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Analysis of Students' Critical Thinking Skills on the Topic of Electromagnetic Induction

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Abstract: Electromagnetic induction is one of the physics topics that is considered difficult. Research shows that students' critical thinking skills on this topic are weak. This study aims to determine the profile of high school students' critical thinking skills on this topic. The research method used is non-experimental quantitative descriptive research with a descriptive research form. Data were collected using essay test. The research sample was 22 students in 12th grade who had studied the topic of electromagnetic induction in one of the high schools in East Java, Indonesia. The sampling technique used is convenience sampling. The instrument used is in the form of a test named electromagnetic induction critical thinking skills instrument. Data were analysed using descriptive statistics. The results of the study showed that students' critical thinking skills are relatively low. Therefore, in learning, methods, models, and media are needed to help students improve their critical thinking skills.

Keywords: Critical thinking skills; Electromagnetic induction

Introduction

Physics studies many phenomena, one of which is electromagnetic phenomena. The laws of electricity and magnetism play a central role in the operation of devices such as radios, televisions, electric motors, computers, high-energy accelerators, and other electronic devices (Serway & Jewett, 2004). Seeing how many technologies in everyday life use the principle of electromagnetic induction, students must have a strong understanding of this topic, so that it is easier to utilize the technology around them. However, research shows that Electromagnetism and Electricity are one of the most difficult Physics chapters to learn (Yusuf et al., 2021). It was found that students still have difficulty understanding the concept of electromagnetic induction (Cahyaningrum & Hidayat, 2018). This can happen because the Electromagnetic Induction material is abstract. Electromagnetic Induction material cannot be seen directly by the eye and is difficult for students to imagine (Maghfiroh & Sucahyo, 2018). In addition to the influence of abstract material characteristics, research shows that students' ability to understand physics concepts related to their critical thinking skills (Lalang & Ibnu, 2017; Tanti et al., 2020). That means the problem of students' lack of conceptual understanding of electromagnetic induction topic can be related to the level of students' thinking skills which is not yet good. Based on this, it can be said that students' critical thinking skills need to be improved.

Critical thinking skills have been applied in learning environments to address students' challenges in the 21st century (Putra et al., 2021). Physics learning in schools is expected to not only refer to students' cognitive abilities but also students with critical and creative thinking skills, communication, and collaboration so that students can make decisions in solving physical problems in everyday life appropriately (Kartika et al., 2019). Critical thinking is an essential skill for enables student to analyze and evaluate complex scientific concepts and problems effectively. That's why

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critical thinking skills are important and needed in Physics including the topic of electromagnetic induction.

Previous research shows that critical thinking skills in several physics topics are still low (Usmeldi et al., 2017; Priyadi et al., 2018; Herliandry et al., 2018; Zain & Jumadi, 2018; Saputra et al., 2019; Risdianto et al., 2020). Students' critical thinking skills on the topic of electromagnetic induction are also still low (Yunita & Ilyas, 2019; Yakob et al., 2020; Wiyono et al., 2020). Efforts to improve students' critical thinking skills have been made (Saputra et al., 2019; Sumardiana et al., 2019; Gunawan et al., 2019; Agustina et al., 2020; Rapi et al., 2022; Indawati et al., 2023).

From several existing studies related to Electromagnetic Induction, efforts to improve critical thinking have been carried out using props or media based learning (Yunita & Ilyas, 2019; Yakob et al., 2020; Wiyono et al., 2020). Due to the abstract nature of the topic of electromagnetic induction, the use of media such as virtual simulation media will be very helpful in facilitating understanding of the phenomenon of electromagnetic induction. Virtual simulation media (VSM) is usually done with the aim of making visual modeling more real and realistic (Darman et al., 2019). Virtual simulations in physics learning provide students with the opportunity to investigate phenomena that are difficult to experience in the classroom or laboratory (Wibowo et al., 2016).

But still, this type of learning is not optimal because it only refers to learning media that is applied without a proper learning model or approach. The weakness of previous research is that the results of improving critical thinking skills are still at a medium level and the improvement between the control and experimental classes is not much different. Learning models must be integrated with the right approach so that they can improve students' critical thinking skills (Usmeldi et al., 2017). Based on the previous research mentioned, the method that are considered effective in improving students' critical thinking skills are the Project Based Learning model and the STEM (Science, Technology, Engineering, and Mathematics) approach. Although the application of PjBL-STEM learning on the topic of electromagnetic induction is still very rare, STEM-Project Based Learning (PjBL) is considered the most suitable to be applied in electromagnetic induction learning because of the characteristics of previous research topics are similar to electromagnetic induction (Parno et al., 2022; Sumardiana et al., 2019; Taufiq et al., 2020).

STEM PjBL is based on the theoretical background of constructivism where students engage in diverse components of problem solving, interdisciplinary curriculum, open-ended questions, hands-on activities, group work, and interactive group activities (Han et al., 2015). The advantages of integrating STEM learning with Project Based Learning include: 1) transferring knowledge and skills to real-world problems, 2) increasing learning motivation, and 3) increasing science and mathematics scores (Laboy-Rush, 2011). Study also show that integrating STEM learning with virtual simulation media is also considered effective for improving students' critical thinking skills (Parno et al., 2021). Based on what has been explained, by integrating STEM-Project Based Learning with Virtual Simulation Media and applying it to learning the topic of electromagnetic induction, it is expected to be able to cover the shortcomings of previous research related to improving critical thinking skills which are still not optimal because they only apply virtual simulation media in learning activities. The application of PjBL-STEM with virtual media simulation is still rarely used to build students' critical thinking skills in electromagnetic induction topic. In addition, most research related to critical thinking skills refers to the Ennis framework, and there is still very little research that discusses students' critical thinking skills, especially on electromagnetic induction topic that refers to the measurement of critical thinking in physics developed by Tiruneh (2017).

Analysis of students' critical thinking skills is very necessary to find out what difficulties students experience in electromagnetic induction material. The results of this analysis can be used as a consideration in developing a method of implementing PjBL-STEM with virtual simulation media to build students' critical thinking skills in electromagnetic induction topic so that students' critical thinking skills can achieve maximum results. Several studies have been conducted to analyze students' critical thinking skills such as on the topics of ocean wave energy, sound and light waves, electricity and magnetism, static fluids, impulse and momentum, Newton's laws of motion, and others (Satriawan et al., 2020; Suganda et al., 2022; Furqon et al., 2023; Puspita et al., 2017; Ariani, 2020; Priyadi et al., 2018). It seems that the research on identifying students' critical thinking skills on the topic of electromagnetic induction is still rarely conducted. Based on the explanation, this study aims to determine the profile of high school students' critical thinking skills on electromagnetic induction topic.

Method

The research method used in this study is no experimental quantitative research. The form of research is descriptive research. The purpose of descriptive research is to provide an accurate description or picture of the status or characteristics of a situation or phenomenon (Burke, 2014). The research sample was 22 students in 12th grade who had studied the topic of electromagnetic induction in one of the high schools in East Java, Indonesia. The sampling technique in this study is convenience sampling. In convenience sampling, researchers choose participants because they are willing to be studied (Cohen, 2018).

The instrument used is in the form of a test named electromagnetic induction critical thinking skills instrument. The instrument consists of 8 essay questions that cover 5 indicators of critical thinking skills based on (Tiruneh et al., 2017) , namely 1) reasoning, 2) hypothesis testing, 3) argument analysis, 4) likelihood and uncertainty analysis, 5) problem solving and decision making. The instrument also covers 4 subtopics of electromagnetic induction namely, 1) the concept of electromagnetic induction, 2) induced voltage (emf), 3) inductance, and 4) transformer and generator. The validity of the instrument has been carried out and the instrument is declared valid and reliable.

Students will take a critical thinking skills test after learned about electromagnetic induction. The data obtained in this study are in the form of answers in the form of descriptions which are then converted into scores on a scale of 0-100 using the following equation.

$$Score = \frac{Total\ score\ gained}{Maximum\ score} \times 100 \quad (1)$$

Data analysis was carried out using descriptive statistics: mean, maximum and minimum. Data were analyzed by using SPSS and Ms Excel software. The same analysis was also carried out based on each sub-topic of the material and each item of the student's critical thinking skills indicator. Based on overall score, score for each indicator and score for each subtopic, the level of students' critical thinking abilities will then be analyzed. The level of critical thinking skills shown in Table 1 (Satriawan et al., 2020).

Table 1. Level of Critical Thinking Skills

Student Score	Level of Critical Thinking Skills
$80 < score \leq 100$	Superior
$60 < score \leq 80$	Above Average
$40 < score \leq 60$	Average
$20 < score \leq 40$	Below Average
$0 < score \leq 20$	Poor

Result and Discussion

Descriptive data of critical thinking skills are presented in Table 2. Based on the results of the critical thinking skills test that has been done by 22 students, the average score of students' critical thinking skills is 46.3 which means the level of students' critical thinking skills is in average level. This shows that the students' critical thinking skills are in the low category.

Table 2. Critical Thinking Skills Scores

N	Minimum	Maximum	Mean
22	6.25	75.00	46.31

There are 4 sub-topics of electromagnetic induction material, namely: 1) the concept of electromagnetic induction, 2) induced voltage (emf), 3) inductance, and 4) transformer and generator. The average of scores on each sub-topic is presented in Figure 1. Based on the results of the analysis carried out, transformer and generator is the subtopic with the lowest average score which is 27.3 or at below average level. As for the subtopic concept of electromagnetic induction, it is at a level above the average, it has the highest average score which is 70.5.

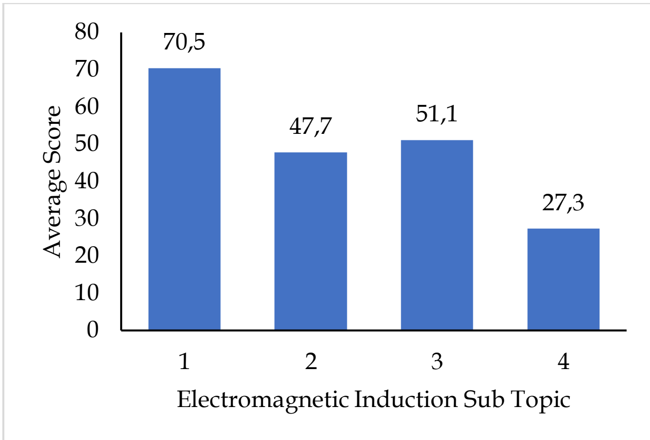


Figure 1. Student's average score for each sub topic

So, it can be concluded that in the electromagnetic induction, students have the difficulty in mastering critical thinking skills on the sub-topic of induced voltage (emf), inductance, transformer and generator and students' critical thinking skills on the three subtopics are in the low category. Students have the most difficulty in solving problems on the transformer and generator sub topics. This is in accordance with the results of previous studies which show that students have difficulty in understanding induced electric field and inductance (Parno et al., 2020), including the concept of emf (Zuza et al., 2016).

Indicator of Critical Thinking Skills

There are five critical thinking indicator which are, 1) reasoning, 2) hypothesis testing, 3) argument analysis, 4) likelihood and uncertainty analysis, 5) problem solving and decision making. Based on the results of the analysis of each indicator or category of critical thinking, the average of the number of correct is obtained, which is presented in Table 3. Based on the results of the analysis of the scores of each critical thinking indicator, it can be seen that students have the lowest average score in the fifth indicator, namely problem solving and decision making, with an average of 27.3. While the highest average score is in the second indicator, namely hypothesis testing, with an average score of 84.1. Based on these results, students have difficulty in the last 3 indicators

Table 3. Critical Thinking Skills Scores for Each Indicator

Indicator	Average Score	Level of Critical Thinking Skills
Reasoning	70.45	Above Average
Hypothesis testing	84.09	Superior
Argument analysis	48.86	Average
Likelihood and uncertainty analysis	31.82	Below Average
Problem-solving and decision-making	27.27	Below Average

To facilitate further analysis, students were then grouped into 2 groups. Group 1 is a group of students who can answer 60% of the critical thinking skills questions in each indicator (above average and superior level). While group 2 are a group of students who have not yet been able to reach 60% in each indicator (average, below average and poor level). The grouping is obtained as in the following graph in Figure 2.

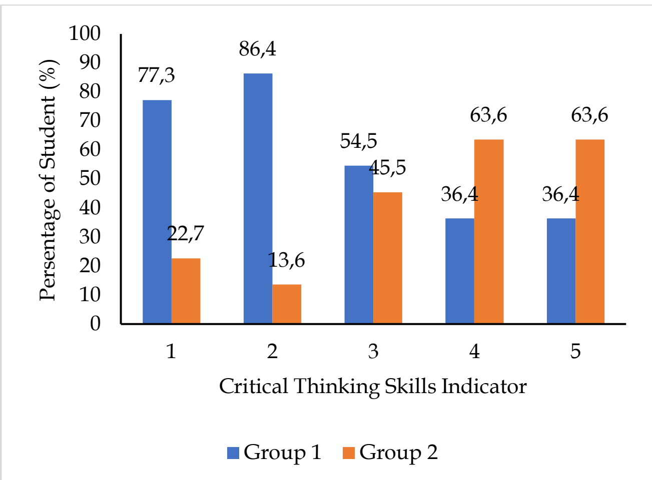
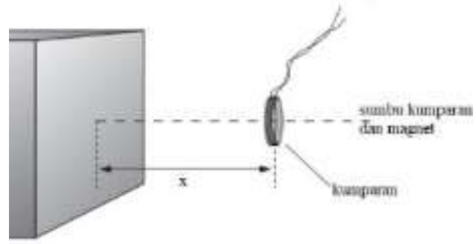


Figure 2. Percentage of student groups on each critical thinking indicator

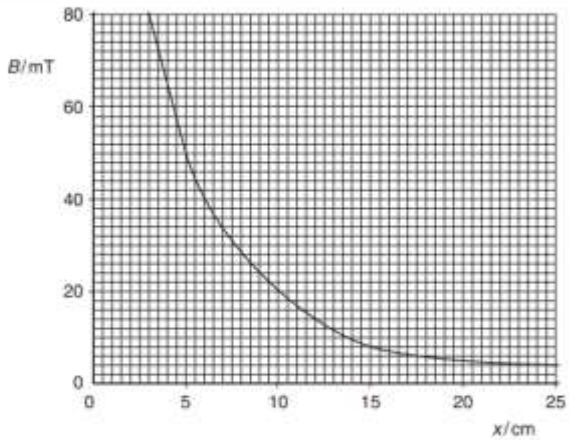
Based on the graph, it can be seen that in indicators 1 and 2, the number of students who are above average is more than students who are at the average level down. In indicator 3 it is not much different, and in indicators 4 and 5 the number of students who are at the average level down is more than the number of students who are at the level above average. The following is an example of the difference in answers between the groups for each indicator of critical thinking skills can be seen in Table 4 until Table 13.

Table 4. Reasoning Question

Reasoning Question
A small coil is positioned so that its axis lies along the axis of a large bar magnet, as shown in the figure below



The coil has a cross-sectional area of 0.40 cm^2 and has 150 turns of wire. The average magnetic induction (B) through the coil varies with the distance x between the surface of the magnet and the plane of the coil as shown in the graph below



a. Where does the circuit have the largest magnetic flux value? Explain!
b. Determine the magnitude of the magnetic flux!

Table 5. Sample of Student's Answer in Reasoning Question

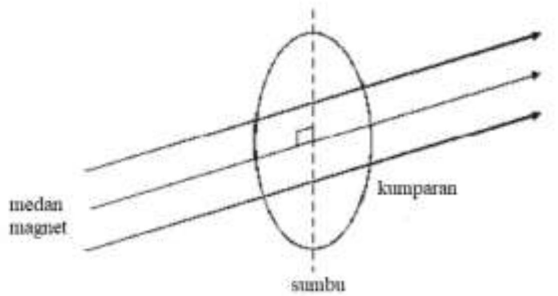
Group 1 answer	Group 2 answer
When the coil and magnet are at their closest distance, the greater the magnetic induction, so the flux is greater, X= 3 cm $\Phi = NBA$ $\Phi = 150 \times 0{,}08 \times 0{,}00004$ $\Phi = 0.00048\ Wb$	X= 3 cm $\Phi = BA$ $\Phi = 80 \times 0{,}00004$ $\Phi = 0.0032\ Wb$

In the reasoning indicator, the number of students at the superior level is 4.5%, at the above average level is 72.7%, at the average level is 22.7%, and at the below average and poor levels is 0%. The expected outcome of this indicator is that students can interpret the results of an experiment (Tiruneh et al., 2018). It can be concluded that students do not experience much difficulty to read the data of experiment and interpret it. Students in the average level usually did not explain the data interpretation in detail and used the wrong formula, which caused the student to not get the maximum score.

Table 6. Hypothesis Testing Question

Hypothesis Testing Question

A circular coil of diameter 140 mm has 850 turns. The coil is placed so that its plane is perpendicular to a magnetic field of 45 mT, as shown in the figure



The coil is rotated by 90° about the vertical axis in 120 ms. Which of the following statements is correct? Explain!

a. The magnitude of the induced EMF produced is 4.9 Volts
b. If the coil is rotated 180° from its initial position, the magnitude of the induced EMF produced is 9.8 Volts

Table 7. Sample of Student's Answer in Hypothesis Testing Question

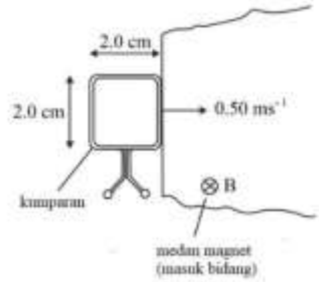
Group 1 answer	Group 2 answer
a. Correct $\varepsilon = \frac{\Delta\Phi}{\Delta t} = \frac{\Delta(\text{NBA}\cos\theta)}{\Delta t}$ $\varepsilon = 4.9\ V$	a. Wrong $\varepsilon = \frac{\text{NBA}\cos 90}{\Delta t}$ $\varepsilon = 0\ V$
b. Correct $\varepsilon = \frac{\Delta\Phi}{\Delta t} = \frac{\Delta(\text{NBA}\cos\theta)}{\Delta t}$ $\varepsilon = 9{,}8\ V$ (The amount of magnetic flux that cut by the coil is twice greater)	b. Wrong $\varepsilon = \frac{(\text{NBA}\cos 180)}{\Delta t}$ $\varepsilon = 9\ V$

In the hypothesis testing indicator, the number of students at the superior level is 63.6%, at the above average level is 22.7%, at the average, below average and poor levels is 4.5%. The outcome of this indicator is to identify important relationships (cause and effect) (Tiruneh et al., 2018). Almost the same as the reasoning indicator, it can be concluded that students do not experience much difficulty in this indicator. Students in group 2 have difficulty understanding the concept of cause and effect relationships between variables in this magnetic induction topic, resulting in errors when using formulas.

Table 8. Argument Analysis Question

Argument Analysis Question

This diagram shows a square coil entering a uniform magnetic field area with a magnetic induction of 0.30 T. The coil has 150 turns and each side is 2.0 cm long. The coil moves at a constant speed of 0.50 m s^{-1}



Consider the following statements:

a. The magnitude of the induced emf passing through the coil is 0.45 V. If the number of turns on the coil is reduced to 100, then the emf value becomes 0.6 V because the induced emf is inversely proportional to the number of turns
b. If the motion of the coil is increased to 2 times (shorter time), then the value of the induced emf will be 2 times the original, this is because time has an inverse relationship with the induced emf

Prove the truth of the statement above!

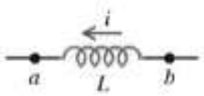
Table 9. Sample of Student's Answer in Argument Analysis Question

Group 1 answer	Group 2 answer
a. Shown that the emf = 0.45 V. The statement is wrong The emf generated when N=150 is correct, but when N=100 the emf value is wrong. The emf is proportional to the number of turns. So, the statement that the emf is inversely proportional to the number of turns is wrong.	a. The statement is wrong $\frac{\varepsilon_1}{\varepsilon_2} = \frac{N_1}{N_2}$
b. The statement is correct. Based on the formula, when the time is shorter, the speed is greater. Speed is directly proportional to emf. So the emf is greater. That means time inversely proportional to emf	b. The period is halved.

In the argument analysis indicator, the number of students at the superior level is 9.1%, at the above average level is 45.5%, at the average level is 13.6%, at the below average level is 4.5 % and poor level is 27.3%. The outcomes of this indicator are identify key parts of an argument (e.g. given a conclusion, identify the reason(s) that support the conclusion) and infer a correct statement (Tiruneh et al., 2018). In this indicator, the number of students in the group 1 is almost the same as the number of students in group 2. However, based on the average results, it is known that students still experience difficulties in this indicator. Students in the group 2 category have difficulty identifying and proving whether the arguments or statements given are true or not. Student have difficulty identifying reasons that support their conclusion. This happens because students still have difficulty understanding the relationship between variables.

Table 10. Likelihood and Uncertainty Analysis Question

Likelihood and Uncertainty Analysis Question
The inductor in the figure below has an inductance of 0.260 H and carries a current as indicated by the arrow. The current decreases at a uniform rate of -0.0180 A/s.



a. Find the self-induced emf and determine which point of the inductor, a or b, has the higher potential!
b. If the current at t = 0 is 12.0 A, what is the current at t = 2.00 s? Is it higher or lower?

Table 11. Sample of Student's Answer in Likelihood and Uncertainty Analysis Question

Group 1 answer	Group 2 answer
a. Find the emf $\varepsilon = L\frac{\Delta I}{\Delta t}$ $\varepsilon = 0{,}047\ V$ point b has a higher potential because the current flows from point b to point a (because the current decreases, the direction of induction is in the same direction as the current) b. I = 12 – (2x0.018) I=11,96 A Its lower because its decreasing	a. Find the emf $\varepsilon = L\frac{\Delta I}{\Delta t}$ $\varepsilon = 14.4\ V$ b. I =2x12 =24 A .

In the likelihood and uncertainty analysis indicator, the number of students at the superior level is 4.5%, at the above average level is 31.8%, at the average level is 4.5%, at the below average level is 13.6% and poor level is 45.4%. The outcome of this indicator is understand the probability and likelihood of an event occurrence or make valid predictions (what-if questions) (Tiruneh et al., 2018). It can be seen that there are still many students who have difficulty in solving questions related to the likelihood and uncertainty analysis indicator. Students in the group 2 have difficulty in predicting what might happen in a given situation. It can be seen that students have difficulty determining the variables and equations used to solve the question.

Table 12. Problem Solving and Decision-Making Question

Problem Solving and Decision-Making Question
You are planning to take your hair dryer to Europe, where the electrical sockets are 240 V instead of the 120 V you have back home. The dryer produces 1600 W of power at 120 V. a. What can you do to operate your dryer at 240 V in Europe? Explain! b. How much current will your dryer draw at that voltage in Europe? Do you think this set up is safe to use?

Table 13. Sample of Student's Answer in Problem Solving and Decision Making Question

Group 1 answer	Group 2 answer
a. Using an adaptor or step-down transformer to lower the voltage from the source. The ratio of the number of primary and secondary coil is 2:1 b. The amount of current $P_1 = P_2$ $V_1 I_1 = V_2 I_2$ $1600 = 240\ I_2$ $I_2 = 6.7\ A$ Yes, as long as we use it in proper way.	a. Using transformer b. The amount of current $V_1 I_1 = V_2 I_2$ $1600 = 120\ I_2$ $I_2 = 13.3\ A$

In the problem solving and decision-making indicators, the number of students at the superior level is 0%, at the above average level is 36.4%, at the average level is 4.5%, at the below average level is 4.5% and poor level is 54.5%. The outcomes of this indicator are identify the best option from a number of alternatives in solving everyday problems and examine the relevance of the procedures in solving problems (Tiruneh et al., 2018). Almost the same as the likelihood and uncertainty analysis indicator, it can be seen that there are still many students who have difficulty or are included in the group 2 in solving the problem solving and decision-making indicator questions. Students have difficulty in determining the best solutions to the problems given, as well as clearly explain the relevance of the procedures in solving problems.

Based on the analysis of the result, it can be conclude that student is most likely expert in reasoning and hypothesis testing. The average score obtained by students in this indicator is the highest and the number of students in the above average category is more than students in the below average category. In previous research, category that has the highest score is different in each study. The first study showed that most students mastered the argument analysis category (Satriawan et al., 2020). Another study, showed that the largest increase in score was in the reasoning category (Parno et al., 2022), in this study these category is the second highest. The last, study showed that the highest student score was in the hypothesis testing category (Furqon et al., 2023), which is the highest based on this research result.

Previous research have also found that students' difficulties differed in each critical thinking category or indicator. As in the first study, students had the lowest score increase in category 2, namely hypothesis testing and category 4 likelihood and uncertainty analysis (Parno et al., 2022). In other study, students experienced difficulties in the likelihood and uncertainty analysis and hypothesis testing (Satriawan et al., 2020). Students also experienced difficulties in the reasoning and likelihood and uncertainty analysis categories (Furqon et al., 2023). The results of this study have similarities with the first study mentioned, this study found that likelihood and uncertainty analysis and problem solving and decision making are the most difficult categories for students. However, most previous studies stated that the likelihood and uncertainty analysis indicator is one of the difficult categories. In this study, this indicator is the second indicator after problem solving and decision making that has low average score. The number of students in the average to lower category (group 2) in the likelihood and uncertainty analysis indicator is the same as the number of students in the problem solving and decision-making indicator.

Although 2 indicators show that the level of students' critical thinking skills is quite good, 3 other indicators show much different results, which are included in the low category. This makes the overall result of students' critical thinking skills on this topic still low. Based on the analysis, the low critical thinking skills of students are caused by several things such as, the students have not yet mastered the indicators of critical thinking skills, and characteristics of the topic of electromagnetic induction which is abstract and considered difficult. Due to the abstract nature of the topic of electromagnetic induction, learning is needed that can describe the abstract phenomenon of electromagnetic induction to be more real and realistic, one of which is with virtual simulation media (Darman et al., 2019).

However, learning will not be optimal if we only use learning media without the right model and approach. Another factor that influences the low critical thinking skills of students is learning process. Based on the results of observations, the learning carried out is conventional learning which is less suitable to support the development of students' critical thinking skills. Critical thinking refers to the ability to analyze information, to determine the relevance of the information collected and then interpret it in solving problems. It requires high-level thinking; it involves the processes of analysis, evaluation, reasoning, and reflection. (Jeevanantham, 2005). Learning with the right approach and model needed to improve students' critical thinking skills (Usmeldi et al., 2017). The model that is considered effective for improving critical thinking skills on the topic of electromagnetic induction is STEM-PjBL (Parno et al., 2022; Sumardiana et al., 2019; Taufiq et al., 2020). STEM PjBL is based on the theoretical background of constructivism where students engage in diverse components of problem solving, interdisciplinary curriculum, open-ended questions, hands-on activities, group work, and interactive group activities (Han et al., 2015). Study also show that integrating STEM learning with virtual simulation media is also considered effective for improving students' critical thinking skills (Parno et al., 2021).

Conclusion

Based on the results and discussion, it can be said that students' critical thinking skills on the topic of electromagnetic induction are relatively low. Students' critical thinking skills score were lowest on the transformer and generator subtopic. Students have difficulty in several critical thinking indicators including argument analysis, likelihood and uncertainty analysis, problem solving and decision making. The low level of students' critical thinking skills is caused by students' lack of mastery of the topic of electromagnetic induction and learning activities that do not support the development of students' critical thinking skills. Therefore, in learning, methods, models, and media are needed to help students train and improve their critical thinking skills. Learning that is considered effective for improving critical thinking skills on the topic of electromagnetic induction is STEM-Project Based Learning which is integrated with virtual simulation media.

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Author Contributions

Conceptualization, N. F., P., N. M., N. D. N. ; methodology, N. F., P., N. M., N. D. N.; validation, P. and N. M.; formal analysis, N. F.; investigation, N. F.; resources, P., N. M., N. D. N.; data curation, N. F.; writing—original draft preparation, N. F.; writing—review and editing, N. F., P., N. M.; supervision, P., N. M., N. D. N. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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