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Using STEM-Based 3D-Multimedia to Improve Students' Critical Thinking Skills in Uniform Circular Motion

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Abstract *- Students' low critical thinking skills are an obstacle in learning uniform circular motion. The aim of the study was to describe the effect of using STEM-based 3D-multimedia in improving the critical thinking skills of students from the northern coast of Java in uniform circular motion material. This research is a pre-experimental with a one-group pre-test post-test design. The research sample was 26 students of class X-IPA MA Hasyimiyah Bancar. The treatment of the samples was carried out by using STEM-based 3D-multimedia during four face-to-face lessons in class. The results show that the students' critical thinking skills improved by 56,1% after the implementation of the STEM-based 3D multimedia. This quantitative result is proven by critical thinking skills indicators that can be identified in the students' critical thinking skills test answers. Therefore, it can be concluded that the use of STEM-based 3D-multimedia enhanced the students' critical thinking skills in uniform circular motion quite significantly.*

Keywords: *3D-multimedia; critical thinking skills; STEM; uniform circular motion*

I. INTRODUCTION

Critical thinking skills are needed by students in order to master physics materials well (Bakri et al., 2019; Dumas, 2017; Khaeruddin & Bancong, 2022). Critical thinking skills (CTS) is a person's ability to carry out clear and directed thinking processes to draw conclusions, identify correlations, analyze possibilities, make predictions and logical decisions, and do complex problem-solving (Damayanti & Kuswanto, 2020; Demirci & Özyürek, 2017; Halpern, 2014; Tiruneh et al., 2017). Unfortunately, in fact, students' CTS is still low. One of the causes is the learning media prepared by the teacher, which still cannot stimulate students' CTS (Velmovská et al., 2019; Zulazhari et al., 2019).

The learning media can be presented in 3D-multimedia representation. The multimedia learning theory state that learning activities using multimedia representations can help students to build mental representations of the subjects they learned and overcome

cognitive overload (Koć-Januchta et al., 2019; Mayer, 2014). According to the Cognitive Theory of Multimedia Learning (CTML), the learning process of the students occur when students not only absorb the new information but are also actively involved in the knowledge construction process (Mayer, 2005). The knowledge construction process demands students' activeness in paying attention to information that is more relevant and meaningful, compiling the new information into a coherent cognitive structure, and integrating the new information with other knowledge to build a coherent mental representation to form a conceptual understanding of the learning material and build critical thinking skills (Altmeyer et al., 2020; Lai et al., 2018; Mayer, 2005; Yeo et al., 2004). To support students' knowledge construction process and build students' CTS, it is necessary to apply a learning approach that can provide authentic learning experiences to students. The application of the Science, Technology, Engineering, and Mathematics (STEM) approach can provide students with authentic learning experiences (Amalia et al., 2023; Nurazmi & Bancong, 2021). STEM is a form of learning approach that unifies two or more STEM domains into authentic learning based on subject relationships with real problems to improve students' learning (Falloon et al., 2020; Kelley & Knowles, 2016). STEM pedagogy is student-centered, project-based, and interdisciplinary, so it can accommodate students' needs to reach learning goals (Falloon et al., 2020; Laforce et al., 2016). In the cognitive domain, STEM develops students' high-level cognitive processes, such as analysis, synthesis, evaluation, and creation (Falloon et al., 2020). Therefore, the STEM approach is suitable for honing students' CTS as the CTS requires processes of analysis, evaluation, feasibility, and reflection (Mutakinati et al., 2018; Khaeruddin & Bancong, 2022). Thus this high-level cognitive process is the core element of students' CTS (Heard et al., 2020).

The results of preliminary observations on students of MA Hasyimiyah Bancar showed that students' CTS in a uniform circular motion was relatively low. The students' background as native to the northern coast of Java makes them familiar with the traffics of the northern coast road (Jalur Pantura). Yet, unfortunately, they have difficulty when they have to explain the car motion when it turns left or right on a curved road based on uniform circular motion, even though they saw that phenomenon every day. Students have difficulty in explaining the real phenomena because they still use naive understanding, and they are not used to analyzing more realistic and complex cases of circular motion (Pendrill, 2020; Pendrill et al., 2019; Volfson et al., 2020). In order to be able to explain the real phenomenon of uniform circular motion, students need critical thinking skills.

In the previous study, there are similar kinds of learning media that have been used,

such as STEM-based learning video (Putri & Saehana, 2021), web-based laboratory for uniform circular motion (Yohandri et al., 2022), and cartoon animation of uniform circular motion (Ozdemir, 2022). The study on the use of STEM-based learning videos did not discuss the improvement of students' CTS, but the improvement of students' conceptual understanding (Putri & Saehana, 2021). The web-based laboratory for uniform circular motion study did not mention the effect of the implementation of the media on learning activity (Yohandri et al., 2022). Meanwhile, the study on the use of cartoon animation of uniform circular motion only discusses that it can initiate students' cognitive conflict without further discussing the students' CTS (Ozdemir, 2022). Therefore, a research on the effect of using STEM-based 3D-multimedia on students' critical thinking skills on the uniform circular motion material needs to be done, especially for the students from the northern coast of Java. It is because the research on the CTS of the students from this area is still lacking, especially in physics education-related studies.

Thus, the purpose of this study was to investigate the effect of using STEM-based 3D-multimedia on the CTS of students from the northern coast of Java on uniform circular motion material. Moreover, another goal is to describe how STEM-based 3D-multimedia can improve northern coast students' CTS.

II. METHODS

This study applies a pre-experimental research design. Research data was taken through one group pre-test post-test design. The research was conducted at MA Hasyimiyah Bancar, Tuban District, East Java.

The population of this study was all students of class X at MA Hasyimiyah Bancar, Tuban District, East Java. The research samples were 26 students of class X-IPA at MA Hasyimiyah Bancar. The research sample was determined by using a purposive sampling technique in order to select the samples based on the student's residence background on the northern coast of Java. The procedure for collecting the data is shown in Figure 1.

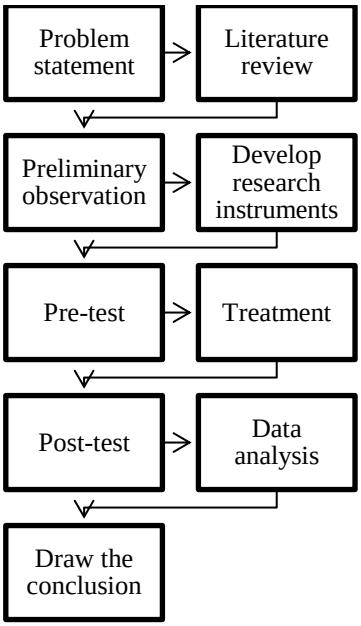


Figure 1. The flowchart of data collection

As we can see in Figure 1, there are nine steps in collecting research data. These steps consist of 1) formulating a problem statement, 2) reviewing the literature and presenting them

to find out the main aspects related to the topic being studied, 3) doing preliminary observation to determine the actual conditions of the students' CTS, 4) developing research instruments for data collection, including the 3D-multimedia, the lesson plan, and the CTS test instrument based on the indicator of students' CTS, 5) conducting a pre-test to determine students' initial CTS before giving the treatment, 6) Giving treatment using 3D-multimedia in four face-to-face lessons in class, 7) administering a post-test to determine the effect of using 3D-multimedia on students' CTS by giving 4 uniform circular motion essay questions, 8) analyzing the data quantitatively to measure the students' CTS improvement, measuring the changes in students' CTS using the N-gain score, and 9) drawing the conclusion based on research findings.

Data analysis was carried out quantitatively based on the N-gain score of the students' pre-test and post-test. The N-gain score category is shown in Table 1 (Meltzer, 2002).

Table 1. N-gain score category

Category	Score
High	$g > 0{,}70$
Moderate	$0{,}30 \leq g \leq 0{,}70$
Low	$g < 0{,}30$

Furthermore, in order to know the effect of using STEM-based 3D-multimedia in improving students' critical thinking skills, the level of effectiveness by Meltzer (2002) is used. The level of effectiveness is shown in Table 2.

Table 2. N-gain percentage category

Percentage	Effectiveness
$g > 70\%$	Effective
$50\% < g \leq 70\%$	Quite effective
$30\% \leq g \leq 50\%$	Less effective
$g < 30\%$	Not effective

The indicators of students' CTS used in this study were compiled based on the CTS domain stated by Tiruneh et al. (2017). There are five domains of CTS: 1) reasoning, 2) hypothesis testing, 3) analyzing arguments, 4) analyzing possibilities and uncertainties, and 5) problem-solving and decision-making (Tiruneh et al., 2017). Table 3 shows the indicator of CTS used in this study.

Table 3. Indicator of CTS

Domain	Indicators
Reasoning	Students are able to interpret information in questions of uniform circular motion
Hypothesis testing	Students are able to draw valid conclusions based on the questions of uniform circular motion presented
Analyzing arguments	Students are able to identify relevant physical quantities that are not yet known in questions of uniform circular motion
Analyzing possibilities and uncertainties	Students are able to determine the additional information needed to solve the problem of uniform circular motion
Problem-solving and decision-making	Students are able to identify the best alternative to complete uniform circular motion project assignments

III. RESULTS AND DISCUSSION

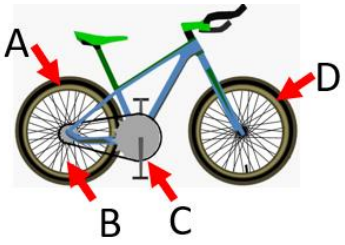
This study aims to investigate the effect of using STEM-based 3D-multimedia on the CTS of students. Based on the data analysis, the descriptive statistics of students' CTS before and after using STEM-based 3D-multimedia are shown in Table 4.

Table 4. Descriptive statistics of students' CTS

	Pre-test	Post-test	N-Gain	Perc. (%)
Max.	50.0	90.0	0.846	84.6
Min.	5.0	35.0	0.316	31.6
Average	27.3	67.1	0.561	56.1

As we can see in Table 4, the average N-gain of the students' CTS is 0.561, with the highest score is 0.846 and the lowest score is 0.316. That means that the improvement of students' CTS is in the quite effective category (56.1%). Thus, it can be claimed that learning uniform circular motion using 3D-multimedia is quite effective in improving students' CTS.

A qualitative description of the students' CTS improvement is given based on the changes in students' answers on the pre-test and post-test. On question No. 4, students are given an illustration of two identical bicycles, except for a different arrangement of the gears with a different radius, students are asked to determine which bicycle is faster.



Selama satu menit, Dea telah mengayuh pedal sepedanya 90 kali. Diketahui diameter bagian A=D=50 cm, B=10, dan C=16 cm. Jika selama waktu tersebut Dea mengayuh sepedanya dengan stabil (tidak berubah kecepatannya), maka berapa kelajuan sepeda Dea selama satu menit tersebut ? Uraikan jawabanmu!

Figure 2. Question no. 4

Based on question No. 2, the example of the changes in students' answers on the pre-test and post-test are shown in Table 5.

Table 5. Changes in student answers to question no. 4

Pre-test	Post-test
Student A (1 point) Bike II goes faster because of the different wheel arrangement	Student A (3 Points) Bike II is going faster than bike I because B_2 is bigger than A_2
Student B (Point 2) Bike II goes faster because B_2 is bigger than B_1	Student B (5 Points) Bike II goes faster than bike I because the wheel arrangement B_2 is bigger than A_2. The bike I is slower because the wheel arrangement is reversed. B_1 is smaller than A_1
Student C (Point 3) Bike II will go faster because B_2 is bigger than A_2	Student C (5 Points) Bike II goes 4 times faster than bike I because B_2 is twice as big as A_2

The CTS indicators that can be identified from students' answers are shown in Table 5. As we can see, there is an increase in the scores of students A, B, and C on the post-test scores compared to the pre-test scores. Students A, B, and C were able to interpret the information contained in the question, and they were also able to give valid conclusions based on that information. In addition, student B could provide an analysis of arguments to support his answer by explaining why bicycle II can go faster and why bike I is slower. Meanwhile, student C provided a mathematical analysis to support his answer. Figure 3 shows the answer sheet of student C after completing question no. 2 in the post-test activity.

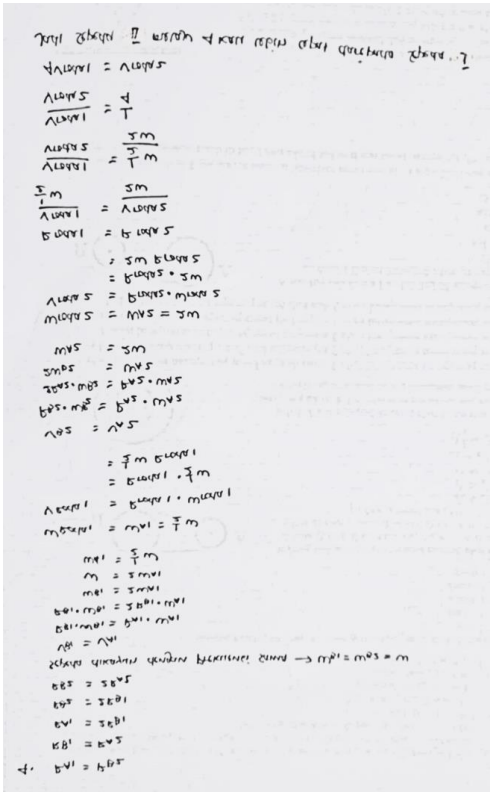


Figure 3. Student C's mathematical analysis to support his argument

The findings show that the use of 3D-multimedia when learning uniform circular motion, improves students' CTS quite effectively. The average increase in students' CTS after participating in learning using STEM-based 3D-multimedia is 56.1% This quantitative result is justified by CTS indicators that can be identified in the students' CTS test answers, as shown as in Table 5. After the treatment, students could do reasoning, hypothesis testing and analyzing arguments well. The use of using STEM-based 3D-multimedia in this study can be seen in Figure 4.

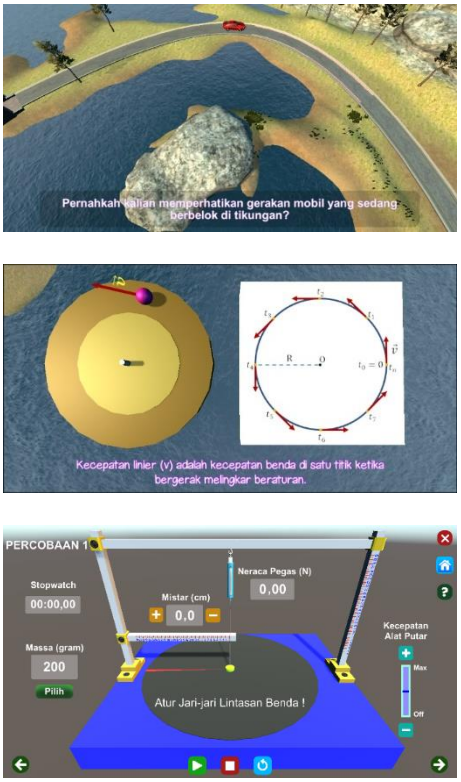


Figure 4. The 3D-multimedia used in this research

The students' CTS improvement found in this study is consistent with the multimedia learning theory and the cognitive theory of multimedia learning (CTML). According to multimedia learning theory, learning activities using multimedia can help students to build a mental representation of what they learned (Koć-Januchta et al., 2019). Meanwhile, CTML state that a coherent mental representation can help students to achieve a conceptual understanding of the learning material and has benefit in building students' CTS (Altmeyer et al., 2020; Lai et al., 2019).

This result was also supported by STEM pedagogical advantages. The application of the STEM approach can provide students with authentic learning experiences (Amalia et al., 2023). It can develop students' high-level cognitive processes, such as analysis, synthesis, evaluation, and creation, which are the core element of students' CTS (Falloon et al., 2020; Heard et al., 2020; Nurazmi & Bancong, 2021).

The implication of this research finding for physics education is that students in the northern coast area need more attention in terms of their CTS development. The teachers, in this area especially, need to be more creative in preparing learning media to stimulate students' CTS in any physics materials. It is because different students' backgrounds might have different types of suitable learning media.

IV. CONCLUSION AND SUGGESTION

Based on the analysis of the research data, it was found that using STEM-based 3D-multimedia in uniform circular motion learning was quite effective (56.1%) in improving students' CTS. The students were able to interpret the information contained in the problem, make a valid conclusion based on the information provided, and they could make an analysis to support their arguments. Therefore, it can be concluded that the students' critical thinking skills in uniform circular motion improved quite significantly after using the STEM-based 3D-multimedia.

This study has several weaknesses, such as the small number of research samples. Therefore, a suggestion for future researchers is to conduct further research on the development of student CTS on the north coast of Java with a large number of samples so that the results obtained are more accurate. Researchers also need to conduct research and development studies to find more effective learning media for improving students' CTS in uniform circular motion material.

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