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Integrated STEM 3.0 Approach to Enhance Critical Thinking Skills: An Empirical Evidence

Ismu Sukamto[1,*], Hervin Maulina[2], Widyastuti[3], Ika Wulandari Utamining Tias[1], Tiyas Abror Huda[4], Dina Maulina[5]

[1]Department of Elementary School Teacher Training, Universitas Lampung, Indonesia
[2]Department of Physics Education, Universitas Lampung, Indonesia
[3]Department of Mathematics Education, Universitas Lampung, Indonesia
[4]Faculty of Education and Teacher Training, Universitas Lampung, Indonesia
[5]Department of Biology Education, Universitas Lampung, Indonesia

*Corresponding email: ismu.sukamto1101@fkip.unila.ac.id

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Abstract: Integrated STEM 3.0 Approach to Enhance Critical Thinking Skills: An Empirical Evidence. Objectives: This study aimed to examine the effect of the STEM 3.0 approach assisted by real material and virtual simulation to enhance the CTS. **Methods:** The research method used Quasi-Experimental Designs with Matching-Only Pretest-Posttest Control Group Design. The subjects of this study were high school students of Class XI in Surabaya. **Findings:** Based on the research data, the increase in the CTS of students in the 2 experimental classes was classified as moderate with an average n-gain value of students in class A2 of 0.69 and class A5 of 0.63 while the increase in CTS in the control class was classified as moderate with a lower value (a score of 0.36). Based on the results of statistical tests, there is a significant difference between the experimental class and the control class. **Conclusion:** Thus, it is concluded that the integrated STEM 3.0 approach can enhance the CTS.

Keywords: integrated STEM 3.0, CTS, real material, virtual simulations.

Abstrak: Pendekatan STEM 3.0 Terintegrasi untuk meningkatkan Keterampilan Berpikir Kritis: Suatu Bukti Empirik. Tujuan: *Penelitian ini bertujuan untuk menguji pengaruh pendekatan STEM 3.0 yang dibantu dengan materi nyata dan simulasi virtual untuk meningkatkan CTS.* ***Metode:*** *Metode penelitian yang digunakan adalah Quasi-Experimental Designs with Matching-Only Pretest-Posttest Control Group Design. Subjek penelitian ini adalah siswa SMA kelas XI.* ***Temuan:*** *Berdasarkan data penelitian, peningkatan CTS siswa pada 2 kelas eksperimen tergolong sedang dengan rata-rata nilai n-gain siswa kelas A2 sebesar 0,69 dan kelas A5 sebesar 0,63 sedangkan peningkatan CTS pada siswa kelas A2 sebesar 0,69 dan kelas A5 sebesar 0,63. kelas kontrol tergolong sedang dengan nilai lebih rendah (skor 0,36). Berdasarkan hasil uji statistik, terdapat perbedaan yang signifikan antara kelas eksperimen dan kelas kontrol.* ***Kesimpulan:*** *Dengan demikian, disimpulkan bahwa pendekatan STEM 3.0 terintegrasi dapat meningkatkan CTS.*

Kata kunci: *STEM 3.0 terintegrasi, CTS, material nyata, simulasi virtual.*

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INTRODUCTION

CTS is one of the essential skills for students in the 21st Century (Rotherham & Willingham, 2010) in order to focus on analyzing a problem and various challenges (Anazifa & Djukri, 2017; Khasanah et al., 2017; Putra et al., 2018). By analyzing, various alternative solutions to problem-solving are easy to find so that ultimately the best solution is found (Kaddoura, 2011). Therefore, this skill is very important to have given that the various problems that students will face always increase along with the development of technology and social conditions of the community (Mutakinati et al., 2018).

Critical thinking requires students to be able to define problems and find alternative solutions based on standard scientific procedures. Therefore, CTS needs to be trained as early as possible so that when solving problems that are directly related to the real world (Shernoff et al., 2017), students are able to become reliable problem-solvers and decision-makers based on critical thinking in determining points of problem in each scientific procedure. By also considering that CTS is not inherited from generation to generation, schools need to create innovative learning environments so that a positive paradigm shifts from teaching to learning where students are actively involved in complex thinking processes (Bustami & Corebima, 2017; Karim et al., 2018).

Physics is a science that plays an important role in improving the quality of life because it not only creates the quality of thinking in studying everything logically and systematically but also how to apply it in everyday life. In addition, the level of complexity of physics has always been complicated by the development of science and technology, especially in abstract matters (Sutarto & Indrawati, 2017). CTS must be applied in learning physics both in learning procedural knowledge so that the facts contained at each stage are easily understood, as well as conceptual knowledge that requires higher quality thinking to be able to connect these facts so that the intended concepts can be conveyed properly (Arends, 2012). Thus, creative thinking skills that are in the realm of CTS, will be channeled with high quality and creative products will always be beneficial along with the development of the quality of human thought.

The importance of CTS also makes it an ability that must be mastered to be able to master Higher Order Thinking Skills (HOTS), which is implicitly stated in the Core Competencies (KI) in the Curriculum 2013, namely: understanding, applying, and analyzing factual, conceptual, procedural, and metacognitive. By mastering CTS, students are able to understand factual knowledge that forms a conceptual knowledge and then apply it in everyday life. When students discover new problems or phenomena, it will be easier to analyze and describe the problem based on the knowledge that has been understood through scientific procedures in which at each step students are trained to think critically in determining each core problem of these steps (Ramos et al., 2013). Therefore, educators must learn physics materials where the main instructional task is to create activities or learning environments that guide students to learn by involving higher-order thinking skills, starting from knowing, understanding, applying, analyzing, evaluating and creating something based on the levels of the cognitive process hierarchy.

Research on CTS has been carried out, but the indicators studied including interpretation, analyzing, explanatory, evaluation, concluding and self-regulation where the average CTS score with these indicators reaches more than 70 (Putra et al., 2018). However, there are still indicators that need to be researched which are also indicators that compile the CTS, namely Overview (Ennis, 1996). An overview really needs to be done in order to be able to solidify students' beliefs regarding the truth of the content in the scientific process in the CTS. With this overview, there is a further stage to review whether the critical thinking process in learning is correct or not. Thus, students have the opportunity to evaluate themselves so that performance increases in subsequent activities. The overview that is the constituent element of the CTS can be trained by applying learning with the STEM 3.0 approach (Science, Technology, and Mathematics). With this approach, students can review the scientific process from the side of science (Science), from the technology used in learning (Technology) and also from the relationship with other factual knowledge (Mathematics).

Technology that has the potential to enhance HOTS development is the use of computer simulations in learning based on Information and Communication Technology (ICT). The development of multimedia technology has also been widespread in the field of education and greatly affects the learning system. By using computer simulation-based learning media, messages from a source can be delivered and channeled in a planned manner through interaction and visualization so that a conducive learning environment occurs where recipients can carry out the learning process efficiently and effectively (Rutten et al., 2012). In addition, the use of digital learning media can also further clarify learning messages and provide more concrete explanations, and enable students to play an active role both physically, mentally, and emotionally (Cheng & Tsai, 2013).

The advantage of using interactive simulation media will increase if the media used are interactive (Huang et al., 2010), where students can receive feedback on an action taken in the media. This kind of simulation allows students to acknowledge the material in it when the computer displays the calculation, storage, and repetition of information. Repetition is done by the process of developing hypotheses, manipulating variables and observing the results, collecting data, rearranging the values of each variable, then running simulations to test the hypotheses that have been made will increase the understanding of concepts in the material (Kaniawati et al., 2016). Concepts in learning physics are important to master. This considers that physics is widely applied to support life activities. This application needs to be supported by an understanding of the correct concepts. Considering that some physics material is classified as abstract, it is necessary to have a simulation that allows abstract material to be more concrete so that it is easier to understand. Another advantage is that students can also complete experiments that are too difficult, too dangerous or unable to be carried out in class or require a long time (Lin et al., 2015) . This shows that in addition to increasing the effectiveness of learning, simulation can also be more efficient in learning time. Even under certain conditions, the use of computer-based simulations in learning further enhances students' functional thinking compared to the use of real material (Lichti & Roth, 2018).

The use of interactive simulations or virtual laboratories in learning has been proven to improve students' science process skills (Gunawan et al., 2019). However, in the Industrial Revolution 4.0 era, science process skills alone were not enough. Students need to have 21st Century skills, one of which is the CTS. Therefore, further research needs to be done on the implementation of a virtual laboratory that is expected to increase the CTS.

However, not all material can be taught better using computer-based simulations. If it is still possible to present material that is often encountered by students in everyday life, then it is better to prioritize its use compared to using simulation. It also provides a learning environment that is in accordance with the experience of students so that students more easily understand the concept of learning material. However, the existence of simulations in learning is also important to improve students' deeper understanding. Therefore, the combination of real material and simulation in learning can be one solution to improve the CTS of students.

The combination of instructional media is appropriate for learning in gas kinetic theory material. Although the symptoms that arise, such as changes in temperature, pressure, and volume, can be felt (macroscopic), but in this material students are also emphasized to understand the causes of these symptoms. These causes are the kinetic characteristics and behavior of a particle or molecule in a gas (microscopic) where there are no concrete examples or images of the atoms that make up the molecule. Therefore, direct experience needs to be given in learning by using real materials to show macroscopic phenomena. The use of computer-based simulations is needed to illustrate something abstract, such as: the behavior of atomic particles of various types of substances related to motion, velocity, and interactions between particles affecting certain variables (pressure, volume, temperature, kinetic energy and internal energy) so students can observe and understand more easily the concepts that connect all of these things (Eskrootchi & Oskrochi, 2010).

The integration will be effective in increasing CTS if it is designed with the right approach. The right learning approach in today's digital era that allows the application of real material and interactive virtual simulation is the STEM 3.0 Approach which consists of 3 aspects, namely: Science, Technology and Mathematics which is generally equipped with Engineering aspects. In this case, the engineering aspect is not applied because the research is focused first on understanding concepts in the realm of CBC. This simplification focuses students to practice critical thinking scientifically. Moreover, not all concepts in physics material can be applied easily in the form of simple tools (Engineering). The STEM approach enables the incorporation of scientific disciplines based on the relationship between teaching material and real-world phenomena so that learning becomes meaningful that is integrated with mathematics and science so that engineering design is formed as a means to develop technology (Moore et al., 2014). Thus, the STEM 3.0 approach allows learners in groups to be able to understand certain concepts (Science) by conducting an integrated experiment with virtual learning media (Technology) and real material. This activity also helps students improve other 21st Century skills, especially in the aspects of collaboration and collaboration (Hammack et al., 2015). In addition, students can also learn to improve work effectiveness and efficiency of resources used by converting concepts into mathematical formulations (Mathematics). The integration of these three aspects enables students to gain mastery of the competencies needed to complete assignments and solve real-world problems (Wang et al., 2011).

Based on the description that has been stated, the purpose of this study is to test the application of the STEM 3.0 approach that is integrated with real material and interactive virtual simulations in teaching material of gas kinetic theory to improve the CTS of high school students. Therefore, the research questions explored in this research are as follows: Can the application of the STEM 3.0 approach that is integrated with real material and interactive virtual simulations in teaching material of gas kinetic theory increase the CTS of high school students?

■ METHODS

Participants

The subjects of this study were high school students of Class XI in Surabaya, amounting to 3 classes by 60 people where 2 classes as experimental class (Class A2 and A5) and 1 class as control class (Class A3). The number of Class A2 students is 9 males and 11 females. The number of Class A5 students is 7 males and 13 females. The number of Class A3 students is 10 males and 10 females. The technique used was purposive sampling based on students' initial cognitive abilities.

Research Design

This research was Quasi-Experimental Designs with the Matching-Only Pretest-Posttest Control Group Design (Fraenkel et al., 2012). The independent variable of this study is a STEM 3.0 approach which is integrated with real material and virtual simulation and the dependent variable is CTS. In this case, there are 3 classes consisting of 2 experimental classes are given the same treatment, namely the application of the STEM 3.0 Approach which is integrated with real material and virtual simulation. The two classes were intended to know the consistency of the effectiveness of this approach. To know whether the approach is more effective, the researchers collect and analysis the data of control class that was given a treatment of conventional learning.

Instruments

The test instrument consists of 6 CTS dimensions. The 6 CTS dimensions are adapted from 6 elements in critical thinking according to Ennis known as the acronym FRISCO to 1) Focus; 2) Reasons; 3) Inference; 4) Situation; 5) Clarity; and 6) Overview (Ennis, 1996). These dimensions are 1) Focus; 2) Reasons; 3) Situation; 4) Decision and Action 5) Inference; and 6) Overview. These dimensions are used to measure the CTS and serve as a reference for the preparation of the CTS test instrument. The instrument is an essay at the cognitive level C4-C6 according to Bloom's Taxonomy (Conklin, 2005). Each dimension is composed of 2 items. The test instrument has been declared valid based on the results of validation by 2 experts. This validation is intended to test the feasibility of compiling indicators based on dimensions and suitability with gas kinetic theory material to measure students' CTS. Based on the validation results, the instrument is declared valid with a score of 3.75 (on a scale of 1-4).

In addition to content validation by experts, the pretest and posttest instruments to test CTS were tested for statistical validity and reliability using SPSS version 25 with 44 respondents. 10 of the 12 items developed based on the 6 CTS indicators were declared valid with a score of 0.379, 0.515, 0.515, 0.364, 0.571, 0.342, 0.412, 0.391, 0.415 and 0.367 where these values were greater than the value of rtabel = 0.291 with a significance level 5% (N = 44). This instrument was also declared reliable with a Cronbach's Alpha value of 0.666.

Procedures

The application of STEM 3.0 Approach was integrated with real material and virtual simulation given to students in class A2 and A5, where students in class A2 have higher academic abilities than class A5 (based on the reported value of learning outcomes). In this case, the STEM 3.0 Approach is a learning approach that integrates 3 of the 4 STEM components, namely: Science, Technology and Mathematics, without Engineering. Science, in this case; is knowledge on the material of the kinetic theory of gases. Technology is the learning media used, namely real material and PhET Simulations. Mathematics is the process of collecting, calculating, analyzing and generalizing experimental data on the kinetic theory of gases using real materials and PhET Simulations. Real material was given to apperception in the form of demonstrations to show the symptoms that arise, such as changes in temperature, pressure, and volume can be felt and observed in plain sight (macroscopic). In this material, students were also emphasized to understand the causes of these symptoms. These causes were the kinetic characteristics and behavior of a particle or molecule in the gas (microscopic) where there is no real example or picture of the atoms that make up the molecule so that virtual simulation in the form of PhET is guided by the Student Worksheet. As for the control class (Class A3), the researcher did not apply the STEM 3.0 approach. Learning on gas kinetic theory did not use real materials and PhET Simulations.

Students in the classes were divided into 4 groups. Each group consisted of 5 people with a combination of students who have high and low academic abilities. The treatment was given during 3 meetings and added 2 meetings for the pretest and posttest given to the class with a fixed group. Each meeting lasted for 90 minutes. At the first meeting giving pretest to students. The second meeting discussed the relationship between pressure, volume, temperature and number of particles. The third meeting discussed the relationship between the speed of a gas molecule, the mass of a gas molecule, pressure, and temperature. The fourth meeting discussed the internal energy, the number of molecules and temperature. The last meeting gave a posttest.

Data Analysis

Statistical tests were performed using SPSS version 25 for Windows. Firstly, it is necessary to test the normality and homogeneity of the data. Secondly, to ensure that there are differences in students' CTS between the experimental class and the control class, the One Way ANOVA test was carried out in class A2, A5 and A3. Thirdly, to find out whether there is an effect of the STEM 3.0 approach on students' CTS, then a Paired Sample Test is carried out in class A2 and A5 (experimental class). Lastly, to determine the effectiveness of the application of the STEM 3.0 approach, the N-Gain score test was carried out in experimental class.

■ RESULTS AND DISCUSSION

Prerequisite Test

Based on the results of statistical tests, the pretest and posttest data were normally distributed as indicated by the Shapiro-Wilk parametric analysis (this determination is based on the amount of data less than 50) where the pretest score Class A2 is 0.524, Class A5 is 0.375 and Class A3 is 0.154; and Class A2 posttest scores of 0.185, Class A5 of 0.095 and Class A3 of 0,457 (greater than 0.05) (See Table 1). While the significance value of the Test of Homogeneity of Variances is 0.889 (greater than 0.05), which indicates that the data have the same variance (homogeneous) (See Table 2).

Table 1. Data of shapiro-wilk parametric analysis

Tests of Normality

	Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Posttest	Class A2	.133	20	.200*	.934	20	.185
	Class A5	.197	20	.040	.919	20	.095
	Class A3	.105	20	.200*	.955	20	.457
Pretest	Class A2	.120	20	.200*	.959	20	.524
	Class A5	.113	20	.200*	.951	20	.375
	Class A3	.165	20	.161	.930	20	.154

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 2. Data of test of homogeneity of variances

Test of Homogeneity of Variances					
		Levene Statistic	df1	df2	Sig.
Posttest	Based on Mean	.118	2	57	.889
	Based on Median	.174	2	57	.841
	Based on Median and with adjusted df	.174	2	56.031	.841
	Based on trimmed mean	.096	2	57	.909

One Way ANOVA Test

After the data is declared normal and homogeneous, One Way ANOVA test can be performed. Overall, the test results produced a significance value of 0.000 (less than 0.05), which means that there are a significant difference in the CTS students of class A2, A5 and A3 (See Table 3).

Table 3. Data of one way ANOVA test

ANOVA

Posttest

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2152.933	2	1076.467	41.689	.000
Within Groups	1471.800	57	25.821		
Total	3624.733	59			

In detail, significant differences occurred in the experimental class (Class A2 and A5) and the control class (Class A3). This is indicated by the value of Sig. between Class A2 and A3 is 0.000 and the value of Class A5 and A3 is 0.000 (less than 0.05). Furthermore, the value of Sig. in both experimental classes of 0.332. This proves that there is no significant difference in the two experimental classes (See Table 4). It shows that learning design with STEM 3.0 approach integrated with real material and virtual simulation can improve the CTS of students regardless of the initial ability of students and any class.

Table 4. Data of multiple comparisons between class a2, a5 and a3

Multiple Comparisons

Dependent Variable: Posttest
Tukey HSD

(I) Class	(J) Class	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Class A2	Class A5	2.30000	1.60689	.332	-1.5669	6.1669
	Class A3	13.70000*	1.60689	.000	9.8331	17.5669
Class A5	Class A2	-2.30000	1.60689	.332	-6.1669	1.5669
	Class A3	11.40000*	1.60689	.000	7.5331	15.2669
Class A3	Class A2	-13.70000*	1.60689	.000	-17.5669	-9.8331
	Class A5	-11.40000*	1.60689	.000	-15.2669	-7.5331

*. The mean difference is significant at the 0.05 level.

The impact of applying STEM 3.0 approach integrated with real material and interactive virtual simulation in learning the kinetic gas theory material to the CTS of students is shown in Table 5.

Table 5 shows that the average CTS posttest score of students in experimental classes (class A2 and A5) are not much different with the average value and standard deviation in class A2 are greater than in class A5. This is because students of class A2 have higher academic abilities. Thus, students in class A2 have a better understanding during the learning process. As a results, CTS posttest scores for A2 class students are higher. The higher average academic ability allows the ability of students to be more varied so that the distribution of CTS values is wider. While the CTS posttest scores of students in the control class (class A3) were lower than those in the two experimental classes.

Table 5. Students' cts descriptive analysis results in class a2, a5 and a3

CTS Elements	Number of Learners	Mean			
		Pretest	Standard Deviation of Pretest	Posttest	Standard Deviation of Posttest
Class A2	20	40.35	4.05	82.90	5.36
Class A5	20	44.45	7.08	80.60	4.88
Class A3	20	45.85	7.38	69.20	4.97

Paired Sample Test

Based on the results of the Paired Sample Test on the pretest and posttest scores in the experimental class (Class A2 and A5), the Sig. (2-tailed) of 0.000 in both classes (See Table 6). This shows that there is a significant difference between the pretest and posttest. That is, there is an effect of the STEM 3.0 approach on increasing students' CTS on the kinetic theory of gases.

Table 6. Data of paired sample test

Paired Samples Test

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper	t	df	Sig. (2-tailed)
Pair 1	Pretest_A2 - Posttest_A2	-42.55000	6.95455	1.55509	-45.80483	-39.29517	-27.362	19	.000
Pair 2	Pretest_A5 - Posttest_A5	-36.15000	7.29293	1.63075	-39.56320	-32.73680	-22.168	19	.000

Furthermore, the comparison of the increase in students' CTS for A2, A5 and A3 is analyzed based on the constituent elements. Figure 1 illustrates the comparison of n-gain scores of each CTS element of students in class A2, A5 and A3.

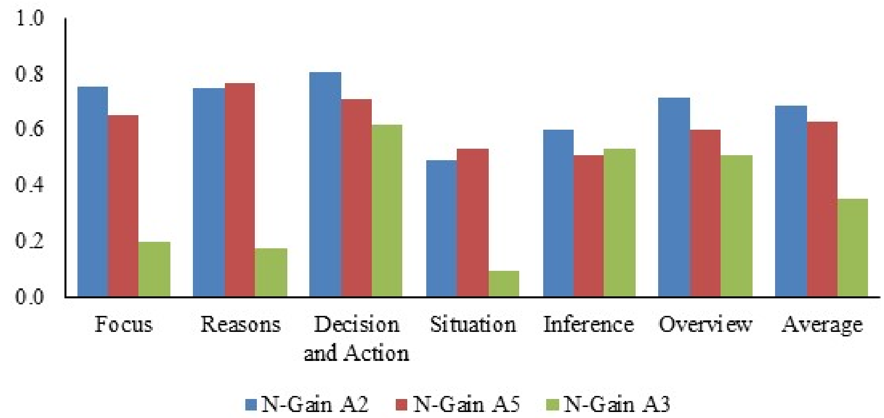

Figure 1. CTS n-gain value of students in class A2 and A5 as experimental class, and class A3 as control class.

Based on Figure 1, the CTS of students increased significantly (Saputri & Rinanto, 2018). This can be seen from the average value of n-gain in each class, where for class A2 is 0.69, for class A5 is 0.63 and for class A3 is 0,36. The highest increase was in the "Decision and Action" element with an n-gain score of 0.80 for class A2 and in the "Reasons" element with an n-gain score of 0.76 for class A5, while the lowest increase was in the "Situation" element for class A3. Although CTS students in class A2 on the element of "Focus", "Decision and Action", "Inference", and "Overview", greater than the A5 class, but the class A5 students get a score on the element of "Reasons" and "Situation" greater. However, the n-gain score of "Inference" element in class A3 as control class is higher than in class A5 as experimental class.

Based on the research data, the implementation of learning with the STEM 3.0 Approach which is integrated with real materials and interactive virtual simulation can improve students' CTS. These 3 components of STEM 3.0 support the activities of students in learning at the critical thinking level. "Science" which is the basic knowledge of students can be mastered more easily with the real material that is applied to learning. For certain abstract and microscopic concepts, students can still understand them completely and comprehensively between one concept and another, supported by virtual simulation (Technology). In addition, students are also guided to be able to relate the concept of material to natural phenomena that occur in the surrounding environment (Mathematics). The combination of STEM 3.0 components facilitates students to develop important aspects of CTS, namely: Focus, Reasons, Decision and Action, Situation, Inference and Overview.

The element of "Focus" has the highest increase because students are not accustomed to formulating problems before searching for and finding solutions and solutions. Generally, problems have been given during learning activities or during exams. Then, students are asked to solve the problems given. Therefore, students are weak in determining the core of the problem when CTS questions are given before the treatment is given. As a result, the students' pretest scores on this element are very low. However, students easily determine the formulation of the problem and then determine a temporary solution to the problem after learning through the STEM 3.0 Approach by combining real material and virtual simulation.

The improvement of the CTS on the "Focus" element is inseparable from the role of the real material given at the beginning of learning. Real material showed a phenomenon that occurs in everyday life as direct learning to show macroscopic symptoms related to the concept of kinetic gas theory (Science of STEM). Presentation of this phenomenon makes learning truly meaningful and embedded in the memories of students so that it becomes the basis for understanding the material more deeply in accordance with the meaningful learning theory proposed by Ausubel (Suyono & Hariyanto, 2015). In addition, the presentation of real material can increase student learning motivation, where motivation is a variable influencing critical thinking (Spector, 2019). Without or lack of motivation can hinder the development of critical thinking skills (Bagheri & Ghanizadeh, 2016; Dehghani et al., 2011).

The students in the group practiced an example of a phenomenon where a lit candle is placed in the middle of a plate filled with colored water and then covered with transparent glass. Just before the flame on the candle died, the surface of the water inside the glass and outside the glass has the same height. However, the surface of the water inside the glass rise and is higher compared to the surface of the water outside the glass after the candle dies because the oxygen used for the combustion process has completely reacted. Based on this phenomenon, students begin to think to determine the core problems of the phenomenon (Focus). Through learning with this real material, a learner-centered learning environment is created where students learn to investigate, engineer solutions based on problems, practice, analyze and build evidence-based explanations of the real-world phenomena that are presented (Shernoff et al., 2017).

The process of critical thinking is increasingly easy to do supported by direct experience. Students use the eye to observe and touch to manipulate the desired variable. Thus, students get scientific knowledge from several points of view that reinforce each other (Reasons). Thus, this makes it easier for students to be able to describe, analyze and find the facts both explicit and implicit, compare two circumstances, predict, determine steps and decide what kind of equation should be applied in order to find a solution to the problem given phenomenon (Norström, 2013).

The act of solving the problem in question is to determine the experimental steps to test the relationship between the variables that are at the core of the problem (Decision). This stage focuses on analyzing the behavior of abstract particle substances and causing microscopic phenomena through experiments using PhET Simulations (Technology of STEM). At this stage, the STEM 3.0 approach allows students to innovate, design solutions and utilize technology (Kelley & Knowles, 2016) so that they can not only identify the characteristics of the gas constituent particles but can also study the effect of the particle's behavior which is affected by temperature and results in its pressure and volume (Action). Students 'activities in learning trigger the formation of critical thinking (Bagheri & Ghanizadeh, 2016) because it is believed that critical thinking is influenced by students' involvement in the actions they take (Dehghani et al., 2011). By acting proactively in conducting this experiment, students can connect the facts found in the experiment so as to form a deeper understanding of concepts. The concept is converted into mathematical equations (Mathematics of STEM). This mathematical equation is useful for proving and reinforcing concepts that are already embedded in the minds of students.

In addition to the facts in experiments on the microscopic aspect, students also consider the facts behind the symptoms of the phenomena presented (Situation). With these considerations, students deduce the relationship between the variables that exist in the kinetic theory of gas (inference). Students who can conclude and evaluate have an increased ability to apply scientific knowledge (Yu et al., 2019). The relationship of scientific knowledge with one another forms a concept which when connected with other concepts forms a principle in the kinetic theory of gas. The concept and principle of the kinetic gas theory is the basis for students to solve problems or other phenomena that occur in real life.

Furthermore, students presented the results of experiments ranging from conducting experiments using real materials to make conclusions on these facts supported by experimental data with virtual simulation. Students in other groups pay attention and share information related to the experiments that have been conducted to complete and review whether learning has been done correctly or not and the improvement of learning has been achieved (Overview) (Sulistijo et al., 2017). Furthermore, students are given the opportunity to review other similar phenomena to strengthen students' understanding of concepts related to the kinetic theory of gas.

The description of these results is a logical explanation of why the CTS of students increases after being given learning with the STEM 3.0 approach integrated with real material and interactive virtual simulation. Every step of learning given requires students to reach every element of the CTS. With this integrated approach, students are helped both in solving real-world problems by applying concepts from various disciplines as well as in collaborating and working (BURRows & Slater, 2015) because each of these disciplines reinforce one another. Its usefulness in daily life is that students can assess and ensure the accuracy of the data, the significance, the validity of various digital sources of information that circulate, and link knowledge with their life experiences (Yeh, 2002).

The development of thinking skills also depends in part on the extent to which students interact actively between and with the environment. Students in each study group are expected to interact with each other between group members to collaborate in solving problems at each learning stage so that the CTS students can be well-honed (DeHaan, 2009). Thus, in this interaction there is a transfer of knowledge from students who are superior in finding knowledge to students who are more superior in socializing so that knowledge sharing occurs in the learning group. Furthermore, the psychomotor of students are also well-formed which is a factor that determines the completeness of student learning outcomes (Prihatiningtyas et al., 2013) where one of them is CTS. In accordance with Vygotsky's Theory, the interaction allows students to communicate actively and productively with each other in sharing knowledge so that the knowledge and experience of each member will complement each other for all group members. This is in accordance with Piaget's theory of development which views cognitive development as a process in which students actively build systems of meaning and understanding of reality through their experiences and interactions (Suyono & Hariyanto, 2015).

■ CONCLUSIONS

Based on the research data, the increase in the CTS of students in the 2 experimental classes was classified as moderate while the increase in CTS in the control class was classified as moderate with a lower value. Furthernore, there is a significant difference between the experimental class and the control class. Therefore, it is concluded that the integrated

STEM 3.0 approach can effectively enhance the CTS.

This research is very useful to improve the quality of learning, especially physics learning. This article provides information on how to apply a STEM 3.0 approach that is integrated with real materials so as to enable students to think critically and act actively in solving problems. However, this study has limitations in involving the number of students. The number of students in equal schools is generally more. Therefore, further research is needed on a larger class.

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