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Analyzing Critical Thinking Skills of Physics Preservice Teachers on Electricity and Magnetism

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Abstract: The primary objective of education is to equip students with the necessary skills and knowledge to effectively engage in their chosen professions and make meaningful contributions to their respective communities. One of the skills needed is critical thinking skills. The mastery of critical thinking skills is deemed essential for preservice physics teachers in the 21st century. This study aims to analyze the critical thinking skills of preservice physics teacher on electricity and magnetism. The research involved 38 preservice physics teacher students at one of the LPTK's in Indonesia. The research method applied is descriptive quantitative. The research instrument used was a description test, namely the Critical Thinking Skills in Electricity and Magnetism (CTEM). Test yang didiadopsi dari Tiruneh et al. (2017). The results showed that the critical thinking skills of physics teacher candidates were low. Efforts are needed to improve critical thinking skills through methods, models, media, and other interventions in learning.

Keywords: Critical thinking skills; Electricity; Magnetism; Physics; Preservice teachers

Introduction

The ultimate goal of education is to prepare students to become professional workers and contribute to their communities, which has become one of the greatest challenges of this century (Sinaga et al., 2022). Therefore, the government, especially the Ministry of Education and Culture, has made various efforts to meet this challenge through various educational policies, especially in relation to the skills that graduates of educational institutions must possess. Based on Permendikbud No. 3 of 2020 on National Higher Education Standards, it is known that one of the skills required of undergraduate graduates is the ability to apply logical, critical, systematic and innovative thinking in the context of developing or implementing science and technology under Consideration and application of the values of the humanities through his field. Additionally, Presidential Decree No. 8 of 2012 on the Indonesian National Qualifications Framework (INQF) stipulates that bachelor's graduates must have at least a level 6 qualification. The field of knowledge in depth, able to formulate solutions to problems and make the right decisions based on information and data analysis.

In the field of skills, graduates of the undergraduate physics didactics program are expected to be able to analyze and solve problems of the physics learning process and to carry out the physics teaching of the intermediate level with a scientific approach based on the characteristics of physics teaching material and student characteristics to be able to develop thinking skills and scientific attitudes. These different legal bases indicate that there are both requirements and hopes for physics education students to have, apply, and develop thinking skills, particularly critical thinking and problem-solving skills, as well as mastery of theoretical concepts in their subject area of knowledge covering the areas education and physics in the context of science and technology. Critical thinking and problem-solving skills as well as pedagogical and physical knowledge must be mastered by preservice physics teachers in the exercise

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of their profession as educators of physics education students.

Critical thinking is an essential skill for physics preservice teachers as it enables them to analyze and evaluate complex scientific concepts and problems effectively. Critical thinking skills, which involve analyzing, evaluating, arguing, and deep reflection, encourage reflection before decisions are made (Thorndahl & Stentoft, 2020). This critical thinking ability is also a reflective activity that guides a person to action (Bezanilla et al., 2019). Critical thinking skills will encourage someone to see events from different perspectives and dimensions, to be open to change and innovation, to examine things through thinking without prejudice, to think openly, to pay attention to details and to think before acting (Bergili, 2015). Therefore, these critical thinking skills combined with the pedagogical competence of physics teachers will help in the analysis of student characteristics, student difficulties and student learning outcomes, which are taken into account in the development of tools and instruments in the learning process and learning assessment. Combined with the professional competence of physics teachers, these critical thinking skills help in the analysis of concepts, laws, theories, experimental data and physical phenomena in life, as well as in qualitative and quantitative reasoning on the processes and laws of physics.

To understand the importance of critical thinking in physics education, numerous studies have explored the relationship between teaching approaches, learning models, and the development of critical thinking skills. For instance, Batlolona et al. (2019) investigated creative thinking skills in physics, while Bigozzi et al. (2018) examined the influence of teaching approaches on conceptual learning in physics. These studies demonstrate the significance of instructional methods in fostering critical thinking skills.

Moreover, the impact of STEM (Science, Technology, Engineering, and Mathematics) education approaches on critical thinking skills has been investigated in the context of blended learning (Ardianti et al., 2020), guided inquiry (Gunawan et al., 2019), and project-based learning (Oyewo et al., 2022). These studies shed light on effective pedagogical strategies that can enhance critical thinking abilities in physics education.

Assessing critical thinking skills in physics education has been the focus of research using various methodologies, including computerized adaptive tests (Abidin et al., 2019), interactive multimedia learning materials (Djamas et al., 2018), and e-modules (Desnita et al., 2022). These assessment tools provide insights into the specific areas of critical thinking that need improvement among preservice teachers.

Furthermore, the influence of factors such as cognitive styles (Verawati et al., 2019) and teaching clarity (Saputro et al., 2022) on critical thinking skills has been examined. Understanding these factors can inform the development of targeted interventions and instructional strategies that support the enhancement of critical thinking abilities in physics preservice teachers.

Numerous studies have explored the development of critical thinking skills in physics education. For instance, Azizmalayeri et al. (2012) investigated the development of critical thinking skills in physics and sociology curricula, highlighting the importance of integrating critical thinking into subject-specific contexts. Similarly, Galih (2019) focused on the development of critical thinking ability in high school students by using analogy content in physics learning. These studies provide a foundation for understanding the significance of critical thinking in physics education.

Various studies have been conducted to provide an overview of the critical thinking skills of physics teacher candidates (Dholo et al., 2019; Wulandari et al., 2021; Yusal et al., 2021). These studies present statistical profiles of physics teachers in terms of critical thinking skills, but have not explained them descriptively or qualitatively. Additionally, these studies have not discussed critical thinking skills related to electricity and magnetism. Therefore, this study aims to statistically and descriptively analyze the profile of critical thinking skills of preservice physics teacher trainees on the material electricity and magnetism in order to get a good picture.

This research holds the potential to enhance critical thinking abilities and advance the acquisition of knowledge in the field of physics. The present study aims to facilitate the enhancement of critical thinking abilities among preservice physics teachers. The development of critical thinking skills entails a comprehensive examination, assessment, persuasive discourse, and introspection. Through an examination of the critical thinking aptitude of potential physics teachers in the context of electricity and magnetism subject matter, this study aims to offer valuable perspectives on their critical faculties and aid in the development of suitable pedagogical approaches. This study aims to provide valuable insights into enhancing the learning of physics by examining the critical thinking skills profile of potential physics teachers in relation to electricity and magnetism topics. Upon analyzing the critical thinking skills profile, it is possible to identify the specific areas that require improvement in the context of physics education. This, in turn, enables the development of more efficient learning strategies.

Method

Research Methods and Participants

In this study, researchers used a descriptive quantitative method. The research was conducted on 38 physics teachers at one of the LPTK in Indonesia, selected by a targeted sampling technique. The student completed the Electricity and Magnetism course in the 2021/2022 academic year.

Collection of Data and Instruments

To profile the physics teacher candidates' critical thinking skills, the researchers adopted the descriptive test from Tiruneh et al. (2017). Critical Thinking Skills in Electricity and Magnetism (CTEM) Test. The accepted test consists of ten descriptive questions covering five indicators of critical thinking ability, namely 1) reasoning, 2) reasoning as a hypothesis test, 3) argument analysis, 4) probability and uncertainty analysis, and 5) problem solving and decision making. The test covers basic concepts in electricity and magnetism.

Data Analysis

The data obtained in this study were in the form of physics preservice teachers' answers in the form of descriptions which were then converted into scores on a scale of 0-100 using the following equation.

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

The data is then analyzed with descriptive statistics: average, mode, maximum and minimum. The data are classified based on the five aspects of critical thinking skills (Tiruneh et al., 2017) and the level of critical thinking skills by Abdulah et al. (2021) as shown in Table 1.

Table 1. Level of Critical Thinking Skills

Student Score	Level of Critical Thinking Skills
$80 < score \leq 100$	Excellent
$60 < score \leq 80$	Good
$40 < score \leq 60$	Fair
$20 < score \leq 40$	Poor
$0 < score \leq 20$	Very Poor

Result and Discussion

Aspects of Critical Thinking Skills

Based on test scores using the CTEM test and based on critical thinking test scores, the average overall score of physics preservice teachers for critical thinking skills is 26.5 on a scale of 0 to 100, placing them in the category "Poor" or "Low" are classified. Of the five indicators, one indicator falls into the very low category, namely reasoning; three indicators are included in the low category, namely argument analysis, probability and uncertainty analysis, and problem solving and decision making; and one indicator is included in the middle category, thinking as a hypothesis test. The assessment of each indicator is shown in Figure 1.

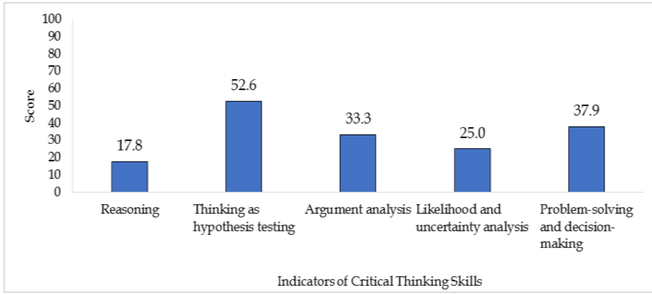


Figure 1. The score of critical thinking skills

The first problem asks respondents to think and determines the resultant Coulomb force that a charge experiences due to discrete and continuous charges around it. This problem shows two positive charges and a positively charged bent rod in an evenly spaced straight line. Then three students commented on the resultant force experienced by the charge at the center. The first problem is shown in Figure 2.

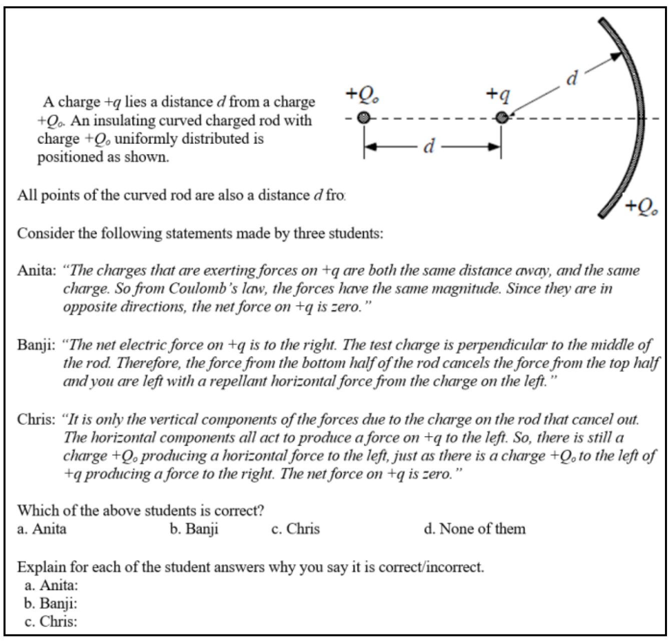


Figure 2. Problem 1

Of the 38 respondents, 20 (52.6%) answered that one of the beginner physics answers was correct. Of the 20 respondents who answered that there is one correct answer, 70% chose Chris and 30% chose Banji. The respondents then explained their reasons for their choice. Respondents who selected Chris as the correct student reasoned that the charge $+Q_0$, the charge +q, and the metal rod charged with $+Q_0$ have the same spacing and charge, so the two forces on the charge +in opposite directions act q are equal, and consequently the net force on the charge +q is zero. Some respondents argued that the +Q-charged bar produced two impacts on the +q-charge with directions crossing, so that the vertical components of the force cancel each other out and the two horizontal components of the force reinforce each other. As a result, the electric force is greater to the right than to the left, so the resulting electric force acts on the charge +q to the right.

Meanwhile, the respondent who selected Banji as the student with the correct answer reasoned that only the vertical component of the force was lost due to the charged rod, but the horizontal component of the force was still there, so the resultant force was on the charge. It shows that most respondents have difficulty arguing correctly the resultant Coulomb force experienced by a charge due to other charges, particularly continuous charges or charged objects. Respondents assume that the Coulomb force between discrete charges and discrete charges, discrete charges and continuous charges is equal when the magnitudes of the three charges and the distance are equal. The Coulomb component of the force on the vertical or horizontal is often neglected and not properly calculated. Figures 3 and 4 show some excerpts of the respondents' answers.

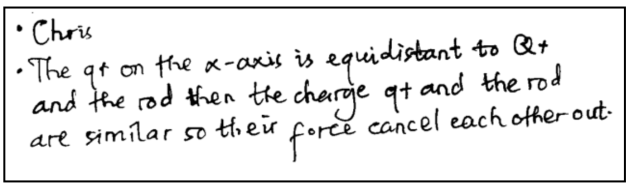

• Chris
• The q+ on the x-axis is equidistant to Q+ and the rod then the charge q+ and the rod are similar so their force cancel each other out.

Figure 3. Respondent's answer to problem 1

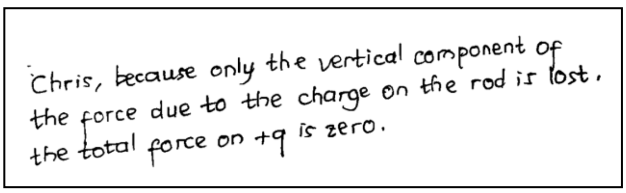

Chris, because only the vertical component of the force due to the charge on the rod is lost. the total force on +q is zero.

Figure 4. Respondent's answer to problem 1

The second problem asked respondents to critique or rate students' opinions and identify the missing relevant information arguments. In this activity, a child performs an electrostatics experiment by bringing a positively charged stick closer to a metal can, and then the can appears to be pulled by a stationary stick. The child argues that the stick attracts the negative electrons while the positively charged nuclei are repelled and the opposing forces cancel each other out, leaving the can stationary. The second problem is shown in Figure 5.

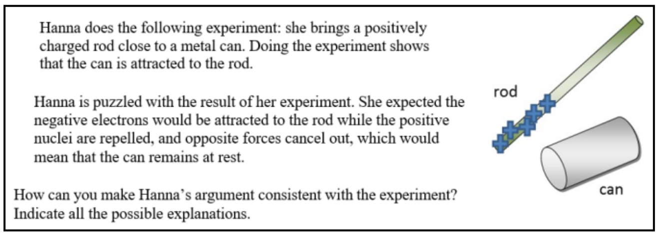


Figure 5. Problem 2

Of the 38 respondents, 28 (73.7%) responded that there is an attractive force between the positive charge of the rod and the electrons of the can and that there is a repulsive force between the positive charge of the rod and the positively charged atomic nucleus of the can that the side of the can, which is closer to the rod becomes negatively charged and the other side becomes positively charged. However, respondents did not generally explain that the distance between charges affects the Coulomb force, resulting in greater attraction than repulsion, so this answer is consistent with experiment. Therefore, in this second problem, the score obtained is still not optimal. An excerpt of the respondent's response is shown in Figure 6.

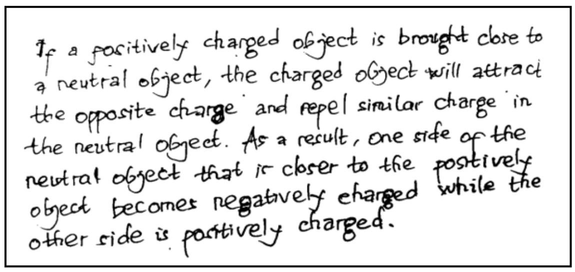

If a positively charged object is brought close to a neutral object, the charged object will attract the opposite charge and repel similar charge in the neutral object. As a result, one side of the neutral object that is closer to the positively object becomes negatively charged while the other side is positively charged.

Figure 6. Respondent's answer to problem 2

The third problem asked respondents to identify and critique the relationship between the two variables using graphical information. In this problem a graph is presented that connects electric force and time. Respondents were then asked whether the graph correctly described the relationship between the electric force and the time variables. The respondent was then asked to explain the answer. The third problem is shown in Figure 7.

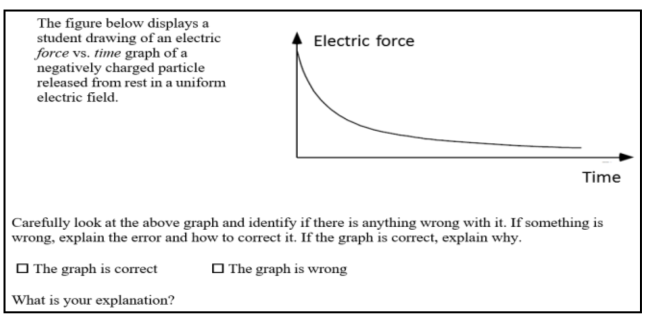


Figure 7. Problem 3

Of the 38 respondents, 30 (78.9%) answered that the graph of the relationship between electric force and distance was wrong, but could not explain exactly why the graph was wrong and what the relationship between electric force and timing should be . They say in general that electric force is not related to time but related to distance. An excerpt of the respondent's response is shown in Figure 8.

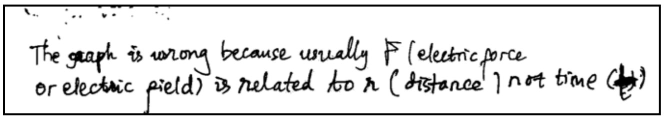
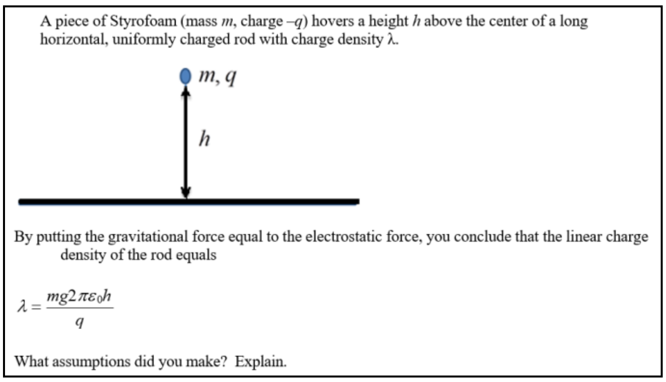

The graph is wrong because usually F (electric force or electric field) is related to r (distance) not time (t)

Figure 8. Respondent's answer to problem 3

The fourth problem asked respondents to identify assumptions. This problem demonstrates that a piece of styrofoam is levitated over the center of a long, evenly charged, horizontal bar with a specific charge density such that the gravitational force equals the electrostatic force. Then respondents were asked to make assumptions based on the figure and the charge density equation. The second problem is shown in Figure 9.


A piece of Styrofoam (mass m, charge $-q$) hovers a height h above the center of a long horizontal, uniformly charged rod with charge density λ.

By putting the gravitational force equal to the electrostatic force, you conclude that the linear charge density of the rod equals

$$\lambda = \frac{mg2\pi\varepsilon_0 h}{q}$$

What assumptions did you make? Explain.

Figure 9. Problem 4

Of the 38 respondents, 26 (68.4%) made no assumptions about components/objects. They generally explain relationships between variables rather than assumptions. It shows that most of them are still struggling to make relevant assumptions. An excerpt of the respondent's response is shown in Figure 10.

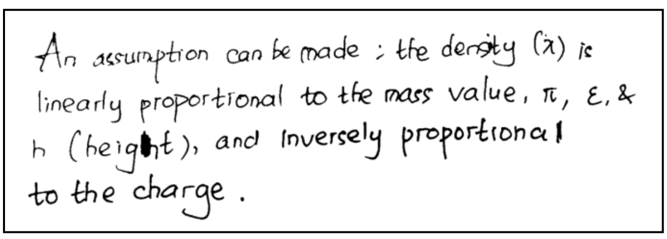
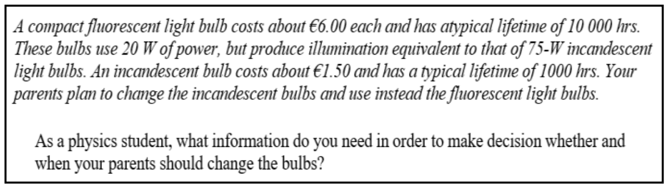

An assumption can be made : the density (λ) is linearly proportional to the mass value, π, ε, & h (height), and inversely proportional to the charge .

Figure 10. Respondent's answer to problem 4

The fifth problem asked respondents to choose a solution to a problem. This problem illustrates that in a house several electrical energy consumptions have a certain duration, power and cost. Then the parents living in the house plan to change the type of light bulb. Next, respondents were asked to identify what information is needed to decide if and when parents should replace the lamp. The second problem is shown in Figure 11.


A compact fluorescent light bulb costs about €6.00 each and has atypical lifetime of 10 000 hrs. These bulbs use 20 W of power, but produce illumination equivalent to that of 75-W incandescent light bulbs. An incandescent bulb costs about €1.50 and has a typical lifetime of 1000 hrs. Your parents plan to change the incandescent bulbs and use instead the fluorescent light bulbs.

As a physics student, what information do you need in order to make decision whether and when your parents should change the bulbs?

Figure 11. Problem 5

Of the 38 respondents, 22 (57.9%) did not directly and correctly state what information is needed to decide if and when parents should replace the lamp. They generally explained that the decision to replace incandescent lamps with fluorescent lamps was correct because they were cheaper in terms of electricity bills, but could not explain when the right time to replace them was. Some replied, but only normatively, replaced when the lamp reached the end of its useful life. It shows that most still have difficulties recognizing the information necessary for decision-making as a solution to the problem. An excerpt of the respondent's response is shown in Figure 12.

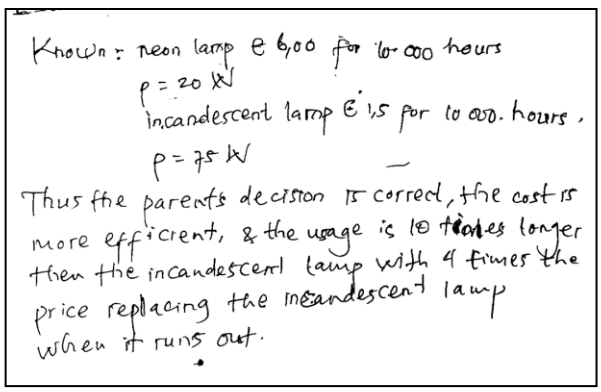

Known : neon lamp € 6,00 for 10.000 hours
P = 20 W
incandescent lamp € 1,5 for 10.000. hours .
P = 75 W
Thus the parents decision is correct, the cost is more efficient, & the usage is 10 times longer then the incandescent lamp with 4 times the price replacing the incandescent lamp when it runs out.

Figure 12. Respondent's answer to problem 5

The results of the Critical Thinking Skills test show that the critical thinking and problem-solving skills of physics student teachers are not yet optimal and need to be improved. Based on analysis of student responses, critical thinking skills are low. Based on the analysis of students' responses, it is known that students face several misunderstandings, namely as follows. First, the shape of a continuously charged object (charge distribution pattern) does not affect the electric field generated at a point. Second, the electrostatic force generated between a discrete charged particle and another discrete charged particle, or between a discrete charged particle and a continuously charged object, is always the same when the charges are the same and the distance is the same. Third, the relationship between the electrostatic force experienced by a charge released from rest in a homogeneous electric field and time is inversely proportional to the square. This is consistent with (Wadana & Maison, 2019) who noted that there were four problems students had related to students' perceptions of solving problems when learning magnetic electricity, namely: 1) Difficulty understanding the material for magnetic electricity, 2) not knowing how to solve problems, 3) difficulty in analyzing concepts, and 4) difficulty in solving problems, accompanied by images. The research results of (Wardana et al., 2021) indicate that most undergraduate students in levels II and III of physics education have a distribution pattern of conceptions on a scale of 1 and 2 with a scale of 0 to 3. This means that most students still cannot answer conceptual questions correctly for all the right reasons. Then most undergraduate physics pedagogy students mostly lack local coherence and local coherence knowledge structures related to concepts in electromagnets. This means that most students still cannot apply various consistent concepts to solve electromagnetic problems. In addition to misunderstandings, students' difficulties in learning about electricity and magnetism material are also related to abstract thinking ability (Mukhopadhyay, 2006), the importance of concepts (Finkelstein, 2005), and the variety of alternative imaginations they have.

Conclusion

The results showed that the critical thinking skills of the physics beginners were still relatively low overall. Therefore, methods, models, media, questions, or other interventions are needed to help students understand concepts, avoid misunderstandings, and train critical thinking skills to improve the conceptual understanding and critical thinking skills of physics beginners improve.

Author Contributions

Conceptualization, M. Furqon; methodology, Parlindungan Sinaga, Liliasari and Lala Septem Riza; software, M. Furqon; validation, Parlindungan Sinaga, Liliasari and Lala Septem Riza; formal analysis, M. Furqon; investigation, M. Furqon; resources, Parlindungan Sinaga, Liliasari and Lala Septem Riza; data curation, M. Furqon; writing—original draft preparation, M. Furqon; writing—review and editing, M. Furqon; visualization, M. Furqon; supervision, Parlindungan Sinaga, Liliasari and Lala Septem Riza; project administration, M. Furqon. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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