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8

The Effectiveness of Science, Technology, Engineering, and Mathematics-Inquiry Learning for 15-16 Years Old Students Based on K-13 Indonesian Curriculum: The Impact on the Critical Thinking Skills

16

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Abstract: Industrial revolution 4.0 is currently present in various countries, including Indonesia. Indonesia responded quickly through technological developments, especially education. The actions of the Indonesian government to deal with industrial 4.0 are contained in the 4C principle, one of which is Critical Thinking. The Science, Technology, Engineering, and Mathematics (STEM) learning approach has become an alternative in building critical thinking skills, especially in science learning. The purpose of this study is to quantitatively measure the impact of the STEM-inquiry model based on the K-13 Indonesian Curriculum towards critical thinking skills of 15-16 years old students. This study employed quasi-experimental with non-equivalent control group design at SMAN 1 (State Senior High School) Padang Cermin, Lampung, Indonesia. The research subjects consisted of 50 students. The critical thinking skill was measured through 10 items of an essay question on the momentum and impulse material. Based on the results of the non-parametric statistical hypothesis test Mann-Whitney, the significance level of 0.004 was obtained (sig < 0.05). The results of the hypothetical test showed that the student's critical thinking skills before and after using the STEM-based inquiry model were different. It can be concluded that the application of the STEM-based inquiry model was effective in increasing students' critical thinking skills.

Keywords: Critical thinking skills, effectiveness of STEM, STEM-inquiry, STEM learning.

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Introduction

Recently, the industrial revolution 4.0 has become a major topic of discussion in the world, including Indonesia (Anwar et al., 2018; Suwardana, 2017; Venti, 2018). Indonesia responded to deal with this phenomenon through education (Anwar et al., 2018). Education, as well as competence and superior skills, can maintain the existence of the nation in global competition (Yani et al., 2018). Education in Indonesia prepares the era of the industrial revolution 4.0 by applying the 4C principles that cover communication, collaboration, critical thinking and problem solving, and creativity and innovation which are listed in the K-13 Indonesian Curriculum (Elyusra & Saputra, 2019).

According to Piaget's theory, students who can think critically can analyze problems scientifically and solve problems around the age of 11-18 years (Piaget & Inholder, 2008). Even in some countries, critical thinking has been applied from an early age (Hurk et al., 2018; Yahaya & Lajium, 2018). Students aged 11-18 should be directed to think critically. In the 21st century, critical thinking is one aspect that must be possessed by a student to activate problem-solving ability, especially in learning physics (Susilowati et al., 2017).

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9

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Physics is a part of the natural sciences that underlies the development of technology and studies the concepts of human life in harmony with natural laws (Sapitri et al., 2016). Therefore, learning physics can grow the ability to solve problems, think logically, think creatively, and think critically (Yuliati et al., 2011). The success of activating students' critical thinking skills is influenced by several factors, including the accuracy of educators in determining learning models and learning approaches (Anwar et al., 2019; Diani et al., 2016; Irwandani & Rofiah, 2015).

One of the learning approaches that have been successfully applied to improve critical thinking skills is the STEM (Science, Technology, Engineering, and Mathematics) learning approaches (Chngtong et al., 2020; Krajcik & Delen, 2017; Piaget & Inholder, 2008; Widayanti et al., 2019). This approach is an alternative science learning in practicing critical thinking skills (Zamista, 2018). This is because the STEM approach in the learning process trains students to bring up science, technology, science engineering, and mathematics in building competencies, solving problems, and being tolerant (Afriana et al., 2016; Parmin et al., 2020).

Related research conducted by other researchers found that STEM learning can train critical thinking skills on sound wave material (Ismayani, 2016), STEM integrated with PBL can improve the mathematical creativity of vocational school students (Lutfi et al., 2017), STEM integrated with PBL can improve scientific literacy, creativity, and learning outcomes (Dewi et al., 2018), and STEM can improve students' problem solving (Khoiriyah et al., 2018).

The novelty of this study lies in the dependent variable which is the ability to think critically of the 15-16 years old students and the application of a STEM-inquiry model based on the K-13 Indonesian Curriculum. The inquiry model trains students to solve problems in learning (Diani et al., 2016; English et al., 2013; Latifah, 2015). The concept of inquiry model also allows students to develop theories or science products through observation, clarification, calculations, formulating hypotheses, conducting experiments, and rational analysis to conclude (Bybee, 2011). In addition, in this study, researchers took momentum and impulse topic as the focus of the material, because this topic requires deep understanding and most students tend to be passive in learning this topic. Besides, students' ability to understand essential concepts is also low (Budiarti et al., 2018). The application of this topic is very close to the daily lives of students and has a high opportunity to practice critical thinking skills (Khasanah et al., 2019). It is hoped that the application of a STEM- inquiry model based on the K-13 Indonesian Curriculum can improve students' critical thinking.

Method

This study employed the quasi-experimental with a non-equivalent control group design. This design involved a control class and an experimental class as shown in Figure 1 below.

Table 1. The Research Design

Pretest	Treatment	Post-test
O ₁	X	O ₂
O ₃	Y	O ₄

Description:

O₁: Pretest in the experimental class.

O₃: Pretest on the control class

X: Treatment using STEM-based inquiry model

Y: Treatment using Student Team Achievement Division (STAD) model

O₂: Posttest in the experimental class

O₄: Posttest in the control class (Sanjaya, 2013)

The population of this study was all tenth-grade students majoring in Mathematics and Natural Sciences at State Senior High School 1 Padang Cermin, Pesawaran, Lampung. The purposive sampling was done to determine 50 subjects with an age range of 15-16 years old. This sampling technique was chosen because the focus of the topic used in this study is momentum and impulse where this topic is applied to class X MIA (Natural Science) with an average age of 15-16 years. The experimental class applied the STEM-inquiry model based on the K-13 Indonesian Curriculum with 25 students as the subjects, and the control class applied the Student Team Achievement Division (STAD) model based on the K-13 Indonesian Curriculum with 25 students as the subjects.

Data Collection

The instrument used in this study was a test instrument in the form of essay questions that consisted of 10 questions to measure students' critical thinking skills. The instrument used has passed the validity and reliability test so that the

instrument is declared valid and can be trusted to measure students' critical thinking. The validity test used the product-moment correlation test by Microsoft excel, with the following provisions (Sugiyono, 2017):

$r_{\text{count}} \leq r_{\text{table}}$ = Not Valid (The item cannot be used)

$r_{\text{count}} \geq r_{\text{table}}$ = Valid (The item can be used)

The results of the validity test can be seen in table 2.

Table 2. The Validity Test Result

No. Item	r_{count}	r_{table}	Criteria
1	0.425	0.3494	Valid
2	0.479	0.3494	Valid
3	0.663	0.3494	Valid
4	0.385	0.3494	Valid
5	0.731	0.3494	Valid
6	0.576	0.3494	Valid
7	0.760	0.3494	Valid
8	0.212	0.3494	Not Valid
9	0.148	0.3494	Not Valid
10	0.500	0.3494	Valid
11	0.104	0.3494	Not Valid
12	0.565	0.3494	Valid
13	0.125	0.3494	Not Valid
14	0.493	0.3494	Valid
15	0.541	0.3494	Valid
16	0.544	0.3494	Valid
17	0.335	0.3494	Not Valid
18	0.335	0.3494	Not Valid
19	0.348	0.3494	Not Valid
20	0.507	0.3494	Valid

Meanwhile, the reliability test used Kude and Richardson method using Microsoft Excel as a tool. The reliability criteria can be seen in table 3 (Siregar, 2015):

Table 3. The Reliability Criteria

Reliability Index	Reliability Criteria
$0.00 < r_{11} \leq 0.20$	Very low
$0.20 < r_{11} \leq 0.40$	Low
$0.40 < r_{11} \leq 0.60$	Enough
$0.60 < r_{11} \leq 0.80$	High
$0.80 < r_{11} \leq 1.00$	Very High

Based on the results of the reliability test using Microsoft Excel, the reliability index value was 0.80, it can be said that the research instrument was declared reliable in the "high" category, so it is suitable for use to obtain the data.

The treatments on material momentum and impulses were given in this study are presented in Tables 4 and 5 in the form of storyboards. Table 4 is for the experimental class and table 5 is for the control class.

Table 4. The Storyboard of STEM-Inquiry model based on K-13 Indonesian Curriculum

Syntax	STEM	Teacher's Role	Students' Role
Problem orientation and questions	<ul style="list-style-type: none"> - Science: material on momentum and impulse - Technology: displaying videos of a water rocket, boxing matches, and football games 	<ul style="list-style-type: none"> - Displaying some of the events that apply the momentum and impulses materials in everyday life through the LCD projector - Asking the questions of the events displayed 	<ul style="list-style-type: none"> - Observing some events displayed by the teacher - Answering the questions posed by the teacher
Creating a hypothesis	<ul style="list-style-type: none"> - Science: material on momentum and impulse - Technology: displaying videos of a water rocket, boxing matches, and football games 	<ul style="list-style-type: none"> - Directing students to make hypotheses from the video shown 	<ul style="list-style-type: none"> - Making hypotheses according to the direction of the teacher through the videos
Planning and conducting an investigation	<ul style="list-style-type: none"> - Science: material displayed about momentum and impulses - Technology: making simple water rockets - Engineering: water rocket schemes - Mathematics: water rocket formulas based on the application of momentum and impulses material 	<ul style="list-style-type: none"> - Dividing the students into groups of five - Directing each group to plan the manufacture of a water rocket by first creating a schema of the water rocket - Directing each group to build the water rocket - Giving instructions to conduct an investigation and retrieving data by launching a rocket that has been made 	<ul style="list-style-type: none"> - Grouping based on groups have been divided by the teachers - The groups plan the process of making a water rocket as directed by the teacher - Each group makes a water rocket according to the teacher's instructions - Each group conducts an investigation and analyzes the concepts that occur in the water rocket
Analyzing and interpreting	<ul style="list-style-type: none"> - Science: material displayed about momentum and impulses - Technology: making simple water rockets - Engineering: water rocket schemes - Mathematics: water rocket formulas based on the application of momentum and impulses material 	<ul style="list-style-type: none"> - Instructing each group to analyze and interpret the data obtained from the launched rocket 	<ul style="list-style-type: none"> - Each group analyzes and interprets the data obtained from the rocket launch. -
Concluding and communicating	<ul style="list-style-type: none"> - Science: material displayed about momentum and impulses - Technology: making simple water rockets - Engineering: water rocket schemes - Mathematics: water rocket formulas based on the application of momentum and impulses material 	<ul style="list-style-type: none"> - Instructing each group to present using PowerPoint and conclude all learning activities 	<ul style="list-style-type: none"> - Each group makes a presentation based on the instructions given by the teacher and concludes all activities that have been carried out in the learning activities

Table 5. The Storyboard of the STAD model based on K-13 Curriculum

Syntax	Teacher's Roles	Students' Role
Delivering goals and motivation	- Conveying learning objectives of the momentum and impulses material and motivating that this material is closely related to daily life such as the application of water rocket launches, boxing matches, and football games	- Paying attention to the teacher's delivery and responding well to the motivation delivered
Group division	- Dividing 5 students per group	- Grouping based on the groups distributed by the teacher
Presentation by the teacher	- Conveying material on momentum and impulses through presentations	- Paying attention and observing the delivered material from the teacher
Learning as a team	- Posing some problems based on the application of momentum and impulses material - Instructing each group to present the solutions	- Each group discusses to provide solutions from several situations posed by the teacher - Each group present the solutions
Evaluation through quiz	- Giving a quiz to all groups	- Each group responds well to the quiz given by the teacher
Appreciation for the group's achievements	- Giving awards to the best group in term of discussion, problem-solving, and group presentations	- The groups appreciate the awards received and the group that do not receive the awards should continue to study harder

Tables 4 and 5 show the STEM storyboards, while the integration between STEM in this study is shown in Figure 1.

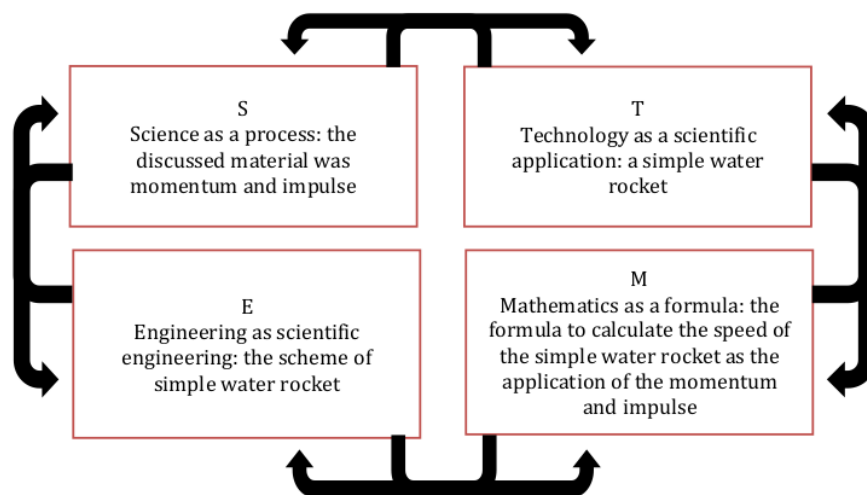


Figure 1. The integration of STEM on momentum and impulse material

Before the treatments were given, the classes were given a pretest to determine their initial abilities. And before testing the hypothesis, we conducted a prerequisite test, including the normality test and the homogeneity test.

Prerequisite Test

After the pretest and posttest data had been obtained, the data was then analyzed. Statistical tests were performed at a significance level of 5%. The requirements that must be met first were the normality and homogeneity tests. If the data

analyzed is normally distributed, then parametric statistical tests should be used and if the analyzed data is not normally distributed, the non-parametric statistical tests should be used instead (Fisher, 2008).

14 Normality Test

The normality test was performed to determine whether the data were normally distributed or not. The formula to determine the normality was the Kolmogorov-Smirnov test on SPSS 17.00 with a significance level of 5%. The normality test results are presented in Table 6.

Table 6. Normality test

	Critical Thinking Ability		
	Statistic	Df	Sig.
Experimental class' Pretest	236	25,	001
Experimental class' Posttest	262	25,	000
Control class' Pretest	220	25,	003
Control class' Posttest	218	25,	003

Table 6 shows that the normality values are <0.05 so that the data was not normally distributed.

Homogeneity Test

The homogeneity test was carried out to find out whether the samples came from homogeneous variance populations or not. The formula to determine the homogeneity was Levene's test on SPSS 17.00 with a significance level of 5% as shown in table 7.

Table 7. Homogeneity test

	Levene's Statistic	df1	df2	Sig.
Pretest	1,204	1	48	.278
Posttest	2,710	1	48.	106

Table 7 shows that the data was homogeneous because the significance level is more than 0.05. This means that the data obtained came from a homogeneous population.

Data Analysis

The data of this study were analyzed using pre-test and hypothesis testing. Prerequisite tests included the normality test and homogeneity test. The hypothesis test used was the non-parametric ANCOVA because the data obtained from the study were not normally distributed (Corder & Foreman, 2009). The hypotheses of this study are:

H_0 : There is no difference in students' critical thinking skills before and after using the STEM-based inquiry learning model.

H_1 : There is a difference in students' critical thinking skills before and after using the STEM-based inquiry learning model.

Findings

The data of this study include data on critical thinking skills. Data obtained from essay tests given to the research subjects in the experimental and control classes. The following data were obtained from the test results.

Table 8. Scores of critical thinking skills

Indicators	Control Class		Experimental Class	
	Pre-test	Post-test	Pre-test	Post-test
Value				
Top	60	82.5	55	85
Low	20	57.5	12.5	65
Average	32.5	70	41.5	76.2
Standard Deviation	4,03	4,41	3,27	5,65

Table 8 shows that the critical thinking scores in both classes increased after administering the treatments. Table 8 shows that the average posttest scores of critical thinking skills in the experimental class are higher than the control class. The significance of improvement can be seen in table 9.

Table 9. The results of n-gain test critical thinking skills

Class	Number	Average Pretest Score	Average Posttest Score	N-gain	classification
Control	25	32.5	70	0.54	Medium
Experiment	25	41.5	76.2	0.58	Medium

Table 9 indicates that there is an improvement in the experimental class and the control class. The N-Gain test results of the experimental class are 0.58 and the control class is 0.54 which belongs to the medium category. The difference in N-Gain results indicates that the experimental class experienced a more significant increase than the control class.

Research hypotheses can be answered by conducting several tests. The prerequisite tests consisted of normality and homogeneity tests and hypothesis testing. The following is a description of the prerequisite test results.

Hypothesis Test

After the prerequisite tests had been done, it was found that the data was not normally distributed, both in the control class and the experimental class. Thus, the non-parametric statistical test using non-parametric ANCOVA (Quade's rank analysis of covariance) with the sig level $\alpha \leq 0.05$ was performed. Table 10 shows the results of the hypothesis test.

Table 10. The results of the hypothesis test

	F	Sig.
Non-parametric ANCOVA (Quade's rank analysis of covariance)	10,049	0,03

Table 10 shows that Sig. $0.03 < 0.05$, which means that H_0 is rejected and H_1 is accepted. The results of this statistical test show that the student's critical thinking skills before and after using the STEM-based inquiry learning model are different.

Discussion

Students' critical thinking skills are needed in the learning process as a basis for understanding various things including concepts in the disciplines of education (Herzon et al., 2018). Critical thinking skills in education are used as a forum to develop a student's cognitive abilities and can convey information effectively. Critical thinking is used in identifying, analyzing, and inferring logical opinions in learning (Zamista, 2018). The STEM learning approach provides opportunities for students to play an active role in improving critical thinking skills and providing hands-on learning experiences. The STEM learning approach is used as an alternative science learning including physics that can build a generation, especially in improving critical thinking skills (Yuberti, 2014).

Learning approaches cannot be separated from real life because the application of learning that is applied needs to present physical or mathematical things (Fitriani et al., 2017). The application of STEM-based inquiry learning models presents the needs of students in learning so that they can apply and practice the basic content of science that can be found in real life (Khoiriyah et al., 2018).

Based on table 10, it is known that the sig level $\alpha \leq 0.05$, so it can be said that there is a difference in students' critical thinking skills before and after using the STEM-based inquiry learning model. And we can say that the difference at n-Gain between the control class and the experimental class is meaningful. So, the critical thinking skill in the experimental class is higher than in the control class. This is because the experimental class applied the STEM learning approach. Also, learning in the experimental class was dominated by student centered-learning learning while the control class was dominated by teacher-centered learning.

In the experimental class, the learning was guided by a phenomenon related to daily life such as the application of material on water rockets, boxers, and football (science as a process). Furthermore, students were given knowledge about the applications of physics in the field of technology. It is intended for the students to know the application of the materials. One application of technology in the momentum and impulse material is boxing gloves. Boxing gloves are used to slow down the impulse force when hitting the opponent because, if the contact time is long then the force that works will also be smaller so that the punch experienced by the opponent is lighter. These events make it easier for students to understand the concept of learning material (Technology as the application of science).

Also, students were given an understanding related to science, engineering, and work processes on technology, in this case, aims to assist students in understanding the concepts of physics in momentum and impulse material. The students were directed to make a simple water rocket and launched it to analyze the data based on their experiments (Engineering as a science). The analysis of the data obtained from the results of water rocket engineering was to calculate the speed of the rocket when sliding. By substituting several mathematical formulas, the students can find the speed of the rocket (Mathematics as a formula).

Previous research states that the STEM learning approach can improve critical thinking skills in learning physics (Khoiriyah et al., 2018). This is relevant to the field conditions that science learning cannot be separated from technology, mathematics, and engineering in real life. During the learning, the students were able to play an active role in learning as well as easy to understand the concepts of the learned materials. The STEM-based inquiry learning model can improve critical thinking skills because the students are allowed to plan, provide solutions, engine, analyze, and communicate through presentations so that the students learned all material based on their learning experience.

The STAD model was applied to the control class. The students were directed to learn as a team. However, a detailed explanation of the material was still dominated by the teacher. The students were given problems that occur in everyday life related to the momentum and impulse material. All of the teams provided solutions to problems posed by the teacher. Each team provided solutions from various sources without constructing the solution into a tool. This makes the memory and understanding became less optimal so that the critical thinking skills were still lacking compared to the STEM-based inquiry model. Nevertheless, the STAD learning model is very good for practicing collaboration in the learning process.

Several previous studies had applied the STAD learning model, including STAD learning, can improve students' scientific literacy (Arisman & Permanasari, 2015), STAD model to find instrumental elements in the saga (Ekawati, 2015), the application of the STAD learning model in Iran (Jahanbakhsh et al., 2019), the implementation of the STAD model in terms of the spatial abilities (Kusuma, 2017), the application of the STAD model in improving learning outcomes (Mahbub et al., 2016), and the application of STAD model in improving writing skills (Suryani & Azlim, 2018).

Also, the inquiry model has been applied in previous studies, including the effectiveness of the inquiry model in achieving the cognitive dimensions of students (Abdurrahman, 2017; Nasution, 2021) the application of inquiry models in enhancing students' understanding of concept and learning attitudes (Ajizi et al., 2018), the application of inquiry models in increasing literacy skills (Anggraeni et al., 2020), the application of inquiry models in improving critical thinking (Diani et al., 2016; Nasution, 2018; Purnamawati et al., 2017), the development of inquiry-based worksheets (Hendri & Faradhillah, 2020), the application of work assessment through inquiry (Kusumastuti et al., 2020), and the improvement of science process skills through the inquiry model (Silaban & Simanjuntak, 2018). In this study, the STEM-based inquiry model can improve critical thinking although the improvement is not significant.

Conclusion

Based on the results of the analysis, it can be concluded that the application of the STEM-based inquiry model (Science, Technology, Engineering, and Mathematics) is effective in improving students' critical thinking skills. The hypothesis test result shows that asymptotic significance (2-tailed) $0.23 < 0.05$, which means that H_0 is rejected and H_1 is accepted. The results of this statistical test show that the student's critical thinking skills before and after using the STEM-based inquiry learning model are different. The addition of approaches in learning can make learning more effective and efficient and able to achieve the measured indicators well.

Recommendation

This study serves as a basis for implementing STEM-inquiry learning to improve students' critical thinking skills in physics. The step integration between the inquiry model and the STEM approach can be used as a reference for classroom implementation. The STEM model and approach are implemented in groups so that the teacher must remain focused on guiding the course of the discussion. Also, the teacher should pay attention to students' activities in each group during the discussion process.

It is recommended for further research to integrate other learning models with the STEM approach or indicators of achievement in psychomotor and affective aspects. Besides, it needs to be applied to students aged fifteen years or above.

Limitation

This study was limited to children aged 15-16 years in one school. The focus of the study was students' critical thinking skills on the momentum and impulses material. The sample consisted of only one class that acted as the experimental and the control. The critical thinking skills had been studied without considering gender. Thus, the opportunity to conduct research related to the application of STEM-inquiry learning towards critical thinking skills is widely open. Further research should review the gender of the sample and other factors that may affect students' critical thinking skills. This study was conducted before the COVID-19 was first discovered in Indonesia.

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