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Development of STEM-Based Physics Module with Self-Regulated Learning to Train Students Critical Thinking Skills

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Abstract: One of the 21st century skills is critical thinking skills. However, according to several research results, it shows that students' critical thinking skills in Indonesia are still low. This is caused by inappropriate learning process, so that it has an impact on the effectiveness of achieving competence in learning. Teaching materials are one of the most important parts that support the learning process. A module is a form of teaching material that is structured to help students master learning objectives. Modules to practice critical thinking skills according to 21st century skills, which are integrated with the STEM approach. Therefore, this study aims to develop a STEM-based physics module with self-regulated learning to train students critical thinking skills. The SRL agent will assist students in studying the material in the module. The method used is a mixed method, with an exploratory sequential design. Mixed method is a combination of qualitative and quantitative research methods in a study. Qualitative data is needed in designing physics modules, while quantitative data is needed to determine the validity of the modules feasibility in practicing critical thinking skills. The critical thinking skills instrument was developed based on aspects of critical thinking skills according to Ennis. Data collection comes from expert validation result sheets. The results of this development indicate that STEM-based modules with SRL agents are feasible to use properly. And during the learning process is expected to improve students critical thinking skills. Therefore, students critical thinking skills still need to be studied in learning.

Keywords: Critical thinking skills; Physics module; Self-regulated learning; STEM

Introduction

The education system in Indonesia is faced with advances in science and technology, so students need skills to be ready to face the challenges of the 21st century (Sukmayadi et al., 2020). This is in accordance with the 21st century which encourages every individual to have skills in dealing with the times, known as 21st century skills (Hidayati et al., 2019). With these 21st century skills, it is hoped that they can help improve learning and develop student-centerd quality learning (Muianga et al., 2018). One of the skills that are appropriate to the challenges of the 21st century according to the US-based Partnership for 21st Century Skills (P21) is critical thinking (Pratama et al., 2019).

Science learning, especially physics, is expected to train students to solve a problem. Where the ability to solve problems can be improved by improving critical thinking skills (Haseli et al., 2013). Thinking is a reflective way of thinking that enters or is based on reason that determines what to believe and do (Ennis, 1993). Critical thinking can also be interpreted as a basic skill that must be possessed by a student to develop thinking skills at a more complex level (Hidayati et al., 2019). Critical thinking skills are expected to make students have the ability to think clearly and rationally. Therefore, critical thinking skills need to be taught and included in the school curriculum (Basri et al., 2019). However, according to several research results, students' critical thinking skills in Indonesia are still in the low category (Saphira et al., 2022). This can be seen from the results of the Program for International Student

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Assessment (PISA) in 2018 which showed that students in Indonesia were still far below other countries, where Indonesia was ranked 74th out of 79 countries (OECD, 2019).

Critical thinking skills are important to be developed in the world of education because the learning process requires good critical thinking skills (Maričić et al., 2015; Peter, 2012). By improving critical thinking skills, it will encourage and motivate students so that learning achievement will increase (Jacob, 2012; Maričić et al., 2015). In addition, critical thinking skills will also have a positive influence, namely increasing academic achievement (Fong et al., 2017). However, this is inversely proportional to the results of critical thinking skills which are still low.

In developing critical thinking skills in students, a learning process that applies 21st century skills is needed, especially critical thinking skills. One of them is by utilizing teaching materials in the learning process. Teaching materials are part of the curriculum that is used as a reference by teachers and students in the learning process (Khine, 2013). Thus, teaching materials become one of the most important parts that support the learning process. A module is a form of teaching material that is structured to help students master learning objectives. However, regarding the teaching materials (modules) used, they still contain only material without training skills for students. Therefore, teachers are required to have creativity in compiling and developing modules according to student needs. It is hoped that with the development of the module, it will have a positive impact on student learning outcomes. Thus it can be concluded that the module is one form of learning material that is packaged intact and systematically that contains a set of planned learning experiences and is designed to help students master specific learning goals. Modules can be used as one of the learning materials to facilitate independent or conventional learning (Siang et al., 2019).

Based on the explanation above, the development of modules to train critical thinking skills is appropriate, which is integrated with the STEM approach. This is in accordance with research on teacher perceptions regarding the integration of STEM into the curriculum which states that the 2013 curriculum is more suitable for the STEM approach (Suwarma et al., 2019). The STEM-based physics module will direct students to be more active in participating in the learning process through activities that hone the knowledge and skills of science, technology, engineering, and mathematics that are needed in the future. In addition, STEM is also a widely used approach and is able to prepare students to face the demands of the 21st century (Rahmania, 2021). Therefore, STEM is an effective way to facilitate and maintain the integration of science, technology, mathematics, and engineering (Estapa et al., 2017).

The STEM approach combines art with STEM subjects to increase student engagement, creativity, innovation, problem-solving skills, and other cognitive benefits (Kusasi et al., 2021). With STEM as a critical approach, it is hoped that it can train students' thinking skills and be able to prepare students to face future challenges. The use of STEM-based teaching materials can help schools in implementing the curriculum optimally (Widya et al., 2019). In line with this, it proves that STEM can improve the quality of the learning process which will have an impact on the quality of graduates (Zamista, 2018). And through STEM education-based modules, teachers can also conduct formative assessments through a student-centered learning process. To maximize this, a self-regulated learning (SRL) agent is needed.

Self-regulated learning is a process of self-regulation of students in learning that uses various cognitive and behavioral strategies that are oriented towards personal goals (Schunk et al., 2011). Self-Regulated Learning (SRL) is an approach that is considered to be able to help us understand students' abilities to manage their learning strategies and achieve increased performance (Rizki et al., 2022). By having SRL, students can actively set goals and plan their learning, monitor their learning process, and adjust their study plans (Cicchinelli et al., 2018). This is consistent with research which states that education will have a positive influence, where SRL agents on student learning can overcome learning barriers (León et al., 2015). In addition, the use of SRL agents in STEM-based physics modules means that the learning process is not carried out 100% offline, but learning activities can be carried out using blended learning because SRL agents can replace the teacher's position as a source of information in giving directions to students. Thus, it can be said that STEM-based physics modules with SRL can train critical thinking skills. Therefore, module development is expected to have a positive correlation with student learning outcomes.

Method

The method used in this study is a type of or Research and Development (R&D). But in this study the data obtained both qualitatively and quantitatively. So, in this R&D research using a mixed methods framework with a sequential exploratory design. Mixed methods is a combination of qualitative and quantitative research methods. Qualitative data is needed in designing physics modules, while quantitative data is needed to determine the validity of the module's feasibility in

practicing critical thinking skills. The flow of R&D research using the mixed methods framework is shown in Figure 1.

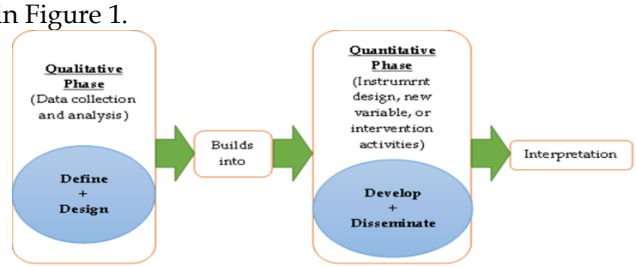

Figure 1. The research flow of R & D uses a mixed methods framework

Population and Sample

Based on the material selected by the researcher, namely Sound Waves, the subjects in this study were high school students of class XI in accordance with the selected physics material. The population in this study were all students of class XI science in one of the public high schools in Cimahi City. The sampling technique used was purposive sampling and the determination of the research sample was based on students whose criteria were eligible to be used as samples. In addition, this study involves expert lecturers to assess the feasibility of the module based on the suitability of the material with STEM aspects, the suitability of the material with SRL (self-regulated learning) and the feasibility aspect of the teaching materials.

Instruments

The instruments used in the study to determine the validity of the feasibility of STEM-based physics modules with self-regulated learning in training critical thinking skills, namely expert validation sheets and module readability sheets. The expert validity sheet used to assess the feasibility of the module based on the suitability of the material with STEM aspects, the suitability of the material with SRL (self-regulated learning) and the feasibility aspect of teaching materials. After the validation process carried out by the validator is complete, then a readability test of the module that has been developed to students is carried out before being distributed. It aims to determine whether the developed module has used a language that can be understood and understood by the user.

Data Analysis

The data from the feasibility validation of the STEM-based physics module with self-regulated learning that has been developed, were analyzed using the formula proposed by Aiken.

$$V = \frac{\sum s}{|n(c-1)|} \quad (1)$$

After getting the results to determine the feasibility of the module, then the data is interpreted using the classification of the validation results described in Table 1.

Table 1. Validation Result Criteria

Validation Result	Criteria
0.8 >	Very high
0.6 > × ≤ 0.8	High
0.4 > × ≤ 0.6	High enough
0.2 > × ≤ 0.4	Low
0.2	Very low

Meanwhile, the test module readability data was processed using the Guttman scale, where students who understand will be given a value of 1 and those who do not understand are given a value of 0. Then the data is analyzed using the following formula.

$$Readability\ test = \frac{scores\ obtained\ by\ students}{score\ maximum} \quad (2)$$

After the results are obtained, then interpret the readability of the module by classification based on the criteria described in Table 2.

Table 2. Module Readability Interpretation Criteria

Percentage (%)	Criteria
77.77 < x ≤ 100	High
55.54 < x ≤ 77.77	Medium
33.31 < x ≤ 55.52	Low
x < 33.31	Very low

Result and Discussion

The feasibility of the module is based on the suitability of the material with STEM aspects

For the feasibility of the module based on the suitability of the material with STEM aspects, it involves expert lecturers. The instrument used is an expert validation sheet which consists of 4 sub-components. The results of the feasibility of the module based on the suitability of the material with STEM aspects after being validated by expert lecturers are shown in Table 3.

Based on Table 3, it can be seen that the data from the validation of the feasibility of the module based on the suitability of the material with the STEM aspect, there are 6 assessment items at the very appropriate level of conformity and 4 assessment items at the appropriate level of conformity. Thus, the results of the assessment carried out by expert lecturers on the suitability of the material with STEM aspects can be said to be appropriate. In addition, the results of the validation of the feasibility of the module based on the suitability of the material with the STEM aspect were at very high criteria with a validation value of 0.89. The purpose of this validation is to determine whether the use of the

STEM aspects in the module is in accordance with the material described or not. Such as an assessment of the structural components of STEM, the definition of STEM science, an explanation of the position of the material in STEM and the preparation of the material. With this assessment, it can be seen how far the suitability of STEM aspects is applied in learning materials. This is important because the suitability of the material with STEM aspects can help maximize the modules developed. Therefore, with the availability of modules that match the material with STEM aspects, it is hoped that it will help the learning process optimally.

Table 3. The results of the validation of the feasibility of the module based on the suitability of the material with STEM aspects

Sub components	Item	Conformity level	Score	Validation	Criteria
STEM Structure	STEM model compatibility	Very suitable	10	0.89	Very High
Definition of STEM science	Science	Very suitable	10		
	Mathematics	Very suitable	10		
	Technology	Suitable	7.5		
	Engineering	Suitable	7.5		
Explanation of the position of the material in STEM	Science	Very suitable	10		
	Mathematics	Very suitable	10		
	Technology	Suitable	7.5		
	Engineering	Suitable	7.5		
Material preparation	Consideration of display order between STEM	Very suitable	10		

The Feasibility of the Module is Based on the Suitability of the Material with SRL (Self-Regulated Learning)

Validation of the feasibility of the module based on the suitability of the material with the SRL is assessed by expert lecturers using the expert validation sheet instrument. The expert validation sheet used consists of 3 sub-components according to the SRL phase. The results of the feasibility of the module based on the suitability of the material with the SRL after being validated by expert lecturers are shown in Table 4.

Table 4. The Results of the Validation of the Feasibility of the Module Based on the Suitability of the Material with SRL

Sub components	Item	Conformity level	Score	Validation
Forethoughts	Goal setting	Very suitable	10	0.92
	Strategic plan	Very suitable	10	
	Self-efficacy	Very suitable	10	
Performance control	Focus attention	Very suitable	10	
	Self-instruction	Very suitable	10	
Self-reflective	Self-evaluation	Suitable	7.5	
	Self-reaction	Suitable	7.5	
Criteria				Very high

From Table 4 it can be seen that the data from the validation of the feasibility of the module based on the suitability of the material with the SRL agent, there are 5 assessment items at the very appropriate level of conformity and 2 assessment items at the appropriate level of conformity. Thus, the results of the assessment carried out by expert lecturers on the suitability of the material with SRL agents can be said to be appropriate. In addition, in Table 4 it can be seen that the material suitability instrument with the SRL agent received a validation value of 0.92 with very high criteria. The purpose of this validation is to determine the suitability of the role of SRL agents in helping students understand the material described in the module. With this assessment, it can be seen to what extent the suitability of the SRL agent is applied in the module. This is important because the suitability of the material with STEM agents can help teachers maximize the learning process. Therefore, with the availability of appropriate modules between the material and SRL agents, it is hoped that it will help students during the learning process and students can be trained to study independently.

Aspects of the Feasibility of Teaching Materials (Modules)

The feasibility aspect of the STEM-based physics module with SRL is measured using an expert validation sheet, where this module is validated by expert lecturers. The module feasibility test consists of 3 components, namely the components of the dimensions of attitude, knowledge and accuracy of the material; presentation component, and language component. Then, each component is made into several sub-components. The

results of the module feasibility test can be seen in Table 5.

Table 5. The Results of the Validation of the Feasibility of Teaching Materials (Modules)

Component	Sub component	Score
Components of the dimensions of attitude, knowledge and accuracy of the material	Attitude dimension	8.5
	Knowledge dimension	8
	Material accuracy	8.5
	Up to date and contextual	8.5
	Strength of law and legislation	8.75
	Skill dimension	8.5
Presentation components	Presentation technique	8.5
	Material presentation support	8.45
	Serving equipment	8.85
Language component	According to the level of development of students	8.5
	Communicative	8.5
	Dialogic and interactive	8.5
	Straightforward	8.25
	Coherence and coherence in the line of thought	8.5
	Conformity with Indonesian Language rules	8.5
	Use of terms and symbols	8.5
Validation		0.83
Criteria		Very high

The results of the analysis in Table 5 show that the module has a validation value of 0.83 with very high criteria. It can be concluded that the STEM-based physics module with SRL developed is very feasible to use. The results of this study are also supported by research that developed an e-physics module based on PBL–Integrated STEM to improve higher order thinking skills in static fluid material, which stated that the developed module was needed as a learning resource to improve higher order thinking skills (Pane et al., 2021). Where, it is known that higher order thinking skills are critical thinking skills.

The validity of the developed module can be caused by several factors, such as having a match between the components of the dimensions of attitude, knowledge and accuracy of the material with the aspects used in the module. The aspects in the module are STEM and SRL agents, where the results of the validation of the suitability of the material with these two aspects are at very high criteria. The module is also developed by presenting a clear sub menu. This is in line with that a module contains parts of the material presented (presentation components). In addition, a module must be easy to understand so that it pays attention to the linguistic component. The goal is that the module can be read easily. Therefore, it can be concluded that the factors that affect the validity of the module are the components of the attitude dimension, knowledge and accuracy of the material, the presentation component, and the language component.

The components of the attitude, knowledge and material accuracy dimensions are used to see the suitability of the module content with core competencies and basic competencies, the suitability of the content of the material with the learning objectives, the clarity of the instructions for using the module, the suitability of the material with STEM, the suitability of the material with SRL agents and the suitability of the content of the questions with the material. Meanwhile, the presentation component has the aim of knowing the attractiveness of the module as a visual encouragement for students during the learning process. And the linguistic component is used to determine the suitability of the language used with the KBBI, to determine the clarity and use of language whether it is effective and efficient. Thus, it will be easier for students to understand the material.

The STEM-based physics module with SRL to train critical thinking skills, which has been declared feasible, can be used as a basis for adding references to teaching materials. Thus, the teaching materials used in learning physics are in accordance with the demands of 21st century skills. In addition, this module can also add references to the strategy of the learning process in dealing with emergencies, such as during the COVID-19 pandemic.

Module Readability Test

The module readability test was carried out by taking a sample of 24 students using the module in digital form (pdf). The goal is to determine the readability of the module before it will be applied in the learning process. In the module testing process, students are asked to read the module, then students are asked to

read the text on each page. After students finish reading one page, students will respond in the form of "understand or not understand" the sentences used in the module and write down the main idea on the page. The results of the validation of the feasibility of teaching materials are described in Table 6.

Table 6. The Results of the Module Readability Test

Module Readability Test	Sample	Max score	Percentage (%)		Criteria
			Understand	Do not understand	
	24	10	79.17	20.83	High

Based on the results of the analysis in Table 6, it can be seen that the data from the readability test for 24 students is in the high criteria with a percentage of 79.17%. Meanwhile, the percentage of students who do not understand is 20.83% with low criteria. Therefore, it can be said that students are able to understand the module well and can be distributed to students. However, based on the results of student responses to the main idea of each page in the module, there are difficulties faced by students. One of them is related to students' lack of understanding of the content of the material presented, especially on sound wave pattern material. In addition, based on the results of interviews, students experienced difficulties in reading the material content on pages 7, 9, 12, 13, 14, 19 and 23 due to time constraints in studying the material in the module properly. Meanwhile, page 25 is an evaluation question and students do not understand because they think they have not tried to work on the question. Differences in students' understanding in reading modules can be caused by the abilities possessed by each student.

However, the existing obstacles can be overcome if students who do not understand get longer time to understand each description of the material content in the module. So, if the obstacles can be overcome, students will be able to understand the content of the material well and the learning process can run optimally.

Critical Thinking Skills Improvement

To find out the improvement of students' critical thinking skills, it was tested through normalized N-gain. Improved critical thinking skills can be seen after students work on critical thinking skills test questions, both before and after the implementation of STEM-based physics modules (Science, Technology, Engineering and Mathematics) with SRL (Self-Regulated Learning). Where, the questions that will be given to students are in the form of multiple choice, totaling 10 questions, using references from Ennis. The results of data processing for all students using normalized N-gain are shown in Table 7.

Table 7. Data processing with Normalized N-Gain

Critical Thinking Skills	Sample	Pretest	Posttest	N-Gain	Category
	34	56.76	80.29	0.54	Medium

Based on Table 7 shows that the N-gain value of improving critical thinking skills of 34 students is 0.54. Where, the average value of the pretest obtained is 56.76 and the average value of the posttest is 80.29. Therefore, it can be said that students' critical thinking skills increased after the STEM-based physics module was applied with SRL in the medium category. This needs to be improved because the results obtained are still in the medium category. In addition, the module can be used to help train critical thinking skills, so it is hoped that it will help the learning process optimally.

Conclusion

Based on the results of the feasibility test of teaching materials, it shows that the STEM-based physics module with SRL to train critical thinking skills has a validation value of 0.83 with very high criteria. Therefore, it can be said that the module developed is feasible to be used as teaching material in physics learning. Because the module is in accordance with the demands of 21st century skills. And for the feasibility of the module based on the suitability of the material with STEM aspects, the criteria are very high with a validation value of 0.89. Meanwhile, for the suitability of the material with the SRL agent, the validation value is 0.92 with very high criteria. After the validation process by expert lecturers is complete, then the module readability test is carried out. The module readability test was carried out by 24 students. The results of the module readability test were in the high criteria with a percentage of 79.17%. Therefore, it can be said that students are able to understand the module well and can be used by students in learning physics. From the results of this study, efforts are needed to train critical thinking skills through the use of modules that are in accordance with the demands of 21st century skills. This is because students' critical thinking skills after applying the STEM-based physics module with SRL obtained a normalized N-Gain value of 0.54, meaning that it is still in the "medium" category. And for further research,

researchers also need to conduct interviews in each category as reinforcement of the results obtained.

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The authors declare no conflict of interest.

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