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The Development of STEM-Based Teaching Materials to Enhance Students' Critical Thinking Skills

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ABSTRACT: This study is developmental research aimed at analyzing the development results of STEM-based physics teaching materials, practitioners' responses, and the effectiveness of STEM-based physics teaching materials in enhancing students' critical thinking skills. The research trial subjects were 28 Grade XI Science students at MA Darul Fallaah Unismuh. The STEM-based physics teaching material development model used was the 4-D instructional model, which consists of Define, *Design, Develop, and Disseminate*. The research instruments included: Validation sheets for STEM-based physics teaching materials Practitioners' assessment questionnaires Critical thinking skills test instrumentsFindings: 1) STEM-based physics teaching materials were declared valid and feasible for use, with physics material integrated into the STEM approach and a collection of questions aligned with critical thinking skill indicators. 2) Practitioners' responses, particularly physics teachers, placed the developed teaching materials in the "Very Good" category. 3) Effectiveness analysis showed that STEM-based physics teaching materials improved students' critical thinking skills, with an N-Gain score of 0.53, categorized as moderate. Students demonstrated improvements in interpretation, analysis, inference, evaluation, and explanation indicators. These results indicate that the STEM-based physics teaching materials developed in this study are effective in enhancing students' critical thinking skills.

KEYWORDS: STEM Learning, Critical Thinking Skills, 4-D Instructional Model

INTRODUCTION

Education is a conscious and planned effort to create a conducive learning environment and learning process. Education is used as a tool to achieve Indonesia's goal of advancing the nation's intelligence, as outlined in the fourth paragraph of the Preamble to the 1945 Constitution. Education, as a response to the fourth industrial revolution (Industry 4.0), gives rise to the concept of Education 4.0. The vision of Education 4.0 is to motivate learners to not only acquire knowledge and skills but also to identify the sources of those knowledge and skills (Ratnaningsih, 2019).

In today's existence, whether in the form of work or other professions, there is a demand for resources with high-level skills, which implies that individuals and society must develop habits of continuous learning, reasoning, critical thinking, decision-making, and problem-solving. Skills are something that can be trained. According to Dunatte (1976), skills mean developing knowledge gained through practice and experience by performing various tasks. This means that the 21st-century skills expected of learners as preparation for producing superior human resources that can compete globally can be trained in the educational setting. One of the learning methods that can support the development of 21st-century skills for learners is implementing STEM-based learning.

STEM is an integrative approach, meaning it is an approach that involves the use of multiple disciplines. Science, Technology, Engineering, and Mathematics (STEM) is a new approach in the development of education that integrates more than one discipline. The National STEM Education Center (2013) states that STEM learning does not only mean strengthening practical education in each STEM field separately, but rather developing an educational approach that integrates science, technology, engineering, and mathematics with a focus on education.

STEM, as an integrated education approach, can help learners apply science, technology, engineering, and mathematics in real-world contexts that bridge the gap between school and everyday life. STEM literacy can enhance learners' competitiveness in the 4.0 era (Singgih & Dewantari, 2020). The problems faced by learners in the real world are not limited to a single field of knowledge. Instead, learners must learn to solve problems from various perspectives. Therefore, it is more appropriate to select topics to be explored from various multidisciplinary fields and relate them to technology (Rizaldi, Nurhayati, & Fatimah, 2020).

Technological advancements are in line with developments in natural sciences, particularly in physics. The development of modern physics since the early 20th century has driven technological advancements and even led to the birth of new technologies.

Therefore, physics education should increase learners' awareness of the importance of physics. This increased awareness is expected to encourage learners to strive to better understand the concepts and principles of physics (BSNP, 2020).

Critical thinking skills are a systematic thinking process that enables learners to formulate and evaluate their own beliefs and opinions (Johnson, 2007). Critical thinking skills include higher-level skills such as analysis, synthesis, understanding and problem-solving, inference, and evaluation. The implementation of critical thinking skills indicators in physics education requires thorough preparation from teachers, one of which is in the development of physics teaching materials.

Teaching materials are a key component needed by teachers in the teaching process. The development of teaching materials is required to align with technological advancements, learner characteristics, and 21st-century skills. By developing the right teaching materials, the implementation of physics learning that meets the indicators of critical thinking skills can be more effective. Pramita et al. (2021), in their research, explained that the use of physics teaching materials significantly impacts critical thinking abilities in terms of educational level, subject matter, and the teaching model used. Therefore, it is important for teachers to develop appropriate physics teaching materials to ensure that the learning objectives can be achieved.

On November 5, 2023, the researcher conducted observations and interviews at MA Darul Fallaah Unismuh to gather an overview of the students' critical thinking skills in physics, the teaching materials used by the teacher, and the characteristics of the students in the physics learning process. The observation was carried out through an interview with one of the physics teachers, followed by observations of the physics teaching and learning process in the classroom.

The results of the observation provided data that among the four 21st-century skills that students need, one of them is critical thinking skills. The researcher measured the critical thinking skills of the students to obtain valid data in class XI IPA, and the results indicated that the students' critical thinking skills were very low. The test results were consistent with the teacher's evaluation, which categorized the skills as low. Meanwhile, critical thinking skills are essential future skills that students need.

Additionally, the teaching materials used by the teacher during the learning process were limited to the teacher's handbook and simple PowerPoint presentations. Other learning resources, such as the internet, were also used, but they had weaknesses, such as poor internet connectivity and the broad scope of material available on Google, which made it difficult for students to understand. The teaching materials used by the teacher had several weaknesses: (1) the questions in the book did not meet the critical thinking indicators, (2) there were no problems for students to solve, which meant that problem-solving indicators were not met, and (3) the content of the book was incomplete, as there was a lack of material elaboration, making it difficult for students to understand the lesson without detailed explanations from the teacher.

Based on the results of the observations and interviews, the analysis of needs showed that students need a learning approach that can develop their critical thinking skills and potential, provide opportunities to be more active, and allow students to connect learning to their everyday environment. Additionally, students need learning resources that can stimulate their curiosity, not just sharpen their mathematical analysis skills.

The quality of the STEM-based physics teaching materials developed by the researcher must meet the criteria of good teaching materials, which include being valid, effective, and practical in improving critical thinking skills. The STEM-based physics teaching materials, which meet the key components of teaching materials, were then validated by experts. The results of the validation were assessed by practitioners, and the effectiveness of these teaching materials was measured in terms of their impact on students' critical thinking skills through the implementation of the developed teaching materials at MA Darul Fallaah Unismuh.

Based on the sequence of identified issues, the researcher is interested in developing an innovation in physics teaching materials at MA Darul Fallaah Unismuh by conducting a Research and Development (R&D) study, with the research title "Development of STEM-Based Physics Teaching Materials to Enhance Critical Thinking Skills."

METHOD

This research is a Research and Development (R&D) study. The aim of this research is to produce STEM-based physics teaching materials to enhance students' critical thinking skills, using the 4-D development model, which includes define, design, develop, and disseminate.

This research procedure was carried out in several stages using the 4-D (Four D) research model, which is adapted from the Thiagarajan model. According to Sugiyono (2009), research and development is a research model used to produce a new product and subsequently assess the effectiveness of that product. The 4-D development model consists of four main stages: (1) define, (2) design, (3) develop, and (4) disseminate.

The experimental design used in this study is the "One Group Pretest and Posttest Design." In this design, a test will be conducted using a learning achievement test instrument to assess the students' learning outcomes before the experiment (O1), referred to as the pre-test, and after the experiment, which involves using STEM-based physics teaching materials in the learning process (O2), referred to as the post-test. This experimental design is illustrated as follows: (Sugiyono, 2013).

O_1 X O_2

X : Treatment (STM- Based Physics Teaching Materials)
O_1 = Pre-test score of physics learning achievement (before the STEM-based physics teaching materials are provided)
O_2 = Post-test score of physics learning achievement (after the STEM-based physics teaching materials are provided)

RESULT AND DISCUSSION

The result of this research development is a STEM-based physics teaching material for 11th grade high school/MA students on the topics of static fluids and dynamic fluids. The teaching materials and instruments developed will be validated by three experts/specialists to assess the feasibility of the content of the developed product. After the instruments are validated by the experts, the scores will be calculated, and revisions will be made as necessary according to the feedback provided by the validators. The results from the experts' validation of the STEM-based physics teaching materials, the practitioner assessment questionnaire, and the critical thinking skills test for student learning are as follows:

Table 1 Analysis of the Expert Agreement Index on the Validation of STEM-Based Physics Teaching Material Items

Aspect	V	Category
Content Feasibility	0,76	Valid
Presentation Feasibility	0,71	Valid
Language Feasibility	0,78	Valid
Graphic Feasibility	0,77	Valid

Source: Processed Primary Data (2023)

Table 1 The analysis of the expert agreement index on the validation of STEM-based physics teaching material items in Table 1 shows that the content feasibility aspect obtained a validity index (V) of 0.76, which falls into the valid category. For the presentation aspect, the validity index (V) was 0.71, also falling into the valid category. The language feasibility aspect obtained a validity index (V) of 0.78, which is categorized as valid, and for the graphic feasibility aspect, the validity index (V) was 0.77, also in the valid category. Based on the analysis from three experts, the STEM-based physics teaching material is considered valid and feasible to use.

Table 2. **Percentage of Feasibility of STEM-Based Physics Teaching Materials**

Aspect	V	Percentage
Content Feasibility	0,76	76,00%
Presentation Feasibility	0,71	71,00%
Language Feasibility	0,78	78,00%
Graphic Feasibility	0,77	77,00%

Source: Processed Primary Data (2024)

In Table 2, the three experts agreed that 76.00% of the content feasibility aspect, 71.00% of the presentation aspect, and 78.00% of the language aspect of the STEM-based physics teaching materials are suitable for use with minor revisions. Meanwhile, for the graphic aspect, the three experts agreed that 77.00% of the teaching materials are suitable for use with minor revisions. The overview of the validity results for the content of the STEM-based physics teaching materials is presented in the form of a percentage graph, as shown in Figure 1.

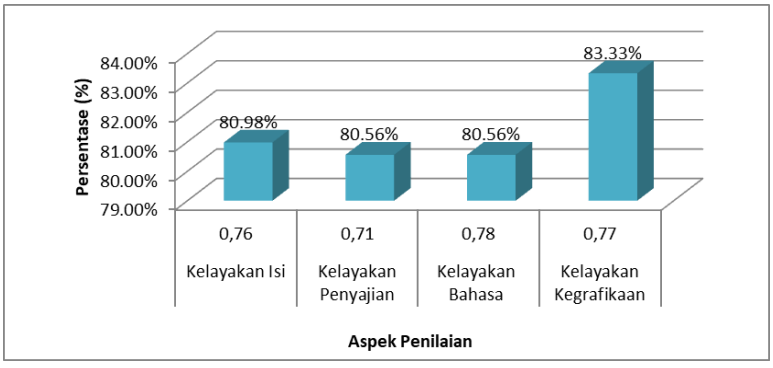


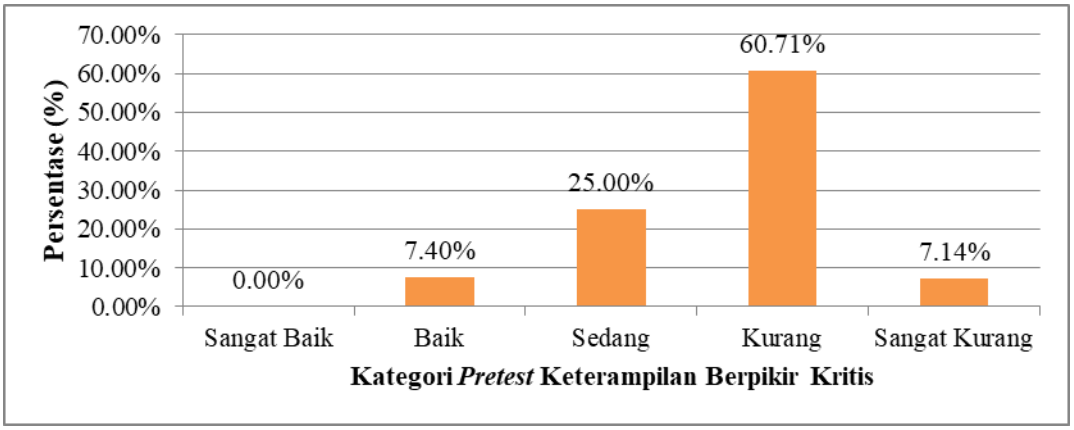
Figure 1 Graph of the Percentage of Feasibility Aspects of STEM-Based Physics Teaching Materials

Table 3. Percentage of Pretest Scores for Students' Critical Thinking Skills by Class

Interval Criteria	Category	Frequenci	Percentage Scor
32 < X □ 40	Very Good	0	0,00%
24 < X □ 32	Good	2	7,14%
16 < X □ 24	Moderate	7	25,00%
8 < X □ 16	Low	17	60,71%
X □ 8	Very Low	2	7,14%
Total		**28**	**100,00%**

Source: Processed Primary Data (2023)

The analysis of pretest scores for critical thinking skills, as shown in the frequency distribution table above, indicates that 2 students (7.14%) achieved a Good category score during the pretest. A total of 7 students (25.00%) were in the Moderate category, while 17 students (60.71%) received a Low score. Additionally, 2 students (7.14%) fell into the Very Low category. The percentage graph of students' pretest critical thinking skills is presented in Figure 4.below.



The results of the research on the development of STEM-based physics teaching materials are explained in the following discussion.

1. The development of STEM-based physics teaching materials follows several stages according to the 4D design model, which includes definition, design, development, and dissemination. During the development stage, the initial product of STEM-based physics teaching materials was created and validated by three experts, referred to as Prototype I.After validation, revisions were made based on feedback and suggestions, resulting in Prototype II. The revised teaching materials were then implemented and assessed by practitioners regarding their feasibility and usefulness. The feedback from practitioners was used for further improvement, leading to the final version, Prototype III.
2. The STEM-based physics teaching materials, which were validated by experts, were then assessed by practitioners to evaluate their applicability and usefulness. The practitioners in this study consisted of 10 high school physics teachers from Gowa Regency. The evaluation was conducted using a validated questionnaire, which included four assessment aspects: Content feasibility Presentation feasibility Language feasibility Graphical feasibility Each aspect contained ten statement items that practitioners used to evaluate the teaching materials.

CONCLUSIONS

The development of STEM-based physics teaching materials falls into the valid category, making them feasible for use. The developed teaching materials are in the form of digital learning resources, characterized by STEM-integrated physics content (Science, Technology, Engineering, and Mathematics) along with a collection of example problems and evaluations aligned with critical thinking skill indicators. The structure of the physics teaching materials aims to enhance critical thinking skills through a STEM approach**.** The assessment by practitioners of the developed STEM-based physics teaching materials falls into the Very Good category. This indicates that practitioners have given a positive response to the developed STEM-based physics teaching materials**.** And The improvement in students' critical thinking skills after the implementation of STEM-based physics teaching materials, as analyzed using N-Gain, falls into the Moderate category. This indicates that there is a notable improvement in the critical thinking skills of Grade XI Science students at MA Darul Fallaah Unismuh**.**

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