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Increasing Critical Thinking Skills Through the Development of STEM-Based Physics Learning Media on Temperature and Heat

Aris Doyan[1,2*], Ayu Safitri Melita[2], Muh Makhrus[1,2]

[1]Physics Education Study Program, FKIP, University of Mataram, Mataram, Lombok, West Nusa Tenggara, Indonesia.
[2] Master Education Program, Post Graduate University of Mataram, Mataram, Lombok, West Nusa Tenggara, Indonesia.

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Corresponding Author:
Aris Doyan
aris_doyan@unram.ac.id

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Abstract: Research has been carried out to improve students' critical thinking skills which are valid, practical, and effective through the development of STEM-based learning media products on temperature and heat material. Data collection techniques used response questionnaires, validation sheets and test instruments, with the 4D model (Design, Define, Development, and Desiminate) as the design. Evaluation of product validity was carried out by media experts and material experts and used Aiken-V as a way of analysis. The practicality of the product is analyzed using a practicality test while the effectiveness is obtained by increasing students' mastery of concepts and critical thinking skills with N-gain. The results of the validator's assessment of the digital calorimeter media showed an average result of Aiken-V of 0.94 which was very valid. The average results for the practicality assessment of the developed media can be seen from the student response questionnaire which shows a value of 4.51 in the fairly practical category. The average result for the effectiveness of the developed media can be seen from the increase in critical thinking skills, namely 0.42 with moderate criteria. It was concluded that STEM-based physics learning media to improve students' critical thinking skills are valid, practical, and effective.

Keywords: Critical thinking ability; Digital calorimeter; Instructional media

Introduction

The digital revolution and the era of technological disruption are other terms for industry 4.0 (Setiadi, 2019). The 21st century was marked by massive transformations in social, economic, political and cultural aspects driven by four major interrelated forces, namely scientific and technological advances, demographic changes, globalization and the environment (Susilo et al., 2018). Education 4.0 is a response to the needs of the industrial revolution where humans and technology are aligned to create creative and innovative opportunities (Lase, 2019).

To face the era of the industrial revolution 4.0, education is needed that can form creative, innovative and competitive generations (Harahap, 2019). This can be achieved by optimizing the use of technology (Lase, 2019).

MA Al Aziziyah Putri is one of the schools in West Lombok which in the learning process, especially related to physics, still uses conventional media as a learning aid at school. This can lead to reduced critical thinking skills of students. Interest in learning is also very influential in learning because if the lessons learned are not appropriate, students will not be interested in carrying out learning properly, one of which is that students do not get satisfaction from the learning (Apriyani et al., 2022). The emergence of various new technologies is a big challenge for education (Cayeni et al., 2019). This is related to tools that have creativity that are able to design learning materials and designs to be better and more precise (Doyan et al., 2023; Nana, 2019).

Media is a physical tool that can be used to channel messages from the sender to the recipient so that it can stimulate students' thoughts, feelings, concerns, and interests in such a way that the learning process occurs

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(Hamid et al., 2018). In conveying learning messages, intermediaries are needed so that value and transfer of knowledge can occur on target. These intermediaries are media and learning resources that are able to support and influence learning success. STEM is an approach that integrates several disciplines, both science, technology, engineering based on contextual problems (Mu'minah et al., 2020). STEM education also leads to individual abilities to reason, think critically, logically and systematically so that they are able to face various global world competitions that require four disciplines of science, technology, engineering and mathematics (Anita, 2021). This approach can also gradually change the attitude of mathematics either affectively or psychomotor. A calorimeter is a tool used to determine the heat capacity, specific heat capacity, and latent heat capacity of an object or material (Syam, 2023).

The STEM approach is an approach in education where Science, Technology, Engineering, Mathematics are integrated with the educational process focusing on solving problems in real everyday life as well as in professional life (Davidi et al., 2021). The STEM approach shows students how concepts, principles, techniques, science, technology, engineering and mathematics (STEM) are used in an integrated manner to develop products, processes and systems that benefit human life (Utami et al., 2017). Students are required to actively use technology products in learning with the STEM approach (Kaniawati et al., 2015). STEM learning connects material with life, involves students in practice, guides students in practice, utilizes technology, uses active student learning strategies, communicates actively with students, and gives assignments in groups. The integration of STEM learning with simple technology can help in understanding a material and improve thinking skills (Yusuf et al., 2019).

Critical thinking is no less important in influencing student learning achievement besides mastering concepts (Herlina, 2020). Critical thinking is a part of higher-order thinking skills. Critical thinking is a complex thinking process that includes skills and attitudes (Prameswari et al., 2018). One of the ways to build students' critical thinking skills in the learning process is by asking the teacher not only "what" happened but also "how" and "why" (Inggriyani et al., 2018). Critical thinking helps students find the cause of a changing variable and its effect on other variables (Suciono, 2021). People who think critically understand the importance of the right thinking in solving a problem (Kurniawati et al., 2020). Critical thinking leads a person to think reflectively and reasoning which is focused on making decisions to solve problems (Wisliani et al., 2022).

Critical thinking is an essential skill for life and functions effectively in all aspects of life. In general, critical thinking is defined as a deep thought process and also includes the ability to evaluate oneself and make a person more independent (Ramadhani et al., 2020). Critical thinking includes reasonable and reflective thinking skills that focus on decisions about what to believe or do. Performance appraisal is able to encourage students to be more active and more responsible, because students have to answer questions and or complete assignments given by the teacher in the form of problems found in real life (Ma'rifah et al., 2022).

Based on the description regarding the problem of students' low critical thinking skills, it is necessary to have further research using STEM-based learning media to improve students' critical thinking. The hope is that the development of this media can be one of the guidelines especially for teachers in the learning process which is able to improve students' critical thinking skills.

Method

This study uses development research methods to determine the feasibility, practicality and effectiveness of the developed learning media. The research design uses a 4D model in the form of four stages, namely: Defining Design, Development and Dissemination.

This research was conducted at MA Al Aziziyah Putri West Lombok with the research subjects being students of class XI IPA 2 for the 2021/2022 academic year. The data collection instrument that was applied was to provide a validation sheet to the validator for the learning media being developed. In addition, a response questionnaire to determine the practicality of learning media and test instruments used to determine the effectiveness of learning media.

The validity of learning media is calculated based on the assessment of the three experts using the Aiken's V equation 1.

$$V = \frac{\sum S}{n\,(c-1)} \quad (1)$$

Table 1. Validity Assessment Criteria (Akbar, 2017)

Aiken's V Score	Category
0.00 – 0.200	Very invalid, should not be used
0.21 – 0.40	Invalid or may not be used
0.41 – 0.60	Invalid, it is recommended not to use it because it needs major revisions
0.61 – 0.80	Valid, or can be used but needs minor revision
0.81 – 1.00	Very valid or can be used without revision

The reliability of learning media assessment results is based on the agreement between validators. Agreement between validators was analyzed using a percentage of agreement. Learning media is said to be reliable if the percentage of agreement is ≥75%. The

percentage of agreement formula is shown in equation 2.

$$PA = 1 - \frac{A - B}{A + B} x100\% \quad (2)$$

Where: PA = Percentage of Agreement, A = The frequency of assessments by experts giving high scores, and B = The frequency of assessments by experts giving low scores.

Data on the practicality of learning media will be obtained from observation sheets of the implementation of learning by observers, and then will be analyzed to determine the average percentage with Equation 3.

$$\% \text{ Average} = \frac{The\ total\ Score\ of\ the\ assessor}{Maximum\ Total\ Score} \text{ x } 100\% \quad (3)$$

After being analyzed, interpretation of the data will then be carried out based on practicality criteria. The level of practicality of the instrument is determined based on Table 2.

Table 2. Practicality Criteria (Prayudi et al., 2022)

Percentage Value Range (%)	Practicality Level
0.00 – 20.00	Very impractical
21.00 – 40.00	Less practical
41.00 – 60.00	Practical enough
61.00 – 80.00	Practical
81.00 – 100.00	Very practical

Analysis of the effectiveness of the media consists of an analysis of the increase in mastery of concepts and critical thinking skills. To analyze the increase, N-gain value analysis will be used as in Equation 4. With the following N-gain acquisition categories.

$$\text{N-gain} = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \text{ x } 100\% \quad (4)$$

Table 3. N-gain Criteria (Kurniawati et al., 2020)

Interval	Criteria
g > 70.00	High
30.00 ≤ g ≤ 70.00	Currently
g < 30.00	Low

Result and Discussion

Validity

Whether or not a learning media is appropriate can be seen when evaluating validity. The validation that has been carried out to determine the feasibility of STEM-based learning media to improve critical thinking consists of three experts related to the learning media that have been developed. The results show a valid category.

Validation of Calorimeter Media

Digital calorimeter media was developed using Arduino uno as the main micro controller, and the results of measurements using the calorimeter will be immediately visible on the LCD screen. As shown in Figure 1.

Figure 1. Digital calorimeter

Based on table 4 the digital calorimeter validation results are categorized as very valid according to the three validators. The average validation component based on Aiken-V is 0.94 which indicates that digital calorimeter media is very valid to be used to facilitate the improvement of students' critical thinking.

Table 4. Aiken-V score data for Digital Calorimeters

Average Item	Aiken-V Score	Criteria
Total Item	0.94	Very Valid

Table 5 shows agreement between validators, it is found that the product developed has a percentage of agreement > 75%, namely 93% or is referred to in the reliable category which shows consistency between the three validators, which are very appropriate and aligned.

Table 5. Percentage of Agreement Score Data for Digital Calorimeters

Average Item	Aiken-V Score	Criteria
Total Item	0.80	Valid

Validation of Student Worksheets

Student worksheets designed to support the use of digital calorimeter media and which facilitate questions with critical thinking indicators. Student worksheets are assessed based on several important components of student worksheet development, namely related to structure and appearance. Details of the average validation score and reliable percentage in Table 6.

Table 6. Data on Average Aiken-V Scores for Student Worksheets

Average Item	Aiken-V Score	Criteria
Total item	0.70	Valid

Table 7. Percentage of Agreement Score Data for Student Worksheets

Instrument	Percentage of Agreement			PA Average	Category
student	PA_{12}	PA_{13}	PA_{23}		
worksheets	99.00	89.00	78.00	92.00%	Reliable

Based on Table 6 it is known that the STEM-based student worksheets are very valid and relevant for use in any experimental implementation related to critical thinking skills. Based on the results it can be seen that the average score of Aiken-V is 0.85 with a very valid category. Based on table 7 the percentage of agreement, which is an agreement between validators, it is known that student worksheets have a high level of relevance with a percentage of 92.00%, which means student worksheets are reliable. The results of the digital Calorimeter validation are presented in Table 8.

Furthermore, the syllabus is an outline lesson plan that contains core competencies, basic competencies, learning materials, competency achievement indicators, time allocation, and learning resources used as Table 9.

Table 8. Aiken-V Average Score Data for Digital Calorimeter

Instrument	Percentage of Agreement			PA Avarage	Category
Digital	PA_{12}	PA_{13}	PA_{23}		
Calorimeter	97.00	99.00	84.00	93.00%	Reliable

Table 9. Average Percentage of Agreement Score Data for Syllabus

Instrument	Percentage of Agreement			PA Avarage	Category
Syllabus	PA_{12}	PA_{13}	PA_{23}		
	89.00	98.00	58.00	81.00%	Reliable

Based on Table 9 it is known that the STEM-based syllabus with the inquiry-based learning model is valid and relevant for use in any experimental implementation related to critical thinking. Based on the results it can be seen that the average score of Aiken-V is 0.8 with a valid category. Then for the agreement score between validators or the percentage of agreement in table 9 it is known that the syllabus has a high level of relevance with a percentage of 81.00% in the reliable category.

Validation of the Teaching Program Plan

The development of the teaching program plan is carried out based on STEM-based learning with the inquiry-based learning model. The teaching program plan is developed based on basic competence in temperature and heat material. The phases listed in the teaching program plan are adjusted to the STEM-integrated inquiry-based learning phase. The validation results for the teaching program plan are presented in Table 10.

Table 10. Aiken-V Average Score Data for Lesson Plans

Item	Aiken-V Score	Criteria
Total item	0.70	Very Valid

Table 11. Average Percentage of Agreement Score Data for Lesson Plans

Instrument	Percentage of Agreement			PA Avarage	Category
Lesson	PA_{12}	PA_{13}	PA_{23}		
plans	92.00	95.00	97.00	94.00%	Reliable

Based on Table 10 it is known that STEM-integrated inquiry-based learning model-based lesson plans are valid and relevant for use in any experimental implementation related to critical thinking skills. Based on the results it can be seen that the average score of Aiken-V is 0.70 with a valid category. In table 11 regarding the percantegae of agreement data it is known that lesson plans have a high level of relevance with a percentage of 94.00% in the reliable category.

Test Instrument Validation

The critical thinking ability test instrument is arranged in the form of reasoned multiple choice with 10 questions. Each question is adjusted to indicators of critical thinking skills. The critical thinking ability instrument was validated by three experts. The validation results are presented in Table 12.

Table 12. Aiken-V Average Score Data for the Critical Thinking Ability Instrument

Instrument Test	Aiken-V Score	Criteria
Critical Thinking skills	0.70	Valid

Table 13. Average Percentage of Agreement Score Data for Critical Thinking Skills Test Instruments

Instrument	Percentage of Agreement			PA Avarage	Category
Critical	PA_{12}	PA_{13}	PA_{23}		
Thinking Skills	83.00	95.00	90.00	89.00%	Reliable

Based on Table 12, it is found that the validation score for the critical thinking skills instrument is very valid and relevant to use in any experimental implementation related to critical thinking skills. Based on the results it can be seen that the average Aiken-V score for critical thinking ability is 0.70 with a valid category. Based on table 13, it shows agreement among validators that all products developed have a percentage of agreement >75%, which is 89% for critical thinking skills instruments or those referred to in the reliable category.

Practicality

The practicality of the developed STEM-based learning media is known from the implementation of

learning, student response questionnaires, and teacher response questionnaires. The implementation of learning can be seen from the learning that was successfully carried out during learning using digital calorimeter media.

Implementation of Learning

The learning process for two meetings using digital calorimeter media obtained an average score of 70.00% in the practical category. This indicates that each learning stage at each meeting is carried out properly as shown in Table 14.

Table 14. Data on the Results of Learning Implementation Analysis

Class	Percentage of Learning Implementation (%)	
	P1	P2
XI IPA2	70.00	70.00

Student Response Questionnaire

After learning is carried out, students are given a response questionnaire to fill out. The statements listed in the questionnaire consist of six questions related to STEM-based digital calorimeter media that are attractive, easy to operate, and support the learning process. From the analysis per category can be seen in Table 15.

Table 15. Data on Analysis Results per Category of Student Responses

Class	Item			Average Score
XI IPA 2	Interesting Digital Calorimeter	Ease of Use	Supporting Learning	4.51
	4.18	4.71	4.62	

Based on table 15, the score for the digital calorimeter statement is attractive with an average value of 4.18, indicating practical. Whereas in the statement of ease in using digital calorimeter media with an average score of 4.71 indicating practicality. Furthermore, statements support learning with an average score of 4.62 indicating practical. This shows that students' responses to the use of digital calorimeter learning media in learning with an average value of 4.51 are stated to be practical.

Teacher Response Questionnaire

The teacher was also given a response questionnaire to fill out. The statements listed in the questionnaire consist of 10 statements related to the use of STEM-based digital calorimeter media in learning. Data from the analysis per category can be seen in table 16.

Table 16. Data Analysis Results per Teacher Response Category

Teacher	Item			Avarage score	Category
	Learning Aspects	Media Aspects of the Digital Calorimeter	Student worksheet Aspects		
Physics Sciences	4.30	4.00	4.20	4.16	Good

Based on table 16, the scores for statements on aspects of using STEM-based digital calorimeter media and student worksheets in learning are at an average score of 4.30 which indicates learning is in the practical category. Furthermore, the teacher also agrees that using STEM-based digital calorimeter media is able to make students interested and happy in learning and is in the range of a score of 4.30. While the average score of all items is 4.16, this shows that the teacher's response to learning using STEM-based digital calorimeter media gets a very good response.

Effectiveness

Improving critical thinking skills by using a test instrument in the form of reasoned multiple-choice questions. In the critical thinking skills test, the results of the test analysis were divided into three, namely the results of the pretest-posttest, the results of the N-gain test and the results of the students' worksheets. At this stage the limited trial subjects used 1 class with 32 students.

Before and after students learn to use a digital calorimeter, an initial test of critical thinking skills is carried out to determine their improvement in abilities. The results of the analysis of the test are divided into three, namely the results of the pretest-posttest, the results of the N-gain test, and the scores of indicators for critical thinking skills in the learning process with student worksheets. Based on the results of calculating the average pretest-posttest score for critical thinking skills, it can be seen in Table 17.

Table 17. Results of Pretest-Posttest N-gain Analysis of Critical Thinking Ability

Class	N	Critical Thinking Ability			Information
		Pretest	Postest	N-gain	
Limited test	32	12.84	45.68	0.32	Middle

Based on the calculation of the average score in Table 17, it was found that the average initial knowledge of students was 12.84. Meanwhile, after learning the improvement experienced by students. The posttest result was 45.68, which means that students experienced a sufficient increase in critical thinking skills. The N-gain

test shows an increase in students' critical thinking skills after learning using the developed STEM-based digital calorimeter. Students experienced an increase which was still in the moderate category. This data shows that the use of STEM-based digital calorimeters is effective in increasing students' critical thinking skills. Supporting data for this increase is obtained from the results of student worksheets and the learning process using a digital calorimeter.

Table 18. Per-Indicator Critical Thinking Ability Scores on Student Worksheets

P	Indicator					Total Average	Category
	1	2	3	4	5		
Meet 1	3.41	2.96	3.94	3.09	4.00	3.48	Practical
Meet 2	3.43	3.12	3.94	3.31	4.00	3.56	Practical

Based on the calculation of the average score of Tables 18, it can be seen that students experienced an increase in their critical thinking skills per indicator at each meeting with an average value of 3.48-3.56 which means the use of STEM-based digital calorimeter media with the help of student worksheets is said to be practical. The results of this critical thinking ability are in line with the results of research which states that the science learning device in the form of syllabus, Lesson Plan, Student worksheet, Instrument of critical thinking Instrument for the model of the concept developed has fulfilled the valid content and valid construct (Doyan et al., 2022; Kartini et al., 2019; Rahman et al., 2021).

Conclusion

Based on the results of research using the 4D model from the define to disseminate stages in the development of physics learning media in the form of digital calorimeters, it can be concluded that the physics learning media on temperature and heat material for students' critical thinking abilities developed are included in the very valid category. This was obtained from the results of validation by three validators which showed an average Aiken-V score of 0.94 and 93% reliable for all supporting devices, namely syllabus, lesson plan, student worksheets, and instruments on concept mastery and critical thinking skills range of values 0.70-0.90 and 80%-94% reliable. And for the results of the practicality test of the implementation of learning 70% in each phase with the responses of students and teachers in the very good category, as well as the acquisition of student worksheet results in the learning process, namely 3.77 for mastery of concepts and 3.56 for critical thinking skills. And for the results of the effectiveness test, the average N-gain score is 0.32 for critical thinking skills in the medium category.

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Aris Doyan: writing—original draft preparation, result, discussion, Ayu Safitri Melita and Muh Makhrus: validation, methodology, analysis, proofreading, and editing; Aris Doyan:supervision, conclusion, and review.

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Conflicts of Interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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