

The Effect of a Process Image-Based Electromagnetic Induction Module on Senior High School Students' Mastery of Concepts and Critical Thinking Skills in Physics

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Abstract

This research aims to examine the effect of an electromagnetic induction module based on process images on high school students' conceptual mastery and critical thinking skills in physics. The research design used is a nonequivalent control group design with cluster random sampling. This research was conducted at SMA Negeri Arjasa Jember in the second semester of the 2024/2025 academic year. The sample consisted of one experimental class and one control class. Data were collected through pretests, posttests, and observations. The analysis of conceptual mastery using the Mann-Whitney U Test showed a significance value of 0.020 (2-tailed) and 0.010 (1-tailed), indicating a significant effect of the module on conceptual mastery. Meanwhile, the analysis of critical thinking skills showed a significance value of 0.519 (2-tailed), indicating that the module did not significantly affect students' critical thinking skills. These findings suggest that the module effectively supported students' conceptual understanding but was insufficient to foster higher-order thinking. The results highlight the need to integrate more inquiry-based or reflective activities into future module designs to better promote critical thinking skills.

Keywords: *Module, images, conceptual, critical thinking.*

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1. INTRODUCTION

In the face of rapid technological and societal change, physics education in the 21st century demands more than just content knowledge. The main skills that students must master in 21st-century learning are critical thinking, collaboration, communication, and creativity (Mahrunnisya, 2023). Among these skills, critical thinking is one of the main aspects that students need to master (Arifah et al., 2021). This ability allows students to evaluate and test the logic and assumptions of other people's ideas (Ramdani et al., 2020). Critical thinking skills can develop if students understand the concepts of the material being studied. Success in studying physics depends on students' mastery of the theories and laws in the material. Mastery of concepts allows students to connect physics with events that occur in everyday life and natural phenomena, thus supporting critical thinking skills (Fauziah & Dewi, 2023). Therefore, critical thinking skills and mastery of physics concepts play an important role in helping students understand the material in depth and apply it in solving real problems.

Physics learning currently still faces challenges, one of which is students' difficulties in understanding physics concepts. According to Rachman et al. (2023), physics lessons require deeper thinking, so they are often considered to have a high level of difficulty. Sevtia et al. (2022) added that weak understanding of physics concepts has an impact on students' weak critical thinking skills. Apart from that, the abstract nature of physical material is a challenge in itself. Musliman & Kasman (2022) state that most concepts in physics cannot be observed directly. These challenges often lead

students to rely on memorization rather than conceptual understanding, limiting their ability to analyze problems, make inferences, or evaluate information critically. In real classroom settings, this may result in students struggling with problem-solving tasks, being unable to link theory with real phenomena, and misinterpreting key concepts during assessments or class discussions. This obstacle can reduce students' level of understanding of physics theory and critical thinking skills in physics. Electromagnetic induction is a physics concept that requires in-depth understanding. This material discusses the interaction between magnetic fields and electric currents which cannot be seen directly, so it often causes difficulties for students. Based on research by Shofiyah (2021), of the entire sample, 71.5% of students experienced conceptual errors in electromagnetic induction material. Other research by Khairunisa et al. (2023) found that 64% of the total sample of students had difficulty connecting the concepts of magnetism and electricity. These findings indicate that the complexity and abstract nature of the material is a major challenge in critical thinking skills and mastery of concepts in physics.

Challenges in understanding abstract physics material can be minimized by using visual learning media, such as process pictures. Sutarto et al. (2018) stated that a process drawing is a modeling drawing of an object from a phenomenon or event, with relative similarities between one drawing and another in terms of position, shape, and conditions, as well as a combination, which thoroughly depicts the stages of an integrated whole. Previous research by Khoirunnisa et al. (2021) showed that student worksheets based on process images can have a significant effect on students' learning outcomes and critical thinking abilities in physics. However, the study focused on general physics topics and did not specifically address abstract concepts such as electromagnetic induction. To date, no studies have been conducted specifically to discuss the use of process image media in electromagnetic induction material, which has the potential to help students understand physics concepts visually. Given the abstract and invisible nature of electromagnetic phenomena, the use of visual representations such as process images is especially relevant. This shows the importance of developing a teaching material that not only addresses conceptual difficulties but also supports students' higher-order thinking skills.

Process image-based learning media needs to be arranged according to the sequence of physics material to support gradual understanding, one of which is integrating process images into modules. Figure 1 illustrates one example of the process images used in the module, showing the clockwise rotation of a generator armature and how this motion leads to the generation of alternating current (AC). Jusuf & Sobari (2021) explain that modules are teaching materials that contain learning material according to the curriculum and are structured to support independent learning. Therefore, the electromagnetic induction module based on process images is expected to facilitate students' understanding of physics concepts on a visual basis, so that students' understanding can be structured systematically. This module is also equipped with indicators of concept mastery, referring to the cognitive process dimensions contained in Bloom's Taxonomy according to Krathwohl (2002). The indicators used in this research are C1 (remembering), C2 (understanding), C3 (applying), C4 (analyzing), and C5 (evaluating). Apart from that, this module is also equipped with indicators of critical thinking skills according to Facione (2015), namely interpretation, analysis, evaluation, inference, explanation, and self-regulation. The full process image module design is presented in Figure 1. By developing a module that combines visual process images with structured indicators of conceptual and critical thinking skills, this research aims to contribute to the improvement of physics learning practices. In the long term, the findings from this study may serve as a reference for developing innovative and effective learning resources for other abstract topics in physics.

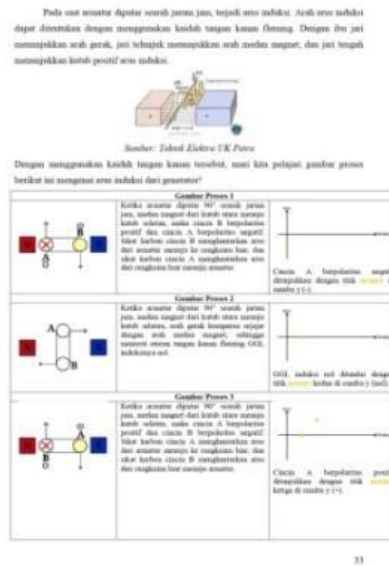


Figure 1. Design of An Process Image-Based Electromagnetic Induction Module

Based on the problems that have been described, it needs to be tested through experimental research entitled "The Effect of Process Image-Based Electromagnetic Induction Modules on High School Students' Mastery of Physics Concepts and Critical Thinking Skills".

2. METHODS

This research uses a quasi-experimental design with a nonequivalent control group. This design was chosen because it allows for the comparison of learning outcomes between two existing classes without random assignment of individual students, which is often impractical in school settings. It also enables researchers to implement treatments under natural classroom conditions, thus maintaining ecological validity. The research design is shown in Table 1.

Table 1. Nonequivalent Control Group Design

Class	Pretest	Treatment	Posttest
Experiment	O ₁	X	O ₂
Control	O ₃		O ₄

Source: Sugiyono, 2022

This research uses a cluster random sampling technique. The research was conducted at SMA Negeri Arjasa Jember during the even semester of the 2024/2025 academic year. The population consisted of all class XII MIPA students. The sample was selected using a cluster random sampling method based on existing groups, meaning that entire classes were randomly selected, not individual students. This method was used because class groupings in schools are typically fixed and cannot be reorganized, making it more feasible to select intact classes randomly than to assign students individually. To ensure group equivalence before treatment, a homogeneity test was conducted using Levene's test on the final summative scores in physics from the odd semester. The result showed a significance value greater than 0.05, indicating that the variance between the groups was homogeneous. This verification is important to ensure that both groups had similar characteristics before the treatment, supporting the validity of the experimental results. Based on this test, Class XII-1 with 29 students was selected as the experimental class, and Class XII-2 with 32 students as the control class. Class XII-1 received treatment in the form of learning using an electromagnetic induction module based on process images, while Class XII-2 continued with conventional learning

using the physics textbook commonly used in schools. The research in both classes was conducted by administering a pretest on concept mastery and critical thinking skills before the learning implementation, carrying out the learning over three meetings, and finally giving a posttest to assess students' concept mastery and critical thinking skills after the learning process.

The data collection technique in this research consists of main data in the form of pretest and posttest, as well as data supporting observations carried out by three observers by filling out learning implementation questionnaires. The research instrument consists of a question sheet pretest and posttest which are arranged according to indicators of mastery of concepts and critical thinking skills. Apart from that, there is a research instrument in the form of a learning implementation questionnaire.

Analysis of pretest and posttest score data was conducted using statistical tests in SPSS Statistics 25. The tests included the Independent Samples t-Test (2-tailed) to examine the significance of differences between the experimental and control classes at a 5% significance level (Widiyanto, 2013). If the data were not normally distributed, the Mann-Whitney U Test (2-tailed) was used as a non-parametric alternative. Furthermore, the Independent Samples t-Test (1-tailed) was used to test the research hypothesis that the experimental class performed significantly better than the control class in terms of concept mastery and critical thinking skills. For non-normally distributed data, the Mann-Whitney U Test (1-tailed) was applied. The 1-tailed test was chosen because the research hypothesis was directional, aiming to determine whether the treatment had a positive effect on student outcomes.

Analysis of observation data was carried out descriptively using score criteria. The assessment was carried out by comparing the average scores of the three observers with the criteria as in Table 2. In this study, the implementation of learning is expected to reach at least the fairly good category.

Table 2. Learning Implementation Score Criteria

Average Score	Category
1.0–1.8	Not good
1.9-2.7	Pretty good
2.8-3.6	Good
>3.6	Very good

Source: Sukaisih *et al.* (2020)

3. RESULT AND DISCUSSION

The research results consist of two types of data, namely main data and supporting data. The main data is in the form of result scores pretest and posttest. Supporting data is in the form of scores from the learning implementation questionnaire completed by three observers. Pretest given in both classes before the implementation of learning aims to assess students' initial abilities in mastering physics concepts and critical thinking skills. Posttest given to both classes after the learning was implemented to identify differences in mastery of concepts and critical thinking skills in physics between the experimental class and the control class after being given treatment. Average score of results pretest and posttest concept mastery is in Table 3.

Table 3. Average Score of Results Pretest and Posttest Students' Mastery of Physics Concepts

	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
Experimental Class Pretest	29	5	67	35.21	15.400
Experimental Class Posttest	29	40	90	70.76	11.722
Control Class Pretest	32	9	66	30.34	15.526
Control Class Posttest	32	28	76	59.72	14.704
Valid N (listwise)	29				

Results average score data pretest and posttest mastery of physics concepts in Table 3 shows that the average score of the experimental class is higher than the control class. Experimental class with average score results pretest 35.21 and the average score of the results posttest 70.76. Control class

with average score results pretest 30.34 and the average score of the results posttest 59.72. Results score data pretest mastery of concepts is analyzed with Independent Sample t-Test (2-tailed) with the aim of assessing the equality of students' initial ability to master physics concepts. Results Independent Sample t-Test (2-tailed) found in Table 4.

Table 4. Results Independent Sample t-Test (2-Tailed) Result Score Pretest Students' Mastery of Physics Concepts

		Independent Samples Test								
		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Pretest	Equal variances assumed	.659	.420	1.226	59	.225	4.863	3.965	-3.072	12.798
	Equal variances not assumed			1.227	58.505	.225	4.863	3.964	-3.070	12.796

Table 4 presents the results Independent Sample t-Test (2-Tailed) with Sig. (2-tailed) 0.225. This significance value is greater than the significance level used, namely 0.05. This shows that there is no significant difference in mastery of concepts between the experimental class and the control class. Thus, experimental class and control class students have equivalent initial abilities in mastering concepts before learning. Analysis of result score data posttest students' mastery of physics concepts is carried out by Mann-Whitney U Test (2-tailed), to test whether there is a significant difference in the result scores posttest mastery of concepts between the experimental class and the control class. Results Mann-Whitney U Test (2-tailed) found in Table 5.

Table 5. Results Mann-Whitney U Test (2-Tailed) Result Score Posttest Students' Mastery of Physics Concepts

	Posttest
Mann-Whitney U	303.500
Wilcoxon W	831.500
Z	-2.323
Asymp. Sig. (2-tailed)	.020

a. Grouping Variable: Class

Table 5 presents the results Mann-Whitney U Test (2-tailed) with Asymp. Sig. (2-tailed) 0.020. This significance value is smaller than the significance level of 0.05. Refers to the basis for decision making for Mann-Whitney U Test (2-tailed). If the significance value < 0.05, then H_0 rejected and H_a accepted. These results show that there is a significant difference in students' mastery of physics concepts between the experimental class which received learning treatment using a process image-based electromagnetic induction module, and the control class which carried out learning using class XII physics books. The right side test is carried out with Mann-Whitney U Test (1-tailed). Results Mann-Whitney U Test (1-tailed) found in Table 6.

Table 6. Results Mann-Whitney U Test (1-Tailed) Result Score Posttest Students' Mastery of Physics Concepts
Test Statistics^a

	Concept Mastery
Mann-Whitney U	303.500
Wilcoxon W	831.500
Z	-2.323
Asymp. Sig. (2-tailed)	.020
Exact Sig. (2-tailed)	.020
Exact Sig. (1-tailed)	.010
Point Probability	.000

a. Grouping Variable: Class

Table 6 presents the results Mann-Whitney U Test (1-tailed) with Exact Sig. (1-tailed) 0.010. This significance value is smaller than the significance level used, namely 0.05. Refers to the basis for determining the results Mann-Whitney U Test (1-tailed). If the significance value < 0.05 , then H_0 rejected and H_a accepted. Results Mann-Whitney U Test (1-tailed) This shows that the score on the mastery of physics concepts test for the experimental class is greater than the control class. Results average score data posttest mastery of the concepts of the experimental class and control class for each indicator can be visualized using a graph as in Figure 2. The graph in Figure 2 presents the average score results posttest each indicator was higher in the experimental class which was treated with learning using an electromagnetic induction module based on process images, than in the control class which carried out learning using class XII physics books. Thus, based on the results Mann-Whitney U Test (2-tailed) and right side test results Mann-Whitney U Test (1-tailed), it can be stated that the electromagnetic induction module based on process images has a significant effect on high school students' mastery of physics concepts.

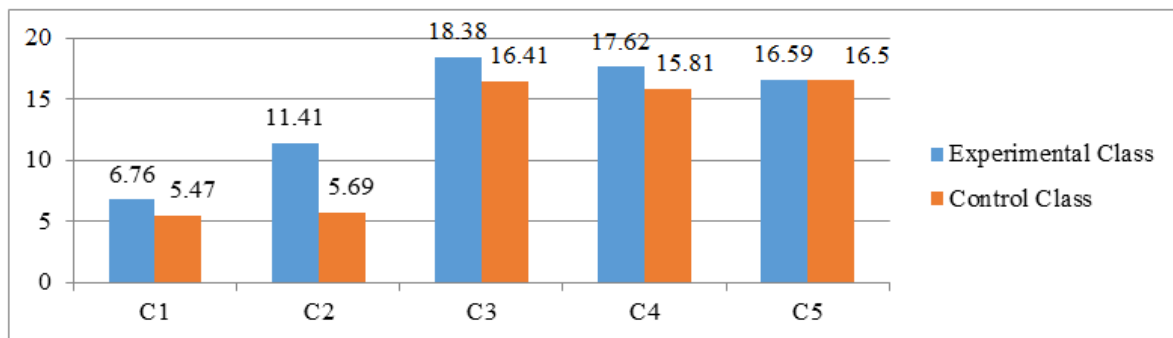


Figure 2. Graph of Average Score Results Posttest Students' Mastery of Physics Concepts for Each Indicator

Critical thinking skills data consists of result score data pretest and posttest. Average score of results pretest and posttest critical thinking skills are listed in Table 7.

Table 7. Average Score of Results Pretest and Posttest Students' Critical Thinking Skills in Physics

	Descriptive Statistics				
	N	Minimum	Maximum	Mean	Std. Deviation
Experimental Class Pretest	29	8.3	50.0	27.007	12.7341
Experimental Class Posttest	29	25.0	91.7	59.052	17.3207
Control Class Pretest	32	8.3	45.8	23.688	10.3505
Control Class Posttest	32	16.7	87.5	53.781	24.2520
Valid N (listwise)	29				

Results average score data pretest and posttest physics critical thinking skills in Table 7 show that the average score of the experimental class is higher than the control class. Experimental class with average score results pretest 27,007 and average score results posttest 59,052. Control class with average score results pretest 23,688 and average score results posttest 53,781. Results score data

pretest critical thinking skills are analyzed with Mann-Whitney U Test (2-tailed) to assess the equality of students' initial physics critical thinking skills. Results Mann-Whitney U Test (2-tailed) found in Table 8.

Table 8. Results Mann-Whitney U Test (2-Tailed) Result Score Pretest Students' Critical Thinking Skills in Physics
Test Statistics^a

	Pretest
Mann-Whitney U	406.000
Wilcoxon W	934.000
Z	-.849
Asymp. Sig. (2-tailed)	.396

a. Grouping Variable: Class

Table 8 presents the results Mann-Whitney U Test (2-tailed) with Asymp. Sig. (2-tailed) 0.396. This significance value is greater than the 0.05 significance level. This shows that there is no significant difference in physics critical thinking skills between the experimental class and the control class. Thus, experimental class and control class students have equivalent initial abilities in critical thinking skills before learning. Analysis of result score data posttest physics students' critical thinking skills are carried out with Mann-Whitney U Test (2-tailed), to test whether there is a significant difference in the result scores posttest critical thinking skills between the experimental class and the control class. Results Mann-Whitney U Test (2-tailed) found in Table 9.

Table 9. Results Mann-Whitney U Test (2-Tailed) Result Score Posttest Students' Critical Thinking Skills in Physics
Test Statistics^a

	Posttest
Mann-Whitney U	419.500
Wilcoxon W	947.500
Z	-.644
Asymp. Sig. (2-tailed)	.519

a. Grouping Variable: Class

Table 9 presents the results Mann-Whitney U Test (2-tailed) with Asymp. Sig. (2-tailed) 0.519. This significance value is greater than the 0.05 significance level. Refers to the basis for decision making for Mann-Whitney U Test (2-tailed). If the significance value > 0.05, then H_0 accepted and H_a rejected. These findings indicate that there is no significant difference in students' critical thinking skills in physics between the experimental class which received learning treatment using a process image-based electromagnetic induction module, and the control class which carried out learning using class XII physics books. Results average score data posttest the critical thinking skills of the experimental class and control class for each indicator can be visualized using a graph as in Figure 3. The graph in Figure 3 presents the average score results posttest on four indicators with higher results in the experimental class, while the other two indicators showed higher results in the control class. Thus, based on the results Mann-Whitney U Test (2-tailed), it can be stated that the electromagnetic induction module based on process images does not have a significant effect on the physics critical thinking skills of high school students.

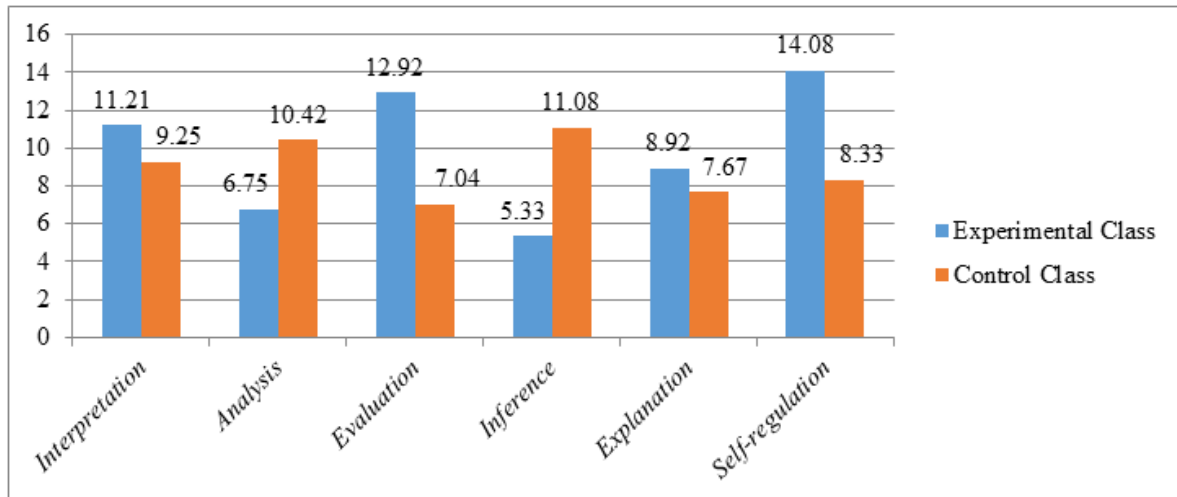


Figure 3. Graph of Average Score Results Posttest Students' Critical Thinking Skills in Physics for Each Indicator

The learning implementation questionnaire was filled out by three observers who assessed the implementation of learning using the electromagnetic induction module based on process images in accordance with the teaching module and learning syllabus. The results of the learning implementation questionnaire data are used to support the main data, namely tests. The learning implementation questionnaire data is in Table 10.

Table 10. Learning Implementation Questionnaire Data

Observer	Meeting 1		Meeting 2		Meeting 3	
	Average Score	Category	Average Score	Category	Average Sore	Category
Observer 1	3.8	Very Good	3.8	Very Good	3.4	Good
Observer 2	3.6	Good	3.9	Very Good	3.8	Very Good
Observer 3	3.5	Good	3.7	Very Good	3.5	Good

Table 10 presents the results of the learning implementation questionnaire, assessments from three observers show that learning implementation is generally in the good to very good category. Observer 1 rated the first two meetings in the very good category, while the third meeting slightly decreased to the good category. Observer 2 gave an assessment that increased from good at the first meeting to very good at the next two meetings. Observer 3 also gave an assessment that tended to be good to very good, with the first and third meetings in the good category, while the second meeting was very good. Overall, the implementation of learning was assessed as positive with a tendency for findings to align in the good and very good categories.

Statistical tests carried out for data analysis showed that there was a significant influence of the process image-based electromagnetic induction module on students' mastery of physics concepts, in line with previous research findings. Mi'rojyah (2019) found that the use of process image-based modules in collision material had a positive impact on student learning outcomes which increased in the high category. Another study by Khoirunnisa et al. (2021) shows that students worksheet based on process images on light material has a significant effect on students' physics learning outcomes. Research by Oktavia (2020) also found that work and energy textbooks based on process images produced learning outcomes and retention of student learning outcomes in the medium category. Mastery of concepts and learning outcomes are related because they both have the same indicators, namely the cognitive process dimension. So, in this research the process image-based module is related to mastery of physics concepts.

The process image-based electromagnetic induction module is equipped with clear instructions to support independent learning. This guide provides direction for students so they can learn independently without dependence on teachers, thereby increasing learning independence. Students participate in group discussions contained in the module, which are designed with indicators of

concept mastery based on Krathwohl (2002), including C1 (remembering), C2 (understanding), C3 (applying), C4 (analyzing), and C5 (evaluating). The concept mastery indicators contained in the module play a role in developing students' mastery of physics concepts. Discussions in learning allow for the exchange of ideas and deeper understanding, complemented by presentations of discussion results by explaining the concept of electromagnetic induction using process images. In accordance with Hidayah's opinion et al. (2021) who revealed that mastery of physics concepts includes understanding theory, practice, and the ability to transfer information to solve problems and analyze physical phenomena. In this research, theoretical and practical understanding is obtained through discussions and practice questions, while the ability to transfer information is developed through presentations.

Results posttest reinforced by the learning implementation questionnaire, three observers assessed the learning implementation in the good to very good category. Questionnaire data shows that learning through group discussions goes well because students play an active role in discussions, are able to analyze and solve problems, and get enough time for discussions. Apart from that, the questionnaire also supports that learning takes place independently with adequate time allocation, so that learning objectives can be achieved well. So, referring to the results of data analysis using statistical tests via Mann-Whitney U Test (2-tailed) and Mann-Whitney U Test (1-tailed), it can be concluded that the electromagnetic induction module based on process images has a significant effect on high school students' mastery of physics concepts.

On the other hand, through statistical tests it was found that the process image-based electromagnetic induction module did not have a significant influence on students' physics critical thinking skills. These findings are different from the results of previous research, namely by Khoirunnisa et al. (2021), which shows that process image-based student worksheets have a significant effect on critical thinking skills. This difference indicates that even though it is based on process images, the effectiveness of media in training critical thinking skills depends on the characteristics and methods of its use in learning. The process image-based electromagnetic induction module is designed with indicators of critical thinking skills according to Facione (2015), including interpretation, analysis, evaluation, inference, explanation, and self-regulation. These six indicators are provided in discussion activities.

One possible reason for the lack of significant improvement is that the module's activities may not have included sufficiently explicit prompts to guide students in critically evaluating ideas or arguments. While students engaged in solving problems, they may not have been adequately encouraged to question assumptions, challenge reasoning, or reflect on their own thought processes. Future refinement of the module could include structured critical thinking tasks, such as guided peer feedback, argument evaluation exercises, or self-reflection checklists.

The absence of a significant influence on critical thinking skills is caused by several factors in the implementation of learning. One of the main weaknesses is the lack of students' ability to criticize errors that appear when presenting the results of other group discussions. Even though students are able to solve problems in discussions, students still have difficulty providing critical responses to other groups' answers. This may be explained by the theory of cognitive load, where students' working memory is already heavily occupied with understanding complex visual concepts, leaving limited capacity for higher-order thinking such as analysis and inference. Integrating critical thinking gradually and explicitly may help students process both content and thought processes more effectively.

The second weakness can be assessed based on the analysis of each indicator of critical thinking skills. The graph in Figure 3 shows that the experimental class has a higher average posttest score on four indicators, namely interpretation, evaluation, explanation, and self-regulation, while the control class has a higher average posttest score on two indicators, namely analysis and inference. This module has a positive impact on interpretation, evaluation, explanation, and self-regulation indicators. However, on the analysis and inference indicators, students still experience errors in solving problems. Further qualitative observation also showed that students often relied on surface-level reasoning and lacked depth when explaining their answers during class presentations. A more detailed comparison between observer ratings and test results could provide insight into whether active participation or engagement level corresponded with performance outcomes.

Therefore, this module needs to be refined to be more effective in building critical thinking skills, especially on analysis and inference indicators. Thus, based on the results of data analysis with statistical tests in the form of the Mann-Whitney U Test (2-tailed), it can be concluded that the electromagnetic induction module based on process images does not have a significant effect on high school students' physics critical thinking skills.

4. CONCLUSION

The conclusion obtained from this research is based on the results and discussion, namely that the process image-based electromagnetic induction module has a significant effect on high school students' mastery of physics concepts, and the process image-based electromagnetic induction module has no significant effect on high school students' physics critical thinking skills. Based on the results of research and discussion, research suggestions that can be given are that further research can focus on improving modules and implementing learning so that it is more optimal in developing all indicators of critical thinking, especially on indicators analysis and inference which in this study has not shown a significant effect.

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