particularly in more technical subjects such as mathematics (Izzah et al., 2023).

The research gap in this study centers on the lack of research addressing the implementation of PBL-based e-modules at the elementary school level to enhance critical thinking skills, particularly in the context of mathematics and science learning. In her study, Fajari noted that although critical thinking skills are essential, many

elementary school students have not yet been able to develop these skills optimally (Fajari & Chumdari, 2021). Critical thinking is a vital skill that students need in order to think logically, evaluate information critically, and apply it in problem-solving. However, its implementation in mathematics and science instruction at the elementary school level remains limited. This study focuses on addressing this gap by utilizing a PBL-based e-module as a medium to enhance critical thinking skills among elementary school students.

One of the distinguishing features of this study compared to previous research is the use of Articulate Storyline technology in combination with PBL. Saralee's research has shown that Articulate Storyline is an effective application for developing interactive e-modules that can enhance student engagement in the learning process (Saralee et al., 2024). By utilizing Articulate Storyline, this study aims to create a learning module that not only presents content in a static format but also actively engages students in the learning process, ultimately improving their critical thinking skills.

Based on previous research conducted by Sulhan, the use of PBL-based e-modules has been proven effective in enhancing students' critical thinking skills across various educational levels (Sulhan et al., 2023). However, the success of implementing this method at the elementary school level still requires further validation. Therefore, this study aims to identify how PBL-based e-modules can facilitate students in developing their critical thinking skills, particularly in solving problems related to mathematics and science.

Meanwhile, Ardiansya emphasized the importance of PBL in enhancing critical thinking skills among elementary school students (Ardiansya et al., 2024). This study demonstrates that PBL provides a deeper learning experience, in which students are not only engaged in problem-solving but also develop their analytical and evaluative abilities.

Overall, the objective of this study is to develop a PBL-based e-module that can be used to enhance critical thinking skills among elementary school students, particularly in mathematics and science education. This research aims to fill a gap in the existing literature by facilitating the development of a PBL-based e-module that is not only effective in improving critical thinking skills but also relevant to students' daily lives, enhances their understanding of more complex concepts, and provides a more interactive and contextual learning experience (Susanto et al., 2022). This study is expected to make a significant contribution to the development of effective

instructional methods at the elementary school level by utilizing digital technology to enhance the quality of education and the development of students' critical thinking skills.

METHOD

Type and Design

This study employs a quasi-experimental research design to examine the effectiveness of a Problem-Based Learning (PBL)-based e-module in enhancing elementary school students' critical thinking skills. The research involves two groups: an experimental group using the PBL-based e-module, and a control group receiving conventional instruction without the use of the e-module (Sutanto et al., 2024).

The quasi-experimental design was selected because it allows for the measurement of changes in students' critical thinking skills under conditions that closely resemble a true experimental setting, but without full randomization of the research groups. This approach is consistent with a previous study conducted by Rodi'ah, which used an experimental design with experimental and control groups to assess changes in students' conceptual understanding of mathematics (Rodi'ah et al., 2024). This study also follows the procedures proposed by Azriyanti, who demonstrated that the use of PBL-based e-modules to enhance critical thinking skills can be validated as an effective independent instructional tool. In this study, the developed PBL-based e-module will be used as the learning material for the experimental group, while the control group will engage in traditional instruction based on textbooks and lectures (Azriyanti & Syafriani, 2023).

To address the research objectives, the following steps were implemented in the design of this study:

1. Sample Selection: This study involved fourth-grade elementary school students selected through purposive sampling. The students were divided into two groups: an experimental group that used the PBL-based e-module and a control group that received traditional instruction.
2. Instruments: The instruments used in this study included a critical thinking skills test administered before (pre-test) and after (post-test) the use of the e-module. This test was designed to measure students' abilities to analyze, evaluate, and solve the given problems.

Tabel 1 Comparison Between the Instruments Used

Group	Instrument	Description
Experimental Group	PBL-based e-module	An interactive digital module integrating Problem-Based Learning in mathematics and science instruction.
Control Group	Conventional Learning	Traditional instruction based on textbooks and teacher-led lectures without PBL elements.

3. e-Module Development Process: Based on the guidelines suggested by Rodi'ah, the e-module developed for the experimental group was designed using Articulate Storyline, which allows for the creation of interactive modules based on real-life problems within the context of students' daily experiences. This e-module focuses on problem-solving and the development of students' critical thinking skills (Rodi'ah et al., n.d.).
4. Data Collection: Data were collected through pre-tests and post-tests administered to both groups. These tests consisted of items designed to measure students' critical thinking abilities in solving mathematics and science problems.
5. Data Analysis: The data obtained from the pre-test and post-test will be analyzed using a t-test to determine if there is a significant difference in the improvement of critical thinking skills between the experimental group and the control group.

Data and Data Sources

The data source for this study is fourth-grade elementary school students selected using purposive sampling technique. This technique is used to choose a sample with characteristics that align with the research objectives, specifically students who are participating in mathematics and science learning. This group of students will be divided into two groups: the experimental group, which will use the PBL-based e-module, and the control group, which will follow conventional learning without the e-module.

The data sources for this study consist of two main categories: students and the instruments used to measure critical thinking skills. For the student category, data is obtained from fourth-grade elementary school students who meet certain criteria, such as their readiness to participate in e-module-based learning. In a study

conducted by Firdaus, fifth-grade students were used as the sample to test the critical thinking skills that can be developed through PBL-based learning (Firdaus et al., 2024). By adopting a similar method, this study aims to evaluate how effectively the PBL-based e-module can enhance the critical thinking skills of fourth-grade students.

In addition, the instruments used to collect data on critical thinking skills are pre-tests and post-tests administered to both groups before and after the intervention. These tests are designed to assess students' abilities to analyze, evaluate, and solve problems, which are key indicators of critical thinking skills. Susanto also used a similar test to measure students' critical thinking skills in science learning, demonstrating how such tests can be used to measure the improvement of students' critical thinking skills after the intervention (Susanto et al., 2022).

The use of PBL-based e-modules in this study is also based on Saralee's statement, which suggests that e-modules can be used as tools to collect data from students in the context of technology-based learning (Saralee et al., 2024a). In this study, the PBL-based e-module will provide contextual problems faced by students, allowing them to interact with the material and develop critical thinking skills.

Table 2 The Distribution of Data Sources Between the Experimental Group and the Control Group

Group	Number of Students	Characteristics	Type of Learning
Experimental Group	30	Fourth-grade students using PBL-based e-modules	PBL-based e-modules
Control Group	30	Fourth-grade students using conventional learning	Conventional learning (textbooks and lectures)

Data Collection Technique

Data collection in this study is conducted through two main techniques: critical thinking skills tests and observation of the implementation of Problem-Based Learning (PBL) based e-modules. These techniques are chosen to evaluate the impact of using e-modules on improving students' critical thinking skills, particularly in the context of mathematics and science learning.

1. Critical Thinking Skills Test

   This test is administered in two stages: a pre-test and a post-test. The pre-test is conducted before students engage in learning with the e-module, while the post-test is given after the intervention to measure changes in students' critical thinking skills. The test includes questions that assess students' abilities to analyze, evaluate, and solve the problems presented. Susanto used a similar test to measure students' critical thinking skills in science learning, demonstrating that PBL-based tests are effective in evaluating improvements in students' critical thinking abilities (Susanto et al., 2022).

2. Observations

   Observations are conducted to examine how students interact with the PBL-based e-modules and how they apply their critical thinking skills in solving the problems presented. The observations are carried out by the teacher involved in the research process, who notes group dynamics, students' responses to the problems they face, and the extent to which students can explain and solve problems logically and analytically.

   Firdaus used observation as a method to assess students' interactions with PBL-based learning materials (Firdaus et al., 2024).

3. Questionnaire

   A questionnaire is also used to collect data on students' perceptions of using the PBL-based e-modules. Saralee's research used a questionnaire to measure students' responses to the use of e-modules and their effectiveness in enhancing critical thinking skills. This study will use a similar questionnaire to gather data on students' perceptions in the experimental group (Saralee et al., 2024).

4. Interview

   Interviews are also conducted with teachers and students to gain deeper insights into their experiences with the PBL-based e-modules. The same method will be applied in this study to evaluate the perceptions of both teachers and students regarding the use of the PBL-based e-modules.

Data Analysis

Data analysis in this study aims to evaluate whether there is a significant improvement in students' critical thinking skills after engaging in learning using PBL-based e-modules. The data collected through pre-tests and post-tests, observations, questionnaires, and interviews will be analyzed using both statistical and qualitative

methods to provide a comprehensive overview of the impact of using PBL-based e-modules on students' critical thinking skills.

1. Descriptive Statistical Analysis

First, the data obtained from the pre-test and post-test will be analyzed using descriptive statistics to depict the distribution of students' critical thinking skills scores before and after using the PBL-based e-modules. According to Saralee, descriptive statistics are very useful for understanding basic patterns in the data, allowing the researcher to observe the distribution of critical thinking skills before and after the intervention(Saralee et al., 2024a). This will provide an initial overview of the impact of PBL-based e-modules on students' critical thinking skills.

2. T-Test

The paired t-test is used to compare the mean scores of the pre-test and post-test within the same group. This test will indicate whether the difference between the pre-test and post-test scores in the experimental group is statistically significant. As mentioned by Rodi'ah, the paired t-test is an effective tool for measuring changes in students' scores after the intervention (Rodi'ah et al., 2024). In the context of this study, the paired t-test will be used to analyze changes in students' critical thinking skills after using the PBL-based e-modules.

3. Qualitative Analysis

The data collected through observations, questionnaires, and interviews will be analyzed using a qualitative approach to explore the perceptions of students and teachers regarding the use of PBL-based e-modules. The results of the observations will be recorded and thematically analyzed to identify recurring patterns in how students approach problems. The questionnaires given to students will be analyzed to identify their perceptions of the use of PBL-based e-modules.

Susanto's study also used qualitative analysis to evaluate students' responses to the use of PBL-based e-modules in science education (Susanto et al., 2022). The results of this analysis provide valuable insights into how students perceive problem-based learning and how their experiences with PBL-based e-modules impact their critical thinking skills.

4. Validation and Reliability of Instruments

The reliability of the instruments will be tested using Cronbach's Alpha technique to measure the internal consistency of the test used to assess students' critical thinking skills. In the study conducted by Azriyanti, the instrument validation

process was also employed to ensure the reliability of the test used in measuring students' critical thinking skills (Azriyanti & Syafriani, 2023).

RESULTS

The table below presents the average scores of students' critical thinking skills based on the pre-test and post-test administered to both the experimental and control groups.

Table 3: Comparison of Pre-Test and Post-Test Average Scores

Group	Pre-Test (Mean)	Post-Test (Mean)	Change (Mean)
Experimental Group	45.6	70.4	+24.8
Control Group	46.1	49.7	+3.6

From the table above, it can be observed that the experimental group, which used the PBL-based e-modules, showed a significant mean change of +24.8, while the control group, which followed conventional learning, only experienced an increase of +3.6. This indicates that the use of PBL-based e-modules had a positive impact on improving students' critical thinking skills.

Analysis of T-Test

The paired t-test was conducted to test whether the changes between the pre-test and post-test in both groups were statistically significant. The t-test results showed a significant difference in the experimental group ($p < 0.01$), while the control group did not show a significant difference ($p > 0.05$).

- Experimental Group: $t = 9.82$, $p < 0.01$
- Control Group: $t = 1.45$, $p > 0.05$

These results support the hypothesis that the use of PBL-based e-modules has a significant impact on improving students' critical thinking skills. This study aligns with Susanto's findings, which show that PBL significantly enhances students' critical thinking skills (Susanto et al., 2022).

Results of Observations and Questionnaires

The results of the questionnaires given to students also showed that the majority of students in the experimental group felt more motivated and challenged in PBL-based learning. A total of 85% of students in the experimental group reported that they found the learning more enjoyable and motivating compared to using only conventional methods.

Similarly, Firdaus found that students who used PBL-based e-modules were more active in critical thinking and creative problem-solving. This suggests that PBL can engage students' thinking in a deeper and more contextual manner. (Firdaus et al., 2024).

Interview Results

Interviews with the teachers who taught both groups revealed that they felt the PBL-based e-modules were very helpful in aiding students to understand more complex material. Teachers in the experimental group reported that students mastered the material more quickly and were more willing to engage in discussions and ask questions during the learning process. Interviews with students showed that they felt more confident in solving problems and found it easier to understand concepts that were previously difficult. A total of 90% of students in the experimental group believed that the PBL-based e-modules enhanced their critical thinking skills.

DISCUSSIONS

The results of the study indicate that the use of Problem-Based Learning (PBL)-based e-modules has a significant impact on the improvement of elementary school students' critical thinking skills. The experimental group using the PBL-based e-modules showed a much greater improvement in critical thinking skills compared to the control group that followed conventional learning. This improvement is reflected in the significant difference between the pre-test and post-test scores in the experimental group, which is supported by the paired t-test results showing statistically significant outcomes ($p < 0.01$) (Andriani et al., 2024; Laksmi et al., 2024).

This study aligns with the findings of Chasanah, which demonstrate that PBL-based e-modules can enhance students' critical thinking skills, particularly in the context of mathematics education. The application of PBL in e-modules provides students with the opportunity to identify, analyze, and solve mathematical problems in depth, which in turn strengthens their critical thinking skills (Chasanah & Fitrianawati, 2023).

In addition, similar results were also found by Saralee, who suggests that the use of Articulate Storyline in the development of e-modules can make PBL-based learning more interactive and engaging. (Saralee et al., 2024). In this study, students who used PBL-based e-modules with Articulate Storyline showed a greater improvement in critical thinking skills compared to students who used conventional learning methods (Andriani et al., 2024; Ismiyanti et al., 2024).

One interesting finding from this study is that although the control group showed a slight improvement, the difference was not statistically significant. This suggests that conventional learning methods are not sufficient to fully develop students' critical thinking skills. This supports Fajari's findings, which state that critical thinking skills need to be given special attention in learning design, especially for students at the elementary school level (Fajari & Chumdari, 2021). Therefore, the development of PBL-based e-modules becomes one of the effective alternatives in enhancing students' critical thinking skills at this level.

The PBL-based e-modules also proved effective in increasing student engagement. The observation results indicated that students using the PBL-based e-modules were more active in group discussions and problem-solving compared to those using conventional learning methods. This aligns with Firdaus' findings, which showed that PBL-based e-modules encourage students to collaborate and think more critically in solving problems (Firdaus et al., 2024). The observations also revealed that students were more interested in completing the tasks provided in the e-modules compared to the tasks given in conventional learning, which mainly focused on memorization (Laksmi et al., 2024).

In addition, the questionnaires and interviews with students and teachers showed positive results regarding their experiences with the PBL-based e-modules. Most students reported feeling more challenged and engaged in solving problems when using these e-modules. This is supported by Susanto's research, which found that PBL-based e-modules not only improve critical thinking skills but also make learning more enjoyable and interactive for students (Susanto et al., 2022). Interviews with teachers revealed that they observed significant progress in students' critical thinking abilities after using the PBL-based e-modules, particularly in mathematics and science, subjects that are often considered difficult.

However, despite the significant improvement, there are several challenges in the implementation of PBL-based e-modules. One of them is the availability of technological devices in schools, which may limit the implementation of these e-modules in some regions. This aligns with the findings in Smith's study, which states that the implementation of technology-based PBL requires adequate infrastructure support to ensure its successful application. (Smith et al., 2023).

Overall, the results of this study indicate that the use of PBL-based e-modules is highly effective in enhancing the critical thinking skills of elementary school students, particularly in mathematics and science education. This research provides

strong evidence regarding the benefits of implementing technology-based PBL in primary education and opens opportunities for further development in this field. This research contributes significantly to the development of PBL-based e-modules as an effective tool to improve the quality of education at the elementary level. It is hoped that the findings of this study can serve as a foundation for further research on the use of technology to enhance critical thinking skills at various educational levels.

CONCLUSION

Based on the results of the conducted research, it can be concluded that the implementation of Problem-Based Learning (PBL)-based e-modules significantly enhances the critical thinking skills of elementary school students. The use of PBL-based e-modules provides a more interactive and relevant learning experience, motivating students to actively engage in the learning process and think critically. This is evidenced by the results of the pre-test and post-test, which show a significant improvement in the critical thinking skills of students in the experimental group using the PBL-based e-modules, compared to the control group that followed conventional learning. However, there are challenges that need to be addressed, such as the availability of adequate technological devices to support the implementation of PBL-based e-modules in certain schools. Therefore, adequate infrastructure support is required to ensure the success of this method's implementation in various regions. This study also indicates that although PBL-based e-modules have a positive impact, the improvement of students' critical thinking skills is highly dependent on the quality and relevance of the problems presented in the module. Thus, PBL-based e-modules have proven to be effective in enhancing the critical thinking skills of elementary school students, particularly in mathematics and science education.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.