INDONESIAN JOURNAL OF SCIENCE AND MATHEMATICS EDUCATION
07 (3) (2024) 451-465
https://ejournal.radenintan.ac.id/index.php/IJSME/index
ISSN: 2615-8639
DOI: 10.24042/ijsme.v5i1.22874
November 2024

An analysis of students' concept application in problem-solving of electrical circuits through inquiry-based learning

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Article history:

Submitted: June 14, 2024
Accepted: November 2, 2024
Published: November 30, 2024

Keywords:

concept application, electrical circuits, inquiry-based learning, problem-solving

ABSTRACT

This study investigates students' conceptual application errors in solving electrical circuit problems in inquiry-based learning. The research involved 32 physics education students from Jambi University (24 females and 8 males) using a mixed-methods approach with an explanatory design. Students completed two multiple-choice questions with reasoning, analyzed using effect size calculation, and coded the reasoning responses to assess conceptual application. The results revealed an effect size of 0.7, indicating a moderate impact of inquiry-based learning on conceptual application in problem-solving. Further analysis showed that correct answers did not always reflect accurate conceptual understanding. For example, in the first question, 62.5% of students selected option D, but not all provided conceptually correct reasoning. In the second question, only 37.5% answered correctly. These findings suggest the need for additional support, such as reflective sessions and scaffolding, to enhance students' conceptual understanding and critical thinking skills in problem-solving tasks.

Analisis aplikasi konsep mahasiswa dalam pemecahan masalah rangkaian listrik melalui pembelajaran berbasis inkuiri

Kata Kunci:

aplikasi konsep, rangkaian Listrik, pembelajaran inkuiri, pemecahan masalah

ABSTRAK

Penelitian ini menyelidiki kesalahan aplikasi konsep mahasiswa dalam menyelesaikan masalah rangkaian listrik pada pembelajaran berbasis inkuiri. Dengan pendekatan metode campuran dan desain eksplanatori, penelitian ini melibatkan 32 mahasiswa pendidikan fisika dari Universitas Jambi (24 perempuan, 8 laki-laki). Mahasiswa menyelesaikan dua soal pilihan ganda beralasan yang dianalisis melalui perhitungan effect size *dan pengkodean alasan jawaban untuk menilai penerapan konsep. Hasil menunjukkan* effect size *sebesar 0,7, yang menunjukkan dampak sedang dari pembelajaran berbasis inkuiri terhadap penerapan konsep dalam pemecahan masalah. Analisis lebih lanjut menunjukkan bahwa jawaban yang benar tidak selalu mencerminkan pemahaman konsep yang akurat. Sebagai contoh, pada soal pertama, 62,5% mahasiswa memilih opsi D, tetapi tidak semuanya memberikan alasan konseptual yang benar. Pada soal kedua, hanya 37,5% yang menjawab dengan tepat. Temuan ini menunjukkan perlunya dukungan tambahan, seperti sesi refleksi dan scaffolding, untuk meningkatkan pemahaman konsep dan keterampilan berpikir kritis mahasiswa dalam tugas pemecahan masalah.*

Contribution to the literature

This research contributes to:

- Adding new insights into the types and patterns of students' errors in applying physics concepts, particularly in electrical circuits, after inquiry-based learning.
- Highlighting the importance of qualitatively analyzing students' answers to identify misconceptions that may be hidden behind correct answers.
- Integrating reflective sessions and scaffolding to address the limitations of inquiry-based learning in enhancing conceptual understanding and critical thinking skills.

1. INTRODUCTION

The main objectives of physics learning are improving the mastery of concepts [1]–[3], understanding physics concepts in depth, and applying them in problem-solving processes [4], [5]. In addition, increasing the quantitative understanding of physics concepts is also the goal of physics learning [6] because mastering physics as a whole allows us to connect conceptual understanding and quantitative understanding of physics concepts.

There are three topics commonly raised in the application of concepts in problem-solving research. They are: (1) identifying student misconceptions; (2) describing the students' conceptual structure; and (3) developing and evaluating learning strategies to improve conceptual understanding [7], [8]. The third topic is widely raised in research, especially in electrical circuits. However, some of the results do not have a very good effect in improving students' conceptual understanding based on the fact that there are still many students who have difficulty understanding electrical circuit concepts [4], [8], [9]. Some of the student's difficulties are in using Ohm's law in analyzing complex circuits and only being able to use Ohm's law to solve simple problems [10]–[12]. Many students have difficulties to understand the concepts of current, voltage, and resistance [13], [14]. Some students argue that voltage is generated by electric currents and resistance, not as a cause of current [12], [14].

Several good practices have been given to improve the application of concept skills in solving problems in electrical circuit concepts. An analogy of flowing water is used to make it easier to understand the current concepts, voltage, and resistance in a circuit [15]. This strategy follows the voltage concept but has a disadvantage if the number of batteries in the circuit increases [14]. A 3-D Model is used to provide a conceptual picture of series and parallel circuits [16], and a thermal imager is used to distinguish series and parallel circuits clearly [17]. Still, they do not solve the problem completely.

In this research, the strategy used to help increase the students' application of concepts in problem-solving is inquiry learning. Inquiry is a learning process in which the lecturer only gives problems to students. Furthermore, students ask questions and use experimental procedures to solve the problems independently [18]–[21]. Inquiry learning not only develops students' understanding as products but also as processes [22] because this learning can help students develop their cognitive, individual responsibilities, and problem-solving [19], [23].

Inquiry-based learning has the advantage of developing students' problem-solving abilities in physics by encouraging them to think critically and creatively when faced with new challenges. In this process, students actively engage in formulating questions, designing experiments, and evaluating outcomes, which ultimately strengthens their understanding of complex physics concepts [24]. By providing students with the opportunity to organize and manage their learning process, inquiry-based learning also fosters essential self-confidence and independent learning skills [25]. This step is crucial in physics education, as students' ability to develop deep understanding and analytical skills enables them to be more adaptive in addressing problem-solving challenges that require analytical and reflective thinking [26].

The results of previous studies conducted as preliminary research in this study show several aspects related to problem-solving and the application of inquiry-based learning. For example, a study showed that students who applied a scientific approach to learning had better problem-solving skills than those who used other approaches [8]. Another study revealed that many students did not use a clear approach and relied on a memory-based method for solving problems [27]. The findings indicate that they do not apply physics concepts in problem-solving and generally only use memorized equations related to problems they have encountered before. Based on the results of these studies, the main focus of this study is to explore the application of students' physics concepts in problem-solving based on the application of inquiry learning.

There are three theoretical frameworks that can be used in assessing students' concepts application in problem-solving, namely naive theory or misconception view, knowledge in pieces or resource theory, and ontological categories view [7]. In this research, the analysis of students' concepts' application in problem-solving is conducted using resource theory. Analysis using resource theory is carried out because only a few studies analyze the students' conceptual understanding using this theory. Several studies focused on analyzing the concepts of energy [28], force [29], wave [2], and rotational dynamics [30].

This study brings novelty by focusing on the application of resource theory to analyze students' conceptual understanding in problem-solving, particularly in a broader and more diverse context beyond previously researched topics such as energy, force, waves, and rotational dynamics. This approach enables a deeper exploration of how students gradually build their conceptual understanding and flexibly utilize their cognitive resources when faced with new problems [30], [31]. Thus, this study aims to provide new insights into understanding the role and interaction among students' cognitive resources, which have not been widely explored in previous research.

The purpose of this study is to explore students' conceptual errors in problem-solving related to electrical circuits after experiencing inquiry-based learning. This article is important for students and lecturers to read, as few lecturers pay attention to students' cognitive resources during the learning process. In fact, to fully understand a concept, students must be able to effectively apply their resources.

2. METHOD

This research used a mixed method with explanatory models. The research subjects were the second-year undergraduate students of the Department of Physics Education, Faculty of Education, Jambi University. There were 32 students, 24 females and 8 males. The sampling was done using the purposive sampling technique. This technique allows researchers to focus on a group of students with a sufficient level of understanding to be further explored, making the results more relevant and representative. After receiving consent from students, the research was conducted.

Data in this study were obtained through tests and interviews. Tests were carried out using seven items of reasoned multiple-choice questions developed from DIRECT [33]. However, this article focused on analyzing two questions that are adjusted to the focus of the study, which is related to determining the brightness of a lamp in a circuit. The use of two questions is intended to maintain a focused, in-depth analysis and avoid excessive cognitive load on students. With just two questions, students can give optimal attention to each concept without feeling rushed, allowing for more reflective and accurate reasoning. The use of reasoned multiple choice questions aims to obtain complete information related to students' concepts application in problem-solving. The interview was conducted to confirm the student's unclear explanations. Interviews were conducted with all students for whom unclear or incomplete information was identified in the test results. The research design used in this research is shown in Figure 1.

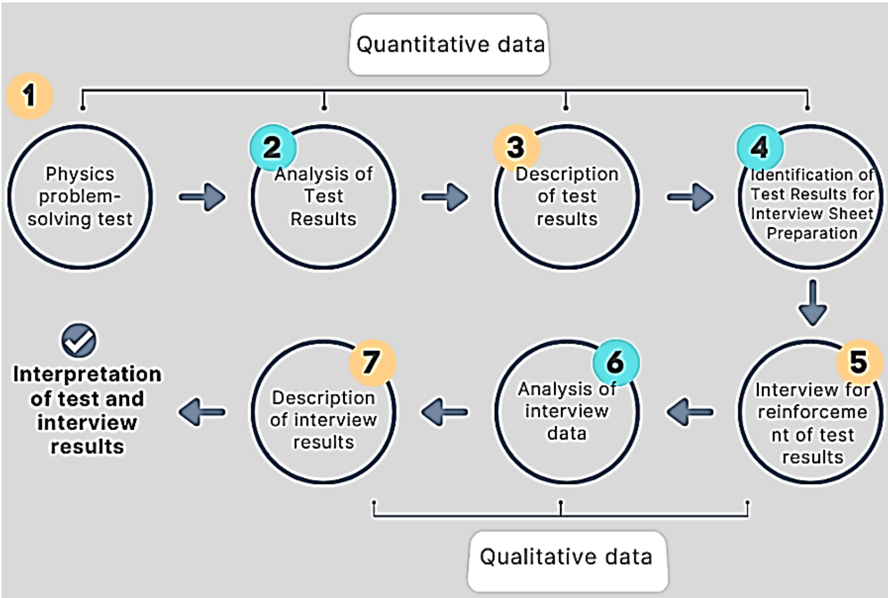


Figure 1. Research Design [32]

The research began with implementation of the inquiry learning. After receiving ethics approval, the research was conducted. The inquiry steps consist of (1) Asking questions, (2) Planning and conducting an investigation, (3) Gathering and analyzing data, (4) Developing a data-based/evidence-based explanation, and (5) Communicating about the investigation [34]. The second stage was a test and interview. The test was conducted as a form of the initial stage of collecting data on students' concepts application in problem-solving. Meanwhile, interviews were conducted to confirm answers to student test results that were not clear. This is done so that the data on students' concepts application in problem-solving obtained are deeper.

Analysis of students' concepts application in problem-solving is based on data on the suitability of students' answers with multiple choice and reasons. The assessment was carried out using a rubric developed by Zacharia and de Jong [12]. Each correct answer for one multiple choice will get a score of 1, while students who provide reasons or explanations are given additional scores depending on how many supporting concept criteria the reasons are found. Each correct concept found in the reasoning is given a score of 0.5. Quantitative data analysis was carried out using paired t-test and effect size to determine the operational strength of inquiry learning to improve students' concepts application in problem-solving. Qualitative data analysis was carried out on students' reasons for each number of questions and adjusted to the interview data.

Quantitative and qualitative data in this study were then combined and analyzed together based on indicators to determine students' deeper understanding of concepts. The stages of drawing conclusions are carried out as follows: (1) the multiple choice answers of each student are grouped according to the choice they choose; (2) each answer choice is coded into several student reasons using the constant comparative method, (3) the results of the test answers are adjusted to the results of the interviews; and (4) based on the results of the coding, conclusions will be obtained regarding the students' concepts application in problems solving.

3. RESULTS AND DISCUSSION

Two forms of electrical circuit problems were tested to express students' concepts' application in problem-solving. The first problem is given in the context of the brightness of two lights before and after the addition of a resistor arranged in series (Figure 2). The second problem is given in the context of changing the brightness of the lights, which are arranged in a series and parallel after the switch in the circuit is closed (Figure 3). In order to solve these problems, some prerequisite knowledge that students must understand includes (1) the concept of current, voltage, and resistance in series and parallel circuits and (2) the concept of energy and electric power.

Identical light bulbs A and B are assembled with a battery as shown in Figure 1. If you add the resistance C with the same magnitude as the resistance in light bulbs A and B in the circuit as in Figure 2, the brightness changes of light bulbs A and B compared before adding resistor C are ...

a. A is remains the same, B is dimmer
b. A is dimmer, B is remains the same
c. A and B are brighter
d. A and B are dimmer
e. A and B are remain the same

Figure 2. Problem Number 1

In the picture below, the identical three light bulbs with the magnitude of the resistance in each lamp are 10 Ω assembled with a voltage source 12 V. At first the switch on branching of light bulb C is open. If the switch is closed, the brightness changes of lights A and B are ...

a. A is remains the same, B is dimmer
b. A is brighter, B is dimmer
c. A and B are brighter
d. A and B are dimmer
e. A and B are remain the same

Figure 3. Problem Number 2

The results show that there were differences in students' concepts application in problem-solving before and after learning with inquiry. The paired *t*-test result score shows a t-value of 2.54 with a significance level of 0.021. The effect size of 0.71 is included in the medium category. It shows that inquiry learning has a moderate influence on improving students' concepts and application in problem-solving. These results indicate that inquiry learning provides more opportunities for students to improve conceptual understanding [35], [36]. These results are similar to the findings [37], showing that inquiry-based learning can be efficiently used to enhance students' deep understanding of science concepts. Meanwhile, this result is different from the previous research on temperature and heat topics, which stated that there was a very high increase in the students' conceptual understanding when they were involved in learning with inquiry and virtual simulation [12], [38].

The results of the identification of the interpretation of test data and interviews explain that the cause of the effect given inquiry learning is still in the medium category is that students still believe in the wrong concept that they believe even though they have been given inquiry learning. These results are in accordance with the theory, which explains that many students still use initial understanding when solving problems that lead to conceptual errors [1], [7]. In addition, some students understand the concept, but they cannot apply it in the correct context. This is because student knowledge is still in the form of pieces of knowledge that cannot be fully activated [7], [30], [31]. A detailed explanation of the findings of this research is as follows.

The first problem was used to assess the student's understanding in determining the brightness changes of two light bulbs arranged in series after adding resistance between the two light bulbs (Figure 2). To successfully solve these problems, students have to connect the following concepts: (1) The magnitude of current at each point is the same on series, while the voltage is divided according to the magnitude of resistance in each lamp; (2) The concept of Ohm's law is the greater the resistance in the circuit, the less current will be; and (3) the concept of electric power, namely $= \frac{V^2}{R}$, $P = I^2R$ dan $P = VI$.

Students who answered the questions correctly with appropriate reasoning proved that they were able to connect the concepts. The variation in students' applied knowledge is presented in Table 1. The test results show that 9.4% of students chose answer A for question number 1. A deeper examination through interviews revealed that these students believed bulb A would remain equally bright while bulb B would dim after adding a resistor to the circuit. Students who chose this answer fell into two categories of arguments, as shown in Table 1. Students in Category 1 reasoned that bulb A would remain equally bright because it receives energy first compared to bulb B, while bulb B would dim because it receives less energy. They believed this was due to the electrical energy provided by the battery being used by bulb A and the resistor. However, this reasoning is not in accordance with Kirchhoff's law [39].

Table 1. The Distribution of Student Answers and Applied Concepts to Answer Problem Number 1 After Learning with Inquiry

Choices	N	Category	Applied Concepts
A	3 (9.4%)	1	• The energy in the circuit will flow first to the A bulb. Even though the resistance is added, the brightness of the A bulb will remain the same. • At B bulb, the light will dim because it gets a little energy because of the energy used by the resistance.
		2	• The A bulbs in circuits 1 and 2 are equally bright because the same current feeds them. However, the brightness of the B bulb in both circuits is different because a resistance has been added in circuit 2. This causes the current that flows through the B bulb on circuit 2 to decrease
B	-		-
C	2 (6.3%)		Unclear
D	20 (62.5%)	1	• The addition of resistances increases the total resistance • The greater the total resistance, the smaller the current is, so that the light dims.
		2	• The brightness of A and B bulbs is caused by flowing currents and voltages associated with electrical power. • In both circuits arranged in series, the current for each bulb is the same, while the voltage is divided. • In circuit 2, additional resistances decrease the current, reducing the power.
E	7 (21.9%)		Unclear

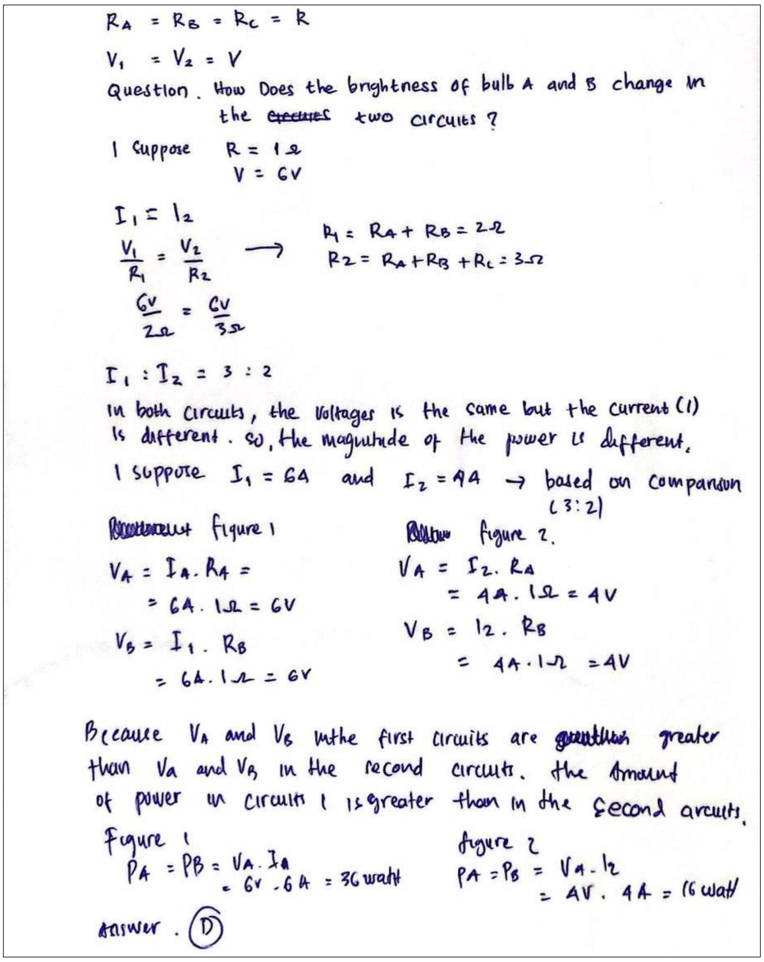
Based on these thoughts, we can identify the concepts applied by students in choosing answer A, category 1. First, students determined that the bright lights are caused by the energy given by the battery at each bulb. The knowledge applied by the students is correct, but they did not apply Kirchoff's law about energy conservation to solve the problem. This result also shows that students have basic mistakes, namely, being unable to apply the concepts of current, voltage, and resistance in a series. Students argue that the bulb closest to the positive pole of the battery will get more energy than others. The students' thinking who chose A Category 1 is almost the same as students who chose A Category 2. Still, students who chose A Category 2 argued that the brightness of a bulb is only influenced by the magnitude of the current. They ignored the concepts of voltage, resistance, energy, and electrical power. Students who choose answer A category 2 treat bulbs in one loop depending on the direction of the current flow. It means that the bulbs closest to the positive of the battery will light up brighter than others [39]. These results prove that students who choose answer A fail to use concepts in solving problems. According to the theory of misconception, students fail to solve problems because the knowledge they have is not in accordance with scientific concepts [30], [31], [40]. According to resource theory, students' failure to solve problems does not mean that knowledge has a fault but is not activated in the right context [41].

A total of 62.5% of the test students chose answer D, which means that lights A and B will dim after adding a resistor. D is the correct answer to all the answer choices provided in this case, but students who choose D did not necessarily use the right concept. The interview results in two categories of student arguments that chose the answer D. Students who chose the D category 1 argued that adding a resistor in a circuit would increase total resistance in the circuit. Increasing resistance in the circuit causes the current to flow smaller and smaller. A resource that students apply is a true concept, but it is not appropriate to solve the problem in this case because many students misunderstand the brightness of the bulb in the series. Students still find it difficult to understand that electric power causes the brightness of a bulb in a circuit.

Students who chose the D category 2 applied the right concept. An example of the results of a student's answer is presented in Figure 4. First, they argue that the brightness of the bulb is influenced by the current flowing, the voltage, and the resistance associated with the concept of electric power. Second, students can determine that the circuit formed before and after adding a resistor is a series circuit so that the amount of current flowing at each bulb is the same and the voltage is divided according to the magnitude of the resistance in the bulb. Third, students use Ohm's law that when a resistor is added to a circuit, the total resistance will increase. This causes the magnitude of the current to be smaller and smaller. Fourth, from all these concepts, by connecting with equations $P = \frac{V^2}{R}$, $P = I^2R$, and $P = VI$, they found that the bulb dims after adding a resistor.

The research results indicate that although the majority of students (62.5%) chose the correct answer (D) with the assumption that the bulbs would dim after adding a resistor, not all of these students understood the concepts correctly. In the D category one responses, students reasoned that adding a resistor increases the total resistance, which results in a decrease in current in the circuit. Still, they could not accurately connect this decrease in current to changes in the brightness of the bulbs. This finding is consistent with the observation that students' understanding of the relationship between current, resistance, and bulb brightness is often limited to a single concept, which makes it difficult for them to apply this understanding in more complex series circuit contexts [42]. Furthermore, similar studies have revealed that this limitation arises from a lack of conceptual understanding of electrical power as a factor affecting the brightness of bulbs in electrical circuits [43].

Students in Category 2 were able to apply concepts more comprehensively and accurately. They understood that the brightness of the bulbs is influenced by electrical power, which is a function of current, voltage, and resistance in the circuit, and successfully identified that adding a resistor would increase the total resistance and decrease the current flowing through the bulbs. These findings align with research, which states that students' understanding of electrical power concepts improves when they also master the relationship between Ohm's law and power equations [44]. This indicates that students with a comprehensive understanding of electrical power concepts are better able to predict changes in circuit conditions and explain bulb brightness with logical reasoning.


$R_A = R_B = R_C = R$

$V_1 = V_2 = V$

Question. How Does the brightness of bulb A and B change in the ~~circuits~~ two circuits ?

I suppose $R = 1\Omega$, $V = 6V$

$I_1 = I_2$

$\frac{V_1}{R_1} = \frac{V_2}{R_2}$ → $R_1 = R_A + R_B = 2\Omega$, $R_2 = R_A + R_B + R_C = 3\Omega$

$\frac{6V}{2\Omega} = \frac{6V}{3\Omega}$

$I_1 : I_2 = 3 : 2$

In both circuits, the voltages is the same but the current (I) is different. so, the magnitude of the power is different.

I suppose $I_1 = 6A$ and $I_2 = 4A$ → based on comparison (3:2)

figure 1

$V_A = I_A . R_A = 6A . 1\Omega = 6V$

$V_B = I_1 . R_B = 6A . 1\Omega = 6V$

figure 2

$V_A = I_2 . R_A = 4A . 1\Omega = 4V$

$V_B = I_2 . R_B = 4A . 1\Omega = 4V$

Because V_A and V_B in the first circuits are greater than V_a and V_B in the second circuits. the Amount of power in circuits 1 is greater than in the second circuits.

Figure 1: $P_A = P_B = V_A . I_A = 6V . 6A = 36$ watt

figure 2: $P_A = P_B = V_A . I_2 = 4V . 4A = 16$ watt

Answer. (D)

Figure 4. The Students' Correct Answer on Problem 1

Problem number 2 was used to assess students' conceptual understanding in determining the brightness change of two bulbs in a circuit that is mixed in series and parallel when the switch is opened and closed (Figure 3). To succeed in solving these problems, students have to connect the following concepts: (1) the concept of currents that in the series, the magnitude of the current at each point is the same, while in parallel circuits, there is the distribution of electric current; (2) the concept that series is a voltage divider circuit, whereas in parallel circuits the magnitude of the voltage at each branch is the same; (3) the concept of total resistance in series and parallel circuits; and (4) the concept of energy and electric power.

Only 37.5% of students have chosen the right answer and the right reason for this. The interview results show that they have choice B, namely, bulb A is getting brighter, and bulb B is getting dimmer, as shown in Figure 5. Students who gave the answer understood and had the ability to apply the concepts of current, voltage, resistance, and power in complex circuits, namely series, parallel, and mixed circuits. The others have chosen the wrong answers by applying inappropriate concepts to the question context, as presented in Table 2.

As many as 21.8% of students chose to answer A, which means that the brightness of the A bulb will remain the same and the B bulb will dim when the switch in the circuit is closed. Based on these thoughts, we can identify the students' conceptual understanding in choosing answer A. First, students were able to determine that when the switch in the circuit is opened, the C bulb does not get a current. Second, students find that due to the absence of current flowing in the C bulb, the circuit formed is a series. If all the lights are identical, the brightness of both A and B bulbs when the switch is opened is the same. Students apply the correct knowledge, but when the switch is closed, there is a misconception applied by the student. First, students argue that what affects the brightness of the bulbs is only the amount of electricity. The concept applied by this student clearly does not fit the context of the question. Secondly, students think that A bulb after the switch is closed will remain as bright as A bulb before the switch is closed. It is because the A bulb is electrified before the other bulbs. This opinion is one of two misconceptions that students often make, namely that the current in a series will be exhausted [13], [16], [33]. In addition, students argue that the no change of voltage makes the current flowing in A bulb will remain the same. In the B bulb, there is a division of current with the C bulb due to a parallel circuit. The concepts applied by this student are incorrect concepts in this question context. It showed that students find it difficult to understand why currents in parallel circuits are larger than currents in series with the same component [45].

Table 2. Distribution of Student Answers and Applied Concepts to Answer Problem Number 2 After Learning with Inquiry

Choice	N	Category	Applied Concepts
A	7 (21.8%)	1	• When the switch is opened, no current flows on the C bulb, so the A and B bulbs are equally bright. • When the switch is closed, the A bulb will have the same light, while the B bulb will fade due to the distribution of current.
B	12 (37.5%)	2	• When the switch is opened, the current does not flow on the C bulb. The circuit formed is a series of circuits, so the magnitude of the current through each bulb is equal to 0.6 A, and the voltage at each bulb is 6V. This is because the bulbs are identical. The relationship between current and voltage will produce power at each bulb of Pa = Pb = 3.6 watts. • When the switch is closed, a series and parallel current is formed, with the current in the A bulb being 0.8 A and the B bulb being 0.4 A. The voltage in the A bulb is 8 V, and in the B bulb, it is 4 V. The relationship between current and voltage will produce power at each bulb of Pa = 6.4 watts and Pb = 1.6 watts.
C	5 (15.6%)	3	The current is greater when the switch is closed because the total resistance value is smaller. This causes the A and B bulbs to get brighter.
D	3 (9.4%)	4	A and B bulbs will dim when the switch is closed because the amount of the total current in the circuit decreases.
E	5 (15.6%)	5	Unclear

It is different with students who choose answers C (15.6%) and D (9.4%). They have the same argument that what influences the brightness of a bulb in a circuit is the amount of electric current. The knowledge applied by students is correct, but this knowledge is not enough to solve case 2. Students who choose answer C only recognize the relationship of current, voltage, and resistance through the concept of Ohm's law. Students apply this when determining the total resistance in a mixture of series and parallel circuits. They assume that when the switch is closed, a mixture of series and parallel circuits causes the total resistance in the circuit to be smaller. The magnitude of resistance will affect the magnitude of the current. As with students who choose D answers, they are unable to apply the concept of resistance in series and parallel. Students argue that when the switch is closed, a mix of circuits will cause the total resistance in the circuit to be larger even though the bulbs are identical. This proves that one of the students' difficulties is misinterpreting circuit diagrams [13], [33], [39]. In addition, students may not be familiar with the internal structure of light bulbs in a circuit [39].

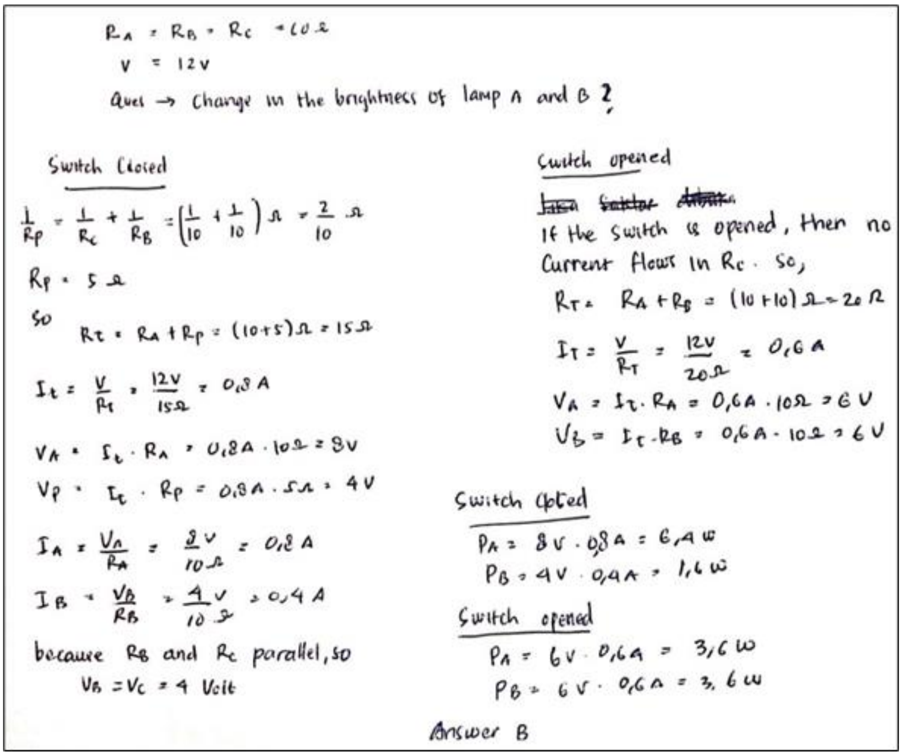


Figure 5. The Students' Correct Answer on Problem 2

The results of this study indicate that, although students were given inquiry-based learning, many still experience difficulties in accurately applying physics concepts when solving problems. This difficulty is evident from test and interview results, where most students tend to memorize concepts without being able to deeply integrate them to address more complex issues. While the inquiry method aids in improving conceptual understanding, some students are still unable to effectively connect fundamental concepts to new situations that require further analysis and critical thinking.

Students' difficulty in applying concepts after inquiry learning may stem from limitations in deep conceptual understanding. In inquiry-based learning, students are actively involved in the process of discovery and exploration. Still, without a strong foundational understanding, they tend to struggle with problems that require the integrated application of multiple concepts. According to recent research, inquiry learning often requires students to independently link previously learned concepts with new concepts in complex scenarios [46], [47]. Without further guidance in building a structured understanding, students may become confused when faced with problems requiring more complex concept applications.

Additionally, students unfamiliar with inquiry learning may face challenges in managing the critical and reflective thinking strategies necessary to solve problems independently. Research shows that inquiry learning demands high metacognitive skills, including the ability to monitor and evaluate their thinking process while working through a problem [46], [48]. Students less skilled in metacognitive thinking often struggle to identify effective problem-solving steps, preventing them from accurately applying physics concepts to find solutions. This suggests that, although the inquiry method fosters exploration skills, students still need additional support in building reflective thinking skills to apply learned concepts effectively.

The results of this study align with the findings of Yuliati *et al.* [8], which demonstrate that inquiry-based learning can enhance problem-solving skills in direct current electricity topics. In that study, students who employed a scientific approach during the inquiry-based learning process, particularly with the assistance of PhET simulations, exhibited better problem-solving abilities compared to those who used memory-based approaches or unstructured methods. These findings support the results of this study, where inquiry-based learning showed a moderate impact (effect size 0.7) in improving students' conceptual application. However, both studies also revealed that students' correct answers do not always reflect deep conceptual understanding, highlighting the need for additional strategies, such as scaffolding and interactive media, to address limitations in conceptual application. Thus, this study reinforces evidence that the inquiry-based approach is effective in enhancing conceptual understanding but requires further support for optimal outcomes.

This study highlights the strength of applying resource theory to analyze students' conceptual understanding, offering a novel approach in the context of electrical circuits. It also effectively combines quantitative and qualitative methods, providing a comprehensive analysis of students' conceptual application. However, limitations include a small sample size from a single institution, the moderate impact of inquiry-based learning, and students' difficulty in fully connecting concepts due to insufficient scaffolding and reflection opportunities. To address these issues, it is recommended that instructors incorporate real-world phenomena into teaching electrical circuits alongside structured reflection sessions and scaffolding to deepen conceptual understanding and critical thinking. Additionally, integrating interactive tools like PhET simulations can make abstract concepts more accessible and engaging, enabling students to develop confidence and independence in solving complex physics problems. Based on these findings, the instructor is advised to provide real phenomena to students when teaching the concept of electrical circuits. This can help students better understand the concept of electrical circuits and can connect between concepts to solve problems.

4. CONCLUSION

These results prove that inquiry learning has an effect on increasing students' concepts application in problem-solving. However, there are still student errors in applying the material to current, voltage, resistance, and electrical power in a circuit, especially in determining the brightness of a lamp in a circuit. This error is caused by students' inability to activate and connect their resources. The concept applied by students is not wrong, but it is not enough to provide information about the application of the concept. This is because the resources activated by students are still not right.

These findings imply that future inquiry-based learning strategies should consider additional support to help students more accurately apply concepts in problem-solving. This can be achieved by adding reflection sessions and scaffolding designed to deepen concept understanding and train the critical thinking skills necessary for problem analysis. By providing gradual guidance or problem-solving strategies, educators can help students overcome challenges in connecting existing concepts to new ones in the context of inquiry. This approach not only enhances conceptual understanding but also encourages students to be more confident and independent in applying physics concepts when facing problem-solving challenges in the future.

AUTHOR CONTRIBUTION STATEMENT

CR contributed to the design of the research, the development of necessary instruments, data collection, and the analysis of the research findings. RR contributed to designing and developing the conceptual framework and learning procedures based on relevant theories. MM contributed to integrating the designed conceptual and procedural frameworks with the characteristics of the selected physics material, namely electrical circuits, and assisted in preparing the assessment instruments. UY contributed to providing essential guidance on writing systems, supervising the data collection process, and analyzing and interpreting the research findings.

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