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# Conflict between physical analysis and mathematics causing failure: A case on diode circuits

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**Abstract**: This study aims to describe the causes of students' failures in solving diode circuit problems. Research data were obtained through tests, dialogs, and interviews with 12 students of the physics education study program at Universitas PGRI Madiun. The research began by providing diode circuit test questions. Referring to the answers to the diode circuit test questions, an investigation was conducted through a basic circuit mastery test, followed by dialogs and interviews. The data from the test results, dialogs, and interviews in this study led to the conclusion that the common causes of students' failures in solving diode circuit problems are the inability to apply Ohm's law and Kirchhoff's law correctly, as well as the inconsistency and lack of systematic application of basic circuit concepts. A specific finding regarding the causes of failure in solving diode circuit problems is the conflict between physical and mathematical analyses. Based on the common causes of students' failures in solving diode circuit problems, a series of conceptual scaffolding needs to be designed. In conceptual scaffolding, complex circuits are transformed into several basic circuits to facilitate scaffolding for each basic concept. Procedural scaffolding needs to be designed to address failures resulting from the conflict between physical and mathematical analyses. One necessary step in procedural scaffolding is confirming answers using Kirchhoff's law.

**Keywords**: ideal diode; ohm's law; kirchhoff's law; equivalent circuits

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## Introduction

The diode is one of the most basic and essential components in electronics. The diode is a unilateral element because it behaves differently under forward and reverse bias conditions (Roy et al., 2018). One key to success in solving diode circuit problems is understanding diode characteristics using ideal and non-ideal approaches. The ideal diode approach is the easiest to apply in quick mathematical analyses that do not require high precision. In the ideal approach, the diode is depicted as equivalent to a closed switch (short connection) when forward biased, or an open switch (disconnected connection) when reverse biased. The non-ideal approach is applied for more meticulous mathematical analyses by considering the knee voltage and bulk resistance. In the non-ideal approach, the diode is depicted as equivalent to a DC voltage source (with polarity + for the p-region and - for the n-region) when forward biased. In reverse bias, the diode is depicted as equivalent to a resistor with a very high value or an open switch.

Understanding diode characteristics and equivalent diode circuits alone is not sufficient preparation for solving diode circuit problems (Perez et al., 2019). Students must also understand basic circuit concepts (Ohm's law and Kirchhoff's law) (Liu et al., 2022; McPadden et al., 2018), as well as

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understand concepts of AC and DC voltages (Ünal, 2022). Students who can transform diode circuits into equivalent circuit forms (ideal diode concept) will not be able to analyze diode circuits if they do not understand basic circuits, concepts of AC and DC voltages (Perez et al., 2019; Van De Bogart & Stetzer, 2018). Students who have understood basic circuits and concepts of AC and DC voltages also cannot analyze diode circuits if they do not understand equivalent diode circuits. Understanding the interconnection between concepts is crucial in diode circuit analysis. In reality, students tend to use one concept in solving problems without utilizing the interconnection between concepts, whereas diode circuit problems often require synthesis skills (Ibrahim & Ding, 2021) that require the assistance of interconnected concepts. Diode circuit analysis requires synthesis between concepts, including basic circuits. Students often fail to understand circuits as a whole (McPadden et al., 2018). The interconnection between concepts is essential; however, end-of-chapter problems in most introductory physics textbooks only contain material and examples discussed within one chapter, not presenting interconnected concepts comprehensively.

Various studies on mastery of basic circuits as well as advanced circuits have been conducted. Studies on mastery of basic circuits show that: 1) students fail to apply Ohm's law and Kirchhoff's law, many students do not consistently and systematically apply basic circuit concepts (Coppens et al., 2017; Ercan, 2016; Liu et al., 2022; Papanikolaou et al., 2015; Ünal, 2022). 2) what happens when circuits are transformed into different circuits remains difficult for students to understand and master. Studies on mastery of diode circuits show that: 1) students still struggle to understand the dynamics of voltage waveforms at various points in the circuit, 2) novice students tend to seek surface-level match of solutions when solving circuit analysis problems (Narayanan et al., 2023).

This present study’s objective is to describe the causes of students' failures in solving diode circuit problems. Other studies state that students who are studying advanced electronic circuits (including diode circuits) still face difficulties and still have to work hard to understand basic circuits (Popat, 2021; Van De Bogart et al., 2017; Van De Bogart & Stetzer, 2018). Unfortunately, these research articles do not clearly present the interconnection between understanding and mastery of basic circuits with success in analyzing advanced electronic circuits. This study clearly presents an example of the interconnection between understanding and mastery of basic circuits with success in analyzing advanced electronic circuits, especially diodes. The common causes of students' failures in solving problems are the failure to apply Ohm's law and Kirchhoff's law, as well as the inconsistency and lack of systematic application of basic circuit concepts (Coppens et al., 2017; Ercan, 2016; Liu et al., 2022; Papanikolaou et al., 2015; Ünal, 2022). The researchers found another cause of failure in solving problems, namely the conflict between physical and mathematical analyses.

## Method

The research was conducted from September 2022 to March 2023 on 12 students of the Physics Education program at Universitas PGRI Madiun in the Electronics I course. The main research instrument, in the form of a diode circuit test, had been content validated by experts and had been piloted in 2020 and 2021 on students from the physics education, electrical engineering, and electrical engineering education programs (who had taken or were currently taking the Electronics I course).

The research on 12 physics education students began with administering a diode circuit test (the test questions are presented in the results and discussion). Prior to the test, students had studied diode circuit concepts through learning and simulation using the Electronics Workbench application for 3 sessions covering semiconductor physics, diode concepts, and diode applications. The failure of students to solve the diode circuit test questions inspired the researchers to conduct an investigation. Consequently, in the next session, the research continued with a test on mastery of basic circuits (the questions are presented in the results and discussion), deliberately selected in relation to the success in solving diode circuit problems. Following the test on basic circuits, direct dialogs and interviews were conducted with students to ascertain what actually happened regarding students' mastery of basic circuit concepts, Ohm's law, and Kirchhoff's law. An interview with one student is presented in the results and discussion to clearly illustrate a finding of how the conflict between physical and mathematical analyses caused failures in problem-solving as seen in Figure 1.

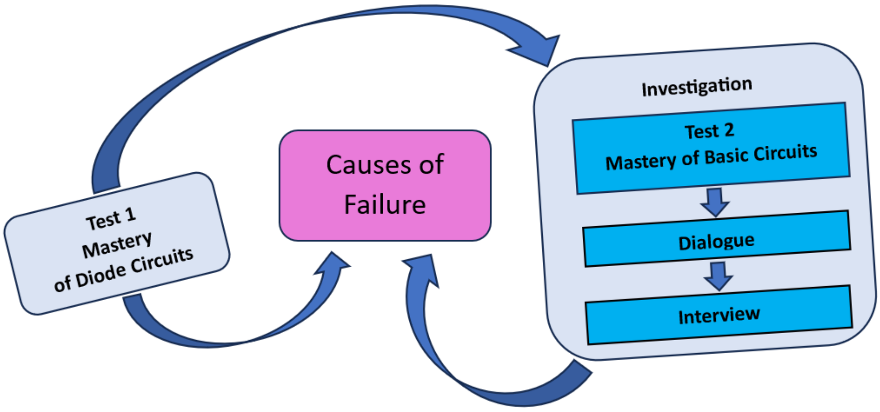


Figure 1. Flowchart of the research

The data collection was done through tests, dialogs, and interviews that are interrelated. Thus, data analysis was conducted using an interactive model. Each time data was collected, analysis was performed immediately. The results of the analysis from the previous data collection session served as a reference for the design of the next data collection. At the end of the research session, data collected through all methods, namely tests, dialogs, and interviews, were analyzed to draw a focused conclusion.

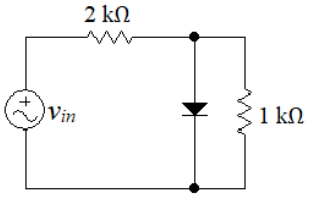
## Results and Discussion

### *Mastery Test of Diode Circuits*

The test was conducted by providing several questions aimed at measuring mastery of diode circuit concepts. In this article, only one essential question relevant to the title and research findings is presented.

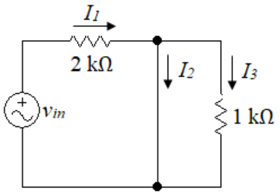
**Question 1**

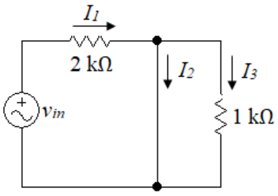
In the circuit shown, $v_{in\ peak}$ = 10 volt, and the diode is considered ideal. During the positive half-cycle of $v_{in}$, what is the maximum current through resistor 2 kΩ ($I_1$), the diode ($I_2$), and resistor 1 kΩ ($I_3$)?



There were 5 variants of student answers to the diode circuit question (question 1). The summary of student answer variants for question 2 is presented in Table 1.

Table 1. Variants of Answers to Question 1

| Variant | Respondent Number | Responses | | Interpretation |
|---|---|---|---|---|
| | | Equivalent Circuit | Mathematical Calculation | |
| A | 9 |  | $I_1 = \frac{v_{in}}{R_1} = \frac{10\ \text{Volt}}{2\ \text{k}\Omega} = 5\ \text{mA}$<br>$I_2 = \frac{v_{in}}{R_2} = \frac{10\ \text{Volt}}{0\ \text{k}\Omega} = \infty\ \text{mA}$<br>$I_3 = \frac{v_{in}}{R_3} = \frac{10\ \text{Volt}}{1\ \text{k}\Omega} = 10\ \text{mA}$ | Can draw the equivalent circuit correctly.<br>Do not fully understand the concept of AC voltage source.<br>Only memorize Ohm's law in mathematical form but do not understand its implementation.<br>When calculating $I_2$ they use the concept of limit, i.e., $R_2$ approaches 0. |

| Variant | Respondent Number | Responses | | Interpretation |
|---|---|---|---|---|
| | | Equivalent Circuit | Mathematical Calculation | |
| B | 5, 6, 12 |  | $I_1 = \frac{v_{in}}{R_1} = \frac{10\ \text{Volt}}{2\ \text{k}\Omega} = 5\ \text{mA}$<br>$I_2 = \frac{v_{in}}{R_2} = \frac{10\ \text{Volt}}{0\ \text{k}\Omega} = 0\ \text{mA}$<br>$I_3 = \frac{v_{in}}{R_3} = \frac{10\ \text{Volt}}{1\ \text{k}\Omega} = 10\ \text{mA}$ | Can draw the equivalent circuit correctly.<br>Does not fully understand the concept of AC voltage source.<br>Only memorizes Ohm's law in mathematical form, but does not understand its implementation.<br>Incorrect understanding in mathematical calculation when calculating $I_2$. |
| C | 8 | Not drawing equivalent circuit | $I_1 = \frac{v_{in}}{R_1} = \frac{10\ \text{Volt}}{2\ \text{k}\Omega} = 5\ \text{mA}$<br>$I_2 = \frac{v_{in}}{R_2} = \frac{10\ \text{Volt}}{0\ \text{k}\Omega} = \infty\ \text{mA}$<br>$I_3 = \frac{v_{in}}{R_3} = \frac{10\ \text{Volt}}{1\ \text{k}\Omega} = 10\ \text{mA}$ | Does not demonstrate the ability to draw the equivalent circuit correctly.<br>Does not fully understand the concept of AC voltage source.<br>Only memorizes Ohm's law in mathematical form, but does not understand its implementation.<br>Incorrect understanding in mathematical calculation when calculating $I_2$, they use the concept of limit, i.e., $R_2$ approaches 0. |
| D | 1, 3 | Not drawing equivalent circuit | $I_1 = \frac{v_{in}}{R_1} = \frac{10\ \text{Volt}}{2\ \text{k}\Omega} = 5\ \text{mA}$<br>$I_2 = \frac{v_{in}}{R_2} = \frac{10\ \text{Volt}}{0\ \text{k}\Omega} = 0\ \text{mA}$<br>$I_3 = \frac{v_{in}}{R_3} = \frac{10\ \text{Volt}}{1\ \text{k}\Omega} = 10\ \text{mA}$ | Does not demonstrate the ability to draw the equivalent circuit correctly.<br>Does not fully understand the concept of AC voltage source.<br>Only memorizes Ohm's law in mathematical form, but does not understand its implementation.<br>Incorrect understanding in mathematical calculation when calculating $I_2$. |
| E | 2, 4, 7, 10, 11 | Not drawing equivalent circuit | $I_1 = \frac{v_{in}}{R_1} = \frac{10\ \text{Volt}}{2\ \text{k}\Omega} = 5\ \text{mA}$<br>$I_2 = \frac{v_{in}}{R_2} = ??$ | Does not demonstrate the ability to draw the equivalent circuit correctly.<br>Does not fully understand the concept of AC voltage source. |

| Variant | Respondent Number | Responses |  | Interpretation |
|---|---|---|---|---|
|  |  | Equivalent Circuit | Mathematical Calculation |  |
|  |  |  | $I_3 = \frac{v_{in}}{R_3} = \frac{10\ \text{Volt}}{1\ \text{k}\Omega}$<br>$= 10\ \text{mA}$ | Only memorizes Ohm's law in mathematical form, but does not understand its implementation. Incorrect understanding in mathematical calculation when calculating $I_2$, does not understand that $R_2$ should be replaced with 0 Ω. |

The first step to facilitate the solution to question 1 is to transform the original circuit into an equivalent circuit. Students in answer variants A and B have correctly drawn the equivalent circuit by applying the concept of an ideal diode (Table 1). In the mathematical equations, students used the notation vin when calculating I. Considering that the question asks for the maximum current, the notation $v_{in}$ should be written as $v_{in\ peak}$ specially when calculating $I_1$. In implementing Ohm's law, students also seem to lack understanding and appear to be using a "plug and chug" approach (Reddy, 2020). Students are indicated to only memorize mathematical equations. They do not understand which voltage should be included in the equation $I = \frac{V}{R}$. When calculating $I_2$, students have already substituted the diode with the value 0 Ω, but the voltage entered into the equation is incorrect (Burde & Wilhelm, 2020; Ünal, 2022). Students in variant A use the concept of limit in dividing with a denominator approaching 0, while students in variant B make a mathematical error. Students in answer variants C, D, and E did not draw the equivalent circuit, but mathematically, their calculations are not different from those of students in answer variants A and B (Table 1). Students in answer variant E did not complete the mathematical calculation when calculating $I_2$.

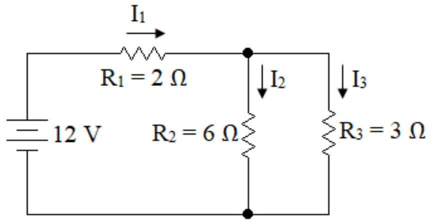
Although it seems very simple, question 1 actually involves synthesis analysis, and its solution requires mastery of several concepts to be implemented synergistically (Dounas-Frazer & Lewandowski, 2017; Ibrahim et al., 2017; Parno et al., 2020; Sutopo, 2016; Yuliati & Parno, 2018). Referring to the answer variants (Table 1), all students appear not to conduct analysis but use a "plug and chug" method to solve the problem (Docktor & Mestre, 2014; Yuliati et al., 2018). Another indicator showing that students do not conduct analysis is that they do not confirm the accuracy of their answers using Kirchhoff's Current Law (Coppens et al., 2017; Ercan, 2016). A common prediction emerges regarding the causes of students' failures in solving question 1. The interim conclusion of the main predicted cause of failure in solving question 1 is that students do not master basic circuit concepts, Ohm's law, and Kirchhoff's law (Coppens et al., 2017; Ercan, 2016; Liu et al., 2022; Papanikolaou et al., 2015; Ünal, 2022). A series of investigations were conducted, starting with administering a test on mastery of basic circuits to ensure whether this interim conclusion is true, followed by dialogs, and sharpened with interviews.

### *Investigation*

The failure of students to answer the diode circuit test question (question 1) became the basis for conducting the investigation. In the initial step of the investigation, a test on mastery of basic circuits (question 2) was conducted. A test question on mastery of basic circuits was deliberately designed in relation to the success in answering question 1. Misunderstanding about AC peak voltage inspired simplification by substituting with a DC voltage in the basic circuit test question (Zuza et al., 2020). The input voltage in question 1 was replaced with a DC voltage of 12 volts in question 2, with the positive terminal directly connected to the p-region of the diode (forward bias). Analogously, in the positive half-cycle off $v_{in}$ in question 1, the diode is forward biased. The voltage value in question 2 is set at 12 volts (ideal), while the resistance values in question 2 are not in kΩ, but are converted to Ω for ease of calculation.

**Question 2**

The source voltage in the basic circuit shown on the side is 12 volts (ideal). If $R_2$ is replaced with a short circuit, calculate the current flowing through each of the resistors $R_1 = 2\ \Omega$ ($I_1$), through the short circuit ($I_2$), and through $R_3 = 3\ \Omega$ ($I_3$).



There are 3 variants of student answers to the basic circuit question (question 2). A summary of student answer variants for question 2 is presented in Table 2.

Table 2. Variants of Answers to Question 2

| Variant | Respondent's number | Responses | Interpretation |
|---|---|---|---|
| A | 8<br>9 | $I_1 = \frac{12}{2} = 6\text{ A}$<br>$I_2 = \frac{12}{0} = \infty\text{ A}$<br>$I_3 = \frac{12}{3} = 4\text{ A}$ | 1. Does not understand the implementation of Ohm's law.<br>2. When calculating $I_2$, uses the concept of limit, i.e., $R_2$ approaches 0. |
| B | 1<br>3<br>6<br>5<br>12 | $I_1 = \frac{12}{2} = 6\text{ A}$<br>$I_2 = \frac{12}{0} = 0\text{ A}$<br>$I_3 = \frac{12}{3} = 4\text{ A}$ | 1. Does not understand the implementation of Ohm's law.<br>2. Incorrect understanding in mathematical calculation when calculating $I_2$. |
| C | 2<br>4<br>7<br>10<br>11 | $I_1 = \frac{12}{2} = 6\text{ A}$<br>$I_2 = \frac{12}{6} = 2\text{ A (short circuit)}$<br>$I_3 = \frac{12}{3} = 4\text{ A}$ | 1. Does not understand the implementation of Ohm's law.<br>2. When calculating $I_2$, does not understand the meaning of a short circuit |

Students in variants A, B, and C (Table 2) consistently show that they use a "plug and chug" method without conducting analysis. All students input the value of 12 volts when calculating $I_1$, $I_2$, and $I_3$. This indicates that they do not understand which voltage should be included in the equation $I = \frac{V}{R}$ (Burde & Wilhelm, 2020). In their study (Burde & Wilhelm, 2020), it was found that students do not understand that the potential difference in parallel circuits is always the same. We found that students input the value of the 12-volt potential difference, which is essentially the source voltage, in all electrical current (I) calculations without considering whether the circuit is in series or parallel (Table 3). This means there is a similarity between their findings (Burde & Wilhelm, 2020) and our findings regarding students' perception of the voltage concept (potential difference).

Table 3. Comparison of Students' Perceptions of Voltage (Potential Difference)

| Burde & Wilhelm (2020) | Current results |
|---|---|
| Students do not understand that the potential difference in parallel circuits is always the same. | Students input the value of the 12-volt potential difference, which is essentially the source voltage, in all electrical current (I) calculations without considering whether the circuit is in series or parallel. |

When calculating $I_2$, variant answer A uses the concept of limit in division with a denominator approaching 0, variant answer B makes a mathematical error, while variant C does not seem to understand the meaning of replacing $R_2$ with a short circuit (Table 2). (Kusairi et al., 2019) stated that students need to be given exercises on conceptual and balanced calculation questions. Sujito et al.

(2021) emphasized that the mathematical methods in physics courses (including electronics) need improvement in the learning process. It seems that the expressions of Kusairi et al., (2019) and Sujito et al. (2021) are proven to be correct. It is evident that variant answer B shows a lack of understanding in division with a denominator approaching zero, both in terms of the concept of limit and the prohibition of dividing by zero.

In the discussion of the results of the diode circuit mastery test (question 1), it was mentioned that the main predicted cause of failure in solving question 1 is that students do not master the concepts of basic circuits, Ohm's law, and Kirchhoff's law (Coppens et al., 2017; Papanikolaou et al., 2015). The students' responses to the basic circuit mastery test (question 2) reinforce the claim that the main cause of failure in solving question 1 is that students do not master the concepts of basic circuits and Ohm's law. Although each student demonstrates different abilities (Stanley et al., 2017), none of the students confirm the correctness of their answers using Kirchhoff's law. The answer of student C variant 1 to question 1 seems correct at first glance if inserted into the expression of Kirchhoff's Current Law $I_1 = I_2 + I_3$. The concept of parallel resistance and the concept of voltage also did not come to the students' minds to be applied. In this question 2 test session, no student answered differently, for example, by using the voltage divider concept (Papanikolaou et al., 2015). They also have not shown the development of higher-order thinking skills by answering using qualitative analysis. The assumption that students do not understand and master Kirchhoff's law and the voltage concept well inspired the implementation of a dialogue to uncover this misunderstanding phenomenon.

The dialogue began by showing a circuit diagram in question number 1 with slight modifications (Figure 2). The purpose of the modification was to facilitate revealing what actually happens to students' understanding and mastery of the concepts of voltage, Ohm's law, and Kirchhoff's law through dialogue. In the modified diagram, the 6 Ω resistor was replaced with a short circuit, and points A, B, and C were added to the diagram.

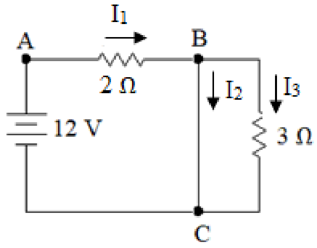


Figure 2. Basic circuit with short circuit

Referring to the modified circuit, there was a relatively long dialogue. In this article, only one essential transcript of the dialogue is shown.

Dialogue transcript:
Lecturer: What is VAB?
Students (all): 12 volts.
Lecturer: What is VBC?
Students (all): 12 volts.
Lecturer: What is VAC?
Students (all): 12 volts.
Lecturer: Is VAC = $V_{AB}$ + $V_{BC}$?
Students (10 individuals): ?? (look confused).
Students (respondents 9 and 12): It should be.
Students (respondent 12): $V_{BC}$ = 0 volts (after thinking for a few moments).

According to the transcript, the majority (10 students) appear to not understand the concept of potential difference. They assume that the potential difference $V_{AC} = V_{AB} = V_{BC} = 12$ Volt. In the cross-check stage of answers using Kirchhoff's Voltage Law (KVL) $V_{AC} = V_{AB} + V_{BC}$ 2 students realize that their answers $V_{AC} = V_{AB} = V_{BC} = 12$ Volt are incorrect (not in accordance with KVL). Referring to the results of question 1 and question 2 tests, as well as the dialogue transcript, it can be clearly stated that the 10 students indeed do not understand and master the concepts of basic circuits, Ohm's law, and Kirchhoff's law (Coppens et al., 2017; Ercan, 2016). It can be ensured that these 10 students cannot correctly calculate $I_2$ and $I_3$ because of errors in determining the value of VBC. The calculation of $I_1$, which results in a value of 6 amperes, is indeed correct, but it is certain that by chance, even without analysis, $I_1$ results in a calculation of 6 amperes.

The response of respondent number 12 inspired further investigation. The interview with respondent number 12 is intentionally presented in this article because it is essential (interviews with other respondents are not shown in this study).

**Interview transcript (between the lecturer and respondent number 12):**

Lecturer: Calculate the equivalent resistance of the short-circuited wire (R = 0 Ω) with $R_3$ = 3Ω!

Student: Calculating on paper:

$$\frac{1}{R_P}=\frac{1}{R_C}+\frac{1}{R_3}=\frac{1}{0}+\frac{1}{3}=??$$

Student: It should be $R_P$ = 0 Ω, but I'm confused because there is one term with a denominator of 0 Ω.

Lecturer: When in the dialogue you answered $V_{BC}$ = 0 Volt, why is that?

Student: Because when $R_2$ is replaced by a short circuit, the resistance $R_2$ becomes 0 Ω so that A and B are one wire or one point.

Lecturer: Armed with a modified diagram with points A, B, C added, try to write equations to calculate $I_1$, $I_2$, and $I_3$!

Student: Writing on paper:

$$\mathrm{I_1}=\frac{\mathrm{V_{AB}}}{\mathrm{R_1}}$$
$$\mathrm{I_2}=\frac{\mathrm{V_{BC}}}{\mathrm{R_2}}$$
$$\mathrm{I_3}=\frac{\mathrm{V_{BC}}}{\mathrm{R_3}}$$

Lecturer: Why do you use $V_{BC}$ when calculating $I_2$ and $I_3$?

Student: Because $R_2$ and $R_3$ are in parallel.

Lecturer: Now, try to calculate $I_1$, $I_2$, and $I_3$!

Student: Calculating on paper.

$$\mathrm{I_1}=\frac{\mathrm{V_{AB}}}{\mathrm{R_1}}=\frac{12\ \mathrm{Volt}}{2\ \Omega}=6\ \mathrm{Ampere}$$
$$\mathrm{I_2}=\frac{\mathrm{V_{BC}}}{\mathrm{R_2}}=\frac{0\ Volt}{0\ \Omega}=??$$
$$\mathrm{I_3}=\frac{\mathrm{V_{BC}}}{\mathrm{R_3}}=\frac{0\ Volt}{3\ \Omega}=0\ Ampere$$

Lecturer: Now, check your answers using the first Kirchhoff's law!

Student: Calculating on paper.

$$\mathrm{I_1}=I_2+I_3$$
$$6\ \mathrm{Ampere}=??+0\ Ampere$$

Lecturer: Does your answer satisfy Kirchhoff's law?

Student: No, it does not.

Lecturer: Then, what should $I_2$ be?

Student: It should be 6 Amperes.

Lecturer: Why?

Student: Logically, after the junction, all currents flow through the short circuit because it has no resistance, but I'm still confused mathematically because when calculated:

$$\mathrm{I_2}=\frac{\mathrm{V_{BC}}}{\mathrm{R_2}}=\frac{0\ \mathrm{Volt}}{0\ \Omega}\neq 6\ \mathrm{Ampere}$$

Referring to the interview transcript, respondent number 12 appears to be starting to develop analytical skills, although they need to be guided with questions. Respondent number 12 seems to be able to perform physical analysis even though they experience conflicts when matching it with mathematical calculations. Conflicts occur when calculating parallel resistance and when calculating $I_2$.

Respondent number 12 appears to be starting to utilize the concepts of basic circuits, Ohm's law, and Kirchhoff's law, although they need guidance. The interview results with respondent number 12 indicate that conflicts between physical and mathematical analyses can also lead to failure in solving diode circuit problems.

Overall, there is a similarity in the causes of failure in solving electrical circuit problems (including diode circuit problems). However, there is an additional finding of the cause of failure in solving problems, namely conflicts between physical and mathematical analyses. A comparison of the findings of various studies with our findings is presented in Table 4.

Table 4. Comparison of failures in solving electrical circuit problems

| (Burde & Wilhelm, 2020; Coppens et al., 2017; Ercan, 2016; Papanikolaou et al., 2015) | Current results |
|---|---|
| Do not understand and master the concepts of basic circuits, Ohm's law, and Kirchhoff's law | 1. Do not understand and master the concepts of basic circuits, Ohm's law, and Kirchhoff's law.<br>2. Conflict between physical and mathematical analyses. |

## Conclusion

Test results and dialogue show that 10 out of 12 respondents failed to solve diode circuit problems because they could not apply Ohm's law and Kirchhoff's law correctly, and did not apply basic circuit concepts consistently and systematically. An interview with one of the respondents (number 12) indicates a specific finding of the cause of failure in solving diode circuit problems, namely conflicts between physical and mathematical analyses.

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