MEASURING STUDENTS’ PROBLEM-SOLVING SKILLS ON DIRECT CURRENT CIRCUITS WITH MULTIPLE REPRESENTATIONS

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Abstract

Purpose of study: This study aims to measure the level of students’ problem-solving skills, using assessment instruments in the form of multiple-choice tests based on the multiple representation approach on DC electrical circuits.

Methodology: This research is a quantitative descriptive involving 46 students of physics education. Students are asked to solve the problem of DC electrical circuits on 12 multiple choice questions with open reasons, involving verbal, mathematical, and picture representations. Data were analyzed by determining means and standard deviations.

Main findings: The results of the study showed that there were 3 levels of students’ problem-solving skills, namely 7 (15%) students in the high category, 22 (48%) students in the medium category and 17 (37%) students in the low category.

Applications of this study: The purpose of this research is to continuously develop assessment instruments based on multiple representations in the form of various types of tests, to help students improve their conceptual understanding, so students can solve physics problems correctly.

The novelty of this study: Researchers explain the right way to solve physics problems, 1) students are trained to focus on identifying problems, 2) students are accustomed to planning solutions using a clear approach, to build an understanding of concepts, 3) students are directed to solve problems accordingly with understanding the concepts they have built.

Keywords: Problem-Solving Skills, Multiple Representations, Assessment Instruments, Concepts Understanding, Direct Current Circuits, Equivalent Resistance.

INTRODUCTION

Physics is a science that integrates phenomena and natural events with an understanding of the human concept of these events (Malik et al., 2019). Physics also has an important role in the development of technology and science that can facilitate human life. Physics itself is obtained through a series of scientific processes which include observing activities, making hypotheses, experiments, and evaluating data that are built based on scientific attitudes and the results are in the form of scientific products (Adams & Wijeman, 2015). That causes problem-solving skills to be a very important skill to be possessed by students in learning physics (Docttor et al., 2015). Problem-solving skills can help students to understand physical concepts in real conditions (Permatasari et al., 2019).

The importance of developing problem-solving skills in learning physics results in students being required to have this ability accompanied by creativity in finding solutions to these problems (Yulindar et al., 2018). Problem-solving skills are students’ skills to integrate their observation skills and analytical skills (Ropika et al., 2019). Students’ knowledge of physical principles or cognitive aspects is one of the important things used in solving problems (Parno et al., 2019). Students who have problem-solving skills can solve physics problems by connecting their knowledge, skills, and understanding. Multiple representations can also help students solve problems better (de Kleer, 2013; Tms & Sirait, 2017). Multiple representations mean representing the same concept with different formats, including verbal, visual, graphical, and mathematical (Rosengrant et al., 2006).

Procedural knowledge is applied as a Core Competency (CC) in physics to instill problem-solving skills in students. That causes the problem-solving skills possessed by students to require assessment by the teacher, and the assessment is used to determine the achievement of student competence (Permatasari et al., 2019). Problem-solving skills also provide long-term benefits for students (Keow et al., 2014). Students are expected to have adequate problem-solving skills, to help them solve academic and non-academic problems (Yulindar et al., 2018). Adequate problem-solving skills will also facilitate students in dealing with work situations with a variety of problems that they must resolve. Therefore, teachers need an assessment instrument that can measure problem-solving skills.

Electrical circuits are one of the physical studies whose applications are often found and can facilitate human life. An electrical circuit is a collection of electrical elements or components that are interconnected and have a closed path. In the closed-circuit, there is current flowing. An example of direct current sources is a battery (Hamid et al., 2017). These components are often used by children to run their toy cars. However, most of them do not understand the concept and are not skilled in solving problems related to the material (Kokkonen & Mäntylä, 2018). The purpose of this study is to
measure the level of students' problem-solving skills, using assessment instruments based on multiple representations, especially in direct current electrical circuits.

The hypothesis of the study is that there are differences in the level of students' problem-solving skills, between students with and without an understanding of concepts in completing assessment instruments based on multiple representations of direct current (DC) electrical circuits.

LITERATURE REVIEW

Problem-solving is a basic human activity in living their lives because to survive and develop, humans always face problems, so problem-solving is defined as a person's ability to overcome a problem (Ince, 2018).

Problem-solving skills are a 21st-century skill that must be improved, especially in education. By having problem-solving skills a student is expected to be able to compete globally (Permatasari et al., 2019). Students are expected to be skilled at systematically solving problems and finding solutions that are relevant to the problems they face (Malik et al., 2019). For students to be skilled in solving problems, learning conditions such as real situations, authentic situations, and meaningful learning experiences by students are needed. Students are taught to carry out discussions with their groups in the process of problem-solving, students are taught to understand the realm of knowledge in learning material, so students understand the material before solving problems (Gok, 2010).

Problem-solving is a fundamental part of learning science in schools in general (Gok, 2010). Problem-solving abilities are considered a core competence in Physics, Technology, and applied mathematics (Shishigu et al., 2018). Problem-solving skills are activities that require students' cognitive abilities, in the process of study and learning in school physics many use cognitive abilities, so problem-solving skills are activities that continue to be developed in learning physics. Problem-solving in learning physics can be seen in quantitative aspects such as the use of mathematical equations, and must also be analyzed qualitatively to choose the correct concepts and principles in answering questions (Docktor et al., 2015; Gok, 2010; Permatasari et al., 2019). The ability to solve complex problems by applying knowledge that the student possesses and students' understanding of daily life is one of the goals of physics learning (Ropika et al., 2019). Usually, students will find new knowledge after successfully solving the problem (Gok, 2010; Permatasari et al., 2019).

Problem-solving as a form of behaviour directed at a goal requires an appropriate mental representation and uses certain methods or strategies to achieve the desired goals (Gok, 2010). In the process of solving physics problems, students are required to use various methods, techniques, and approaches to help solve problems correctly, such as the use of multiple representations (Dewati et al., 2019a). Multiple representation is a method that is being developed to foster understanding of concepts, solving physics problems and various problems that use images (Dewati et al., 2019b; Prahani et al., 2016). Multiple representations can be considered a tool in the learning process that is able to visualize various concepts and bridge them into various equations that are correct to solve problems (Dewati et al., 2019a, 2019b). Multiple representations help students to develop complex knowledge and scientific concepts, so students are able to develop their competencies (Dewati et al., 2019a).

The use of systematic methods and appropriate cognitive strategies is the process of solving problems. In the process of problem-solving activities, an assessment is needed to measure the achievement of a students' problem-solving competencies (Permatasari et al., 2019). Measurements are carried out by using assessment instruments in the form of tests. The test is a planned measurement instrument used by educators to provide opportunities for students to show their achievements in accordance with predetermined goals (Permatasari et al., 2019). Assessment in learning physics is an important part because the success and failure of learning are determined by the assessment obtained from student learning outcomes. Assessment of students can be reviewed based on cognitive, affective, and psychomotor aspects.

The assessment instrument used by the teacher must be able to accurately measure students' problem-solving skills. The instrument is considered valid if the use of the instrument can measure students' problem-solving and the resulting data is accurate (Permatasari et al., 2019). The instrument used to measure students' problem-solving skills must have a problem-solving indicator that has been developed in accordance with scientific science. For example, Louck’s problem-solving indicator (2007), is a development of Polya’s problem-solving indicator (1945) and has a similar shape to Savage and William (1990) with five steps to solving physics problems, a) identifying the types of problems, b) sorting problems based on intervals/object, c) finding the equation that is known / not, d) describing the solution or chain reaction, e) completing it mathematically (Gok, 2010). The teacher is expected to understand the indicators that will be used as guidelines for developing students' problem-solving skills assessment instruments so that the level of achievement of students' problem-solving skills competency is measured.

METHODOLOGY

This research uses a descriptive method. The research subjects were 46 physics education students at Indraprasta University PGRI Jakarta. The student had previously received direct current circuit material. Subjects were determined based on random sampling techniques. Data were collected with an assessment instrument that contained multiple representation aspects in it. The assessment instruments used are multiple choices with open reasons. This is due to the fact that multiple-choice questions cannot measure problem-solving skills. Multiple-choice questions cannot be used to
see what steps students take to solve problems. Problem-solving skills can be measured using four criteria. The assessment criteria are shown in Table 1.

### Table 1: Problem-solving Skills Assessment Criteria

<table>
<thead>
<tr>
<th>Score</th>
<th>Criteria</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Correct</td>
<td>Correct</td>
</tr>
<tr>
<td>3</td>
<td>Incorrect Answer</td>
<td>Correct</td>
</tr>
<tr>
<td>2</td>
<td>Correct</td>
<td>Incorrect Answer</td>
</tr>
<tr>
<td>1</td>
<td>Incorrect Answer</td>
<td>Incorrect Answer</td>
</tr>
</tbody>
</table>

The assessment instruments used in this study consisted of 12 items. Each question is given an evaluation according to the criteria in Table 1, then analyzed to determine the average and standard deviation. Students' problem-solving skills can be divided into several categories according to the results of the comparison between the scores they have obtained with the average and standard deviations (Permatasari et al., 2019) shown in Table 2.

### Table 2: Category of Problem-solving Skills

<table>
<thead>
<tr>
<th>Score</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>X &gt; Mean + SD</td>
<td>High</td>
</tr>
<tr>
<td>Mean – SD ≤ X ≤ Mean + SD</td>
<td>Medium</td>
</tr>
<tr>
<td>X &lt; Mean – SD</td>
<td>Low</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

The results of this research showed that only a few students have high problem-solving skills. Most of the students, 47.83% categorized in middle problem-solving skills. Students categorized in low problem-solving skills are 37%. If the students can not understand the concept correctly, then they do not have high problem-solving skills. Some of the students do not understand the correct concepts although they have learned direct current electricity in Basic Physics courses. The results of test analysis can determine students’ problem-solving skills, shown in Table 3.

### Table 3: Descriptive Statistic for the Result of Test

<table>
<thead>
<tr>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>28.03</td>
<td>53.06</td>
<td>40.54</td>
<td>12.51</td>
</tr>
</tbody>
</table>

Table 3 shows the minimum, maximum, and average values obtained by students after taking a test on the direct current material consisting of 12 items. Standard deviations from the test results can also be seen in Table 3. Based on the results of the descriptive analysis of the test analysis it is known that the average value is 40.54, while the standard deviation is 12.51. The category and percentage of students’ problem-solving skills are shown in Table 4.

### Table 4: Category of Students’ Problem-solving Skills

<table>
<thead>
<tr>
<th>Interval Score</th>
<th>Category</th>
<th>Number of Students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>X &gt; 53.05</td>
<td>High</td>
<td>7</td>
<td>15.22%</td>
</tr>
<tr>
<td>28.03 ≤ X ≤ 53.05</td>
<td>Medium</td>
<td>22</td>
<td>47.82%</td>
</tr>
<tr>
<td>X &lt; 28.03</td>
<td>Low</td>
<td>17</td>
<td>36.96%</td>
</tr>
</tbody>
</table>

Problem-solving indicators used in this study consist of how students identify problems, plan solutions, implement plans, and evaluate (Gok, 2010). Table 4 shows that most students are categorized as having medium problem-solving skills. This illustrates that the problem-solving skills possessed by students on direct current electricity circuit material are good enough. There are 17 students with low problem-solving skills. Table 5 shows some questions that were considered difficult by students.

### Table 5: Example Student performance in answering difficult questions

<table>
<thead>
<tr>
<th>Answer of students’</th>
<th>Item number (2)</th>
<th>Item number (6)</th>
<th>Item number (7)</th>
<th>Item number (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct</td>
<td>23</td>
<td>6</td>
<td>21</td>
<td>6</td>
</tr>
<tr>
<td>Incorrect Answer</td>
<td>23</td>
<td>40</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
</tr>
</tbody>
</table>

Based on table 5, there are 4 items that have a high degree of difficulty, students' correct answers only range from 58% - 13%. One example, namely in item number 6, the students that answered correctly are only 6 people or about 13%, while students' answers were incorrect answers by 87%. For example, the answers of students with low problem-solving skills scores can be shown in Figure 1.
6. Final semester assignments physics students are asked to make a series of simple electricity that will be applied to billboards with various shapes, several choices of shapes have been prepared by the instructor, and one of them is like the picture. Help students determine the equivalent resistance value on this circuit, so they can immediately flow through an electric current (from I₁ to I₃) and turn on the billboard correctly!

   a. 2/3 R  b. 1/6 R  c. 3/6 R  d. 4/6 R  e. 5/6 R

Student answer: A

If reviewed based on students’ argumentation, it can be concluded that the students cannot identify existing problems, do not plan a settlement strategy such as using a multiple representation approach, so they do not find the right solution to solve the problem question number 6.

In answering the problem given in problem number 6, it is known that students do not understand the basic concepts of direct current electricity circuits, this is due to the students’ low mastery of concept knowledge (Dewati et al., 2019b). If students’ understanding of the basic concepts of physics are low, it will result in students' difficulties in solving problems related to the concepts and laws of physics (Dewati et al., 2019b; Larkin & Reif, 2007).

One known way to help students improve understanding of concepts or basic principles of physics is by using a multiple-representation approach (Dewati et al., 2019a; Lusiyana et al., 2019). Using multiple representation approaches such as mathematical representations, verbal representations, graphical representations, pictures, and diagrams, can be used by the students to solve problems (Dewati et al., 2019b; Kohl et al., 2007; Yuliati, 2018).

The analysis of problem number 6, determining the equivalent resistance magnitude in cube-shaped circuits, can use symmetry analysis (Kong et al., 2019) or analyze circuits with current flow in each wire shaft using Kirchhoff's law and other related circuit theorems. The weakness of this technique is that it is a bit complicated and students tend to forget to analyze in more detail using mathematical analysis, this is because students are trapped in a long calculation process (Kong et al., 2019; Yongzhao & Shuyan, 1998).

The problem is solved by an approach technique that is able to help students solve problems correctly, namely the multiple representations approach, using series drawings in detail, and each part of the picture is directly analyzed mathematically. As shown in Figure 2, Figure 3, Figure 4, and Figure 5:

Figure 1: Example of a student’s answer on item number 6

If reviewed based on students' argumentation, it can be concluded that the students cannot identify existing problems, do not plan a settlement strategy such as using a multiple representation approach, so they do not find the right solution to solve the problem question number 6.

Figure 2: Flow circuits according to Kirchhoff's law on a cube

Based on Figure 2 above, the analysis of the electric current flowing in the circuit must be drawn correctly and based on Kirchhoff's law that the current flowing (in) to each intersection must be equal in number to the current flowing out (Wörner, 2019; Yongzhao & Shuyan, 1998). In Figure 2, the current entering the circuit is (Ia) flowing at the branching
currents I1, I2, I3, through identical resistance on the symmetric cube ABCDEFGH, the current flowing at the branch will exit the circuit is the current (IG), where the IG current equal to the amount of current IA (Kagan, 2015). Like equations (1), (2), and (3) below:

\[ I_{\text{in}} = I_1 + I_2 + I_3 \] .................................1)
\[ I_{\text{out}} = I_1 + I_2 + I_3 \] .................................2)
\[ I_{\text{eq}} = I_{\text{in}} \] .................................3)

In Figure 2, the current flows along the circuit because there is a voltage source (E) between nodes A and G, according to Ohm's law where the current flowing is connected to the potential difference (∆V) across all corresponding nodes (Kagan, 2015) such as equation (4) below:

\[ I = \Delta V / R \] .........................................................4)

In equation (3), it is explained that the current flowing from the voltage source is the same as the current going out, and some resistance in the circuit must be equalized in a single resistor, the resistance of this single resistor is usually called the equivalent resistance \( R_{\text{eq}} \) which replaces all the resistance in the circuit, so will produce the same amount of resistance at outflows (Kagan, 2015) as in equation (5) below:

\[ R_{\text{eq}} = E / I_{\text{out}} \] .........................................................5

Determining the resistance value equal to \( R_{\text{eq}} \) on figure 2, the symmetric circuit of the ABCDEFGH cube can be done by drawing a resistance arm that is powered by an electric current according to its branching, as follows: 1) Current \( I_3 \) flows through the resistance shaft \( R_{AD} \), and current \( I_3 \) will branch off flowing on the resistance shaft \( R_{DC} \) and \( R_{DH} \). 2) Current \( I_2 \), flow through the resistance shaft \( R_{AB} \), and current \( I_2 \) will branch off flowing on the resistance shaft \( R_{BC} \) and \( R_{BF} \). 3) Current \( I_1 \), flows through resistance shaft \( R_{AE} \), and current \( I_1 \) will branch off flowing on the resistance shaft \( R_{EH} \) and \( R_{EF} \). 4) Current \( I_3 \) flows through the resistance shaft \( R_{DC} \) combined with the current \( I_2 \) through resistance shaft \( R_{BC} \) so that it meets on current \( I_1 \) which flows on resistance shaft \( R_{CG} \). 5) Current \( I_3 \) which flows on the resistance shaft \( R_{DH} \) combined with the current \( I_1 \) through resistance shaft \( R_{EH} \) so that it meets on current \( I_2 \) flowing on the resistance shaft \( R_{HG} \). 6) Current \( I_1 \) flowing on the resistance shaft \( R_{EF} \) combined with the current \( I_2 \) through the resistance shaft \( R_{BF} \) so that it meets on current \( I_3 \) flowing on the resistance shaft \( R_{FG} \). Based on the explanation in point 1 to point 6, it is proven that Kirchhoff's law in equations (1), (2) and (3) applies to cube-shaped electrical circuits. The explanation is shown in Figure 3 below:

![Figure 3: Description of resistance handles on cube-shaped electrical circuits](image)

In figure 3, the electrical circuit between node A to node G has the same potential difference (∆V), the resistance shaft in the circuit is identical (R), to get an equivalent resistance, the circuit in figure 3, must be re-arranged in a parallel circuit, shown in figure 4 below:

![Figure 4: Parallel circuit to determine equivalent resistance](image)
In figure 4, the ABCDEFGH cube series is arranged into 3 parallel circuits, each having the first equivalent resistance, i.e. \( R_{eq1} \), which consists of 3 parallel resistance shafts \( R_{AD}, R_{AB}, R_{AE} \), which has an identical magnitude (\( R \)), the second equivalent resistance, \( R_{eq2} \), consists of 6 parallel resistance handles \( R_{DC}, R_{BC}, R_{DH}, R_{EH}, R_{BF}, R_{EF} \), which has an identical magnitude (\( R \)), as for the third equivalent resistance, \( R_{eq3} \), which consists of 3 parallel resistance handles \( R_{CG}, R_{HG}, R_{FG} \), has an identical magnitude (\( R \)). The value of each equivalent resistance \( R_{eq1}, R_{eq2}, \) and \( R_{eq3} \) is shown in equations 6a, 6b, 7a, 7b, and 8a, 8b below:

\[
\frac{1}{R_{eq1}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R} \quad \text{........................................... 6a)}
\]

\[
R_{eq1} = \frac{R}{3} \quad \text{........................................... 6b)}
\]

\[
\frac{1}{R_{eq2}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{6}{R} \quad \text{........................................... 7a)}
\]

\[
R_{eq2} = \frac{R}{6} \quad \text{........................................... 7b)}
\]

\[
\frac{1}{R_{eq3}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R} \quad \text{........................................... 8a)}
\]

\[
R_{eq3} = \frac{R}{3} \quad \text{........................................... 8b)}
\]

Based on the results of the equation of equivalent resistance \( R_{eq1}, R_{eq2}, R_{eq3} \) is shown in equations 6b, 7b, and 8b, and to find the total equivalent resistance value \( R_{eq\text{total}} \), then the three equivalent resistance must be arranged in series, as in figure 5, below:

![Figure 5: Series circuit to determine total equivalent resistance (\( R_{eq\text{total}} \))](image)

Figure 5 shows a series circuit originating from 3 equivalent resistances in the ABCDEFGH cube series, which will be used to determine the total equivalent resistance \( R_{eq\text{total}} \). The value of \( R_{eq\text{total}} \) can be explained by completing equations 9a, 9b below:

\[
R_{eq\text{Total}} = R_{eq1} + R_{eq2} + R_{eq3} \quad \text{........................................... 9a)}
\]

\[
R_{eq\text{Total}} = \frac{R}{3} + \frac{R}{6} + \frac{R}{6} + \frac{2R}{6} + \frac{R}{6} + \frac{2R}{6} = \frac{5R}{6} \quad \text{........................................... 9b)}
\]

Based on the equation 9b, the total equivalent resistance value obtained from the ABCDEFGH cube in question number 6 is equal to \( 5/6 \ R \). The proven answer is in option E.

Based on table 5, question number 8 is another example of a problem that is difficult for students to solve; this proved to be answered correctly by 6 students, and 40 students answered incorrectly. The students' answers will be shown in figure 6, below:

![Student answer: A](image)

1. All circuit below has 7 identical resistor units (the same), if this circuit is powered by voltage and electric current, determine what the equivalent resistance value in the AB circuit is:
   a. \( \frac{3}{7} \) R
   b. \( \frac{1}{7} \) R
   c. \( \frac{5}{7} \) R
   d. 2 R
   e. \( \frac{1}{2} \) R

Student answer: A
Argumentation:

Figure 6: Example of student’s answer on item number 8

Seen in figure 6, the students’ answer on question number 8, it was concluded that students had difficulty identifying questions in a structured manner, as evidenced by students not paying attention to the current (I) flowing and branching in this simple circuit. Students are required to plan solutions by representing them in the form of images, then students determine the solutions to find the equivalent resistance ($R_{eq}$) which is represented mathematically or verbally. If students do not understand the basic concepts of simple electrical circuits, students will have difficulty in solving problems of simple electrical circuits (Dewati et al., 2019a; Hamid et al., 2017).

The initial step that students must take to solve problem item number 8, is that students focus on identifying problems, such as the current flowing in the circuit and the current flowing out of the circuit, the position of the branching current, according to Kirchhoff’s rule of law in a direct current electric circuit. The next step is to redraw the entire current flow in the circuit, shown in figure 7 below:

![Figure 7: Trapezoidal current flow circuits according to Kirchhoff's law](image)

In the next step, students focus on the set of figure 7, to plan the way to solve it, and the equivalent resistance is determined by cutting the series into 2 equal parts (half of the symmetric circuit), shown in figure 8, below:

![Figure 8: Half of the symmetric trapezoid circuit](image)

The total equivalent resistance is determined based on figure 8, by multiplying two equivalent resistances of half the circuit. On figure 8, it is explained that half of the resistance ($R_{eq}$) arranged in parallel with the resistance ($R_2$), based on the flow of branching currents, so the first equivalent resistance ($R_{eq}$) can be calculated. To make it easier to get the equivalent resistance value in the series of figure 8, the picture is simplified as in figure 9, below:

![Figure 9: Simple circuit of half the symmetric trapezoid](image)

The next step is to solve the question number 8, the electrical circuit is represented in the form of a mathematical equation based on figure 8 and figure 9 above, and explained in equations 10a, 10b below:
\[
\frac{1}{R_{eq1}} = \frac{1}{R} + \frac{1}{\frac{R}{2}} = \frac{1}{R} + \frac{2}{R} = \frac{3}{R} \quad \ldots \quad 10a)
\]

\[
R_{eq1} = \frac{1}{3}R \quad \ldots \quad 10b)
\]

To determine the second equivalent resistance \( (R_{eq2}) \) by looking at the relationship between the series \( R_{eq1} \) and \( R_2 \) are series circuit, shown in equations 11a and 11b below:

\[
R_{eq2} = R_{eq1} + R_2 \quad \ldots \quad 11a)
\]

\[
R_{eq2} = \frac{1}{3}R + \frac{4}{3}R = \frac{7}{3}R \quad \ldots \quad 11b)
\]

To determine the third equivalent resistance \( (R_{eq3}) \) on figure 9, we connect the parallel circuits between \( (R_{eq2}) \) and \( (R_4) \) as explained in equations 12a and 12b below:

\[
\frac{1}{R_{eq3}} = \frac{3}{4R} + \frac{1}{R} = \frac{3}{4R} + \frac{4}{4R} = \frac{7}{4R} \quad \ldots \quad 12a)
\]

\[
R_{eq3} = \frac{4}{7}R \quad \ldots \quad 12b)
\]

Total equivalent resistance \( (R_{eqTot}) \) from the trapezium circuit in figure 7, is determined by multiplying two equations 12b) and becoming equation 13a and 13b as explained below:

\[
R_{eqTot} = 2 \times R_{eq3} \quad \ldots \quad 13a)
\]

\[
R_{eqTot} = 2 \times \frac{4}{7}R = \frac{8}{7}R \quad \ldots \quad 13b)
\]

Based on the descriptions above, the answer for question number 8 is, according to equation 13b) \( \frac{8}{7}R \). This answer is in option E.

The third problem that is considered difficult by students based on table 5, is item number 7. Of the total 46 students, questions were answered correctly around 21 students, while students who answered incorrectly were more than 50% or about 25 students. One example of student answer for question number 7 is shown in figure 10, below:

7. Look at the picture of a simple electric circuit, if the voltage source \( \Sigma E \) is 38.5 volt, how much current is flowing in the circuit and the power supply owned by the circuit? Choose the correct answer, then describe your reasons in the column correctly!

a. 2.5 A; 96 W
b. 5.5 A; 211,75 W
c. 3 A; 115 W
d. 3.5 A; 134,75 W
e. 4 A; 138,6 W

Student answer: E

Argumentation:
Based on the example of students' answers to problem number 7, students have represented the questions with pictures and solutions explained from the series, the first, second, and third equivalent resistance ($R_{eq1}, R_{eq2}, R_{eq3}$) has been determined and the three equivalent resistances are summed to total equivalent resistance ($R_{eqTot}$). But if analyzed further, students misunderstand in identifying problems, such as identifying circuit images. The misunderstanding that occurs is caused by student's incorrect answer perception, student's perception occurs when the initial information is received by the student, then it will be processed by the brain based on the student's knowledge. Thus, the perception is the basis for building student knowledge, if the student's perception is an incorrect answer, it will cause an incorrect answer conception, this will cause misunderstanding in the students' concept. Because students' understanding of the concepts is influenced by initial concepts, their perception of concepts, and the depth of concepts received by students (Setyani et al., 2017).

To minimize the misunderstanding of the concept of electricity, students must have a strong basic concept of understanding of electric current, voltage, resistance in a simple circuit (Saputro et al., 2018). Like solving question number 7, what students have to do is 1) identify the form of this simple electrical circuit to determine the current flow and voltage source, what should be focused on in the circuit in accordance with the questions asked, 2) students begin to plan solutions, for example by representing a simpler circuit to determine the flow of electric current, and equivalent resistance, 3) students implement solutions using image representations, mathematical representations in detail, 4) students evaluate the solutions obtained associated with theories related to item number 7. In figure 11, below is a series of images to determine the equivalent resistance ($R_{eq1}, R_{eq2}$).

**Figure 10:** Example of students' answer on item number 7

![Figure 10](image)

The initial step is to simplify the circuit image to determine the first equivalent resistance ($R_{eq1}$) which is indicated by a red circle and the second equivalent resistance ($R_{eq2}$) marked with a blue circle, the circuit must be accompanied by a flowing electric current.

As for determining the circuit of the first equivalent resistance ($R_{eq1}$) is the resistance that is passed by branching current, that is, a parallel circuit represented by equation 14) below:

$$R_{eq1} = \frac{20 \times 5}{20 + 5} = \frac{100}{25} = 4\Omega \quad \text{..................................................14}$$

To determine the value of the second equivalent resistance ($R_{eq2}$), is a circuit of series with the first equivalent resistance ($R_{eq1}$), as found in equation 15) below:

$$R_{eq2} = R_{eq1} + 1 = 4 + 1 = 5\Omega \quad \text{..................................................15}$$

**Figure 11:** Electric circuits for equivalent resistance ($R_{eq1}, R_{eq2}$)

![Figure 11](image)
The third set of equivalent resistance \( R_{eq3} \), and \( R_{eq4} \) shown in figure 12, below:

![Electric circuit for equivalent resistance](image1)

**Figure 12:** Electric circuit for equivalent resistance \( R_{eq3} \) and \( R_{eq4} \)

The circuit that forms \( R_{eq3} \) is a parallel circuit marked by a yellow circle, while the circuit that forms \( R_{eq4} \) is the series that is marked with a green circle in figure 12. The values of equivalent resistance \( R_{eq3} \) and \( R_{eq4} \) will be represented mathematically in equations 16) and 17) below,

\[
R_{eq3} = \frac{5 \times 20}{5 + 20} = \frac{100}{25} = 4 \Omega \quad \text{..............................................} \quad 16)
\]

\[
R_{eq4} = R_{eq3} + 2 = 4 + 2 = 6 \Omega \quad \text{..............................................} \quad 17)
\]

Equivalent resistance \( R_{eq5}, R_{eq6} \) represented in the form of parallel circuits, marked by brown circles, and blue. While the total equivalent resistance \( R_{eqTot} \) is represented in a series of circuits, as shown in Figure 13 below:

![Electric circuit for equivalent resistance](image2)

**Figure 13:** Electric circuit for equivalent resistance \( R_{eq5}, R_{eq6} \) and \( R_{eqTot} \)

To determine the magnitude of \( R_{eq5}, R_{eq6} \) and \( R_{eqTot} \) it is represented mathematically in equation 18, 19, and 20.

\[
R_{eq5} = \frac{9 \times 18}{9 + 18} = \frac{162}{27} = 6 \Omega \quad \text{..............................................} \quad 18)
\]

\[
R_{eq6} = \frac{R_{eq5} \times R_{eq4}}{R_{eq5} + R_{eq4}} = \frac{6 \times 6}{6 + 6} = \frac{36}{12} = 3 \Omega \quad \text{..............................................} \quad 19)
\]

\[
R_{TotalAB} = R_{eq6} + 8 = 3 + 8 = 11 \Omega \quad \text{..............................................} \quad 20)
\]

The simple AB electrical circuit on question number 7 has a potential difference \( \Delta V \) of 38.5 V, and has a total equivalent resistance \( R_{eqTotalAB} \) of 11Ω, to determine the current \( I \) flowing in the circuit, we must comply with Ohm’s law (Cohen et al., 2005; Dewati et al., 2019a) as in equation 21, 22 below.

\[
I = \frac{\Delta V}{R_{equivalentAB}} \quad \text{..............................................} \quad 21)
\]

\[
I = \frac{38.5V}{1 \Omega} = 3.5A \quad \text{..............................................} \quad 22)
\]

Meanwhile, to determine the power \( P \) or the rate at which energy is delivered to the resistor, by a voltage source that carries current \( I \) and has a potential difference \( \Delta V \) between the two ends, is shown in equations 23a, 23b below:

\[
P = I \Delta V \quad \text{..............................................} \quad 23a)
\]

\[
P = 38.5 \times 3.5 = 134.75W \quad \text{..............................................} \quad 23b)
\]
Based on the results from solving equations 21 and 23 above, the amount of current flowing is 3.5 A and the power in the circuit is 134.74 W. The results of this calculation are provided in answer option D, in question number 7.

CONCLUSION

Based on the results of this study, it was concluded that students’ problem-solving skills still had to be improved. This is because based on 46 students studied, only 7 students or 15% were in the high category of problem-solving skills, 48% were in the medium category, and 37% or around 17 students included in the low category. The reason for the low problem-solving skills is because there is a tendency for students not to use clear approach techniques, such as using multiple representation approaches to help solve problems. Another cause is that the students lack understanding of concepts in DC electrical circuits, especially understanding of concepts related to a voltage (potential difference), electric current, equivalent resistance, and applying Ohm's Law, Kirchhoff's Law in the development of mixed circuits. Problem-solving skills will develop well in students if the approach techniques can be mastered and used correctly, and students are able to explain the problems they have solved, this proves that the understanding of concepts has been mastered by students. If students try to solve problems without the help of technical approaches, they will not be able to solve the problems correctly. If students have a low understanding of concepts and are unable to present and use a clear approach, students will have difficulty in solving problems, thus it is necessary to develop approaches such as multiple representations and reinforce the students’ understanding of concepts so that the problem-solving skills of students are high.

LIMITATIONS AND FUTURE STUDIES

Research limitations because the assessment instrument is still in the form of multiple-choice tests with open reasons, and does not attend to the learning model used; in the future research is needed with certain learning models and forms of tests that are more suitable for developing students' problem-solving skills.

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AUTHORS CONTRIBUTION

Maria Dewati a doctoral student in physics education is the main researcher whose contribution in this research includes designing, planning, and conducting the assessment, retrieving, processing, and analysing the data gathered, and also writing the research paper. A. Suparmi, a physics professor, is a co-promotor in this research who contributes by helping to develop the physics study material and supervising the research from the beginning of the study until the end of the research. Widha Sunarno, a physics education professor, is the promoter whose role in this research is to supervise and assist the main researcher. Sukarmin, a doctorate of physics education, is a co-promotor in the research who accompanies the main researcher and supervises the processing of the research data. C. Cari, a professor of physics and lecturer in magnetic electricity courses study, acts as an advisor and supervises the main researcher in developing the assessment instrument used in the research.

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