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ANALYSIS OF FIRST-YEAR UNIVERSITY STUDENTS' CONCEPTUAL UNDERSTANDING OF DIRECT CURRENT ELECTRIC CIRCUITS

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Abstract

The concept of direct current (DC) electricity is taught from elementary school through higher education. The concepts covered include electric current, voltage (potential difference), and electric circuits in series and parallel configurations. However, students often experience difficulties in understanding these concepts, and such misconceptions frequently persist into university education. Therefore, this study aimed to analyze first-year university students' conceptual understanding of direct current electric circuits. A descriptive survey with qualitative explanation was employed to investigate students' conceptions in depth, involving 107 participants. Students completed multiple-choice questions and were asked to provide written explanations for each selected answer. The analysis revealed that more than 50% of the students were unable to answer the questions correctly. Most students believed that a battery is a constant source of electric current. In addition, many students assumed that adding more batteries would always increase the voltage regardless of the battery configuration. Furthermore, students demonstrated difficulties in understanding the behaviour of bulbs in series and parallel circuits. These findings indicate that first-year university students hold significant misconceptions related to direct current electricity. Therefore, educators need to implement instructional approaches that effectively support students in constructing scientifically accurate concepts of DC electric circuits.

Keywords: conceptual understanding, direct current, physics, learning difficulties.

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INTRODUCTION

Conceptual understanding in physics has remained one of the major research topics in physics education research (Docktor & Mestre, 2014; Hernandez et al., 2025). Previous studies have identified various issues, including students' difficulties in understanding specific concepts, misconceptions, and students' ability to explain physical phenomena scientifically (Nie et al., 2019; Xu et al., 2020). These findings can assist teachers in designing appropriate instructional strategies to develop students' thinking skills, designing experiments to support conceptual understanding, and improving physics curricula in general. Moreover, students' conceptual understanding significantly influences learning processes and problem-solving abilities (Musengimana et al., 2025).

One of the physics topics taught from elementary school to university level is direct current (DC) electric circuits (Li & Singh, 2016). This topic is essential because it is directly observable in everyday life, and students frequently use electrical devices based on DC electricity concepts. One of the simplest examples is a flashlight consisting of batteries, bulbs, and switches. Furthermore, DC electric circuits serve as a foundational topic for learning more advanced electricity-related concepts at higher levels of education (Etkina et al., 2019).

The domain knowledge of electric circuits includes several major conceptual ideas, such as macroscopic concepts involving voltage, current, resistance, Ohm's law, electromotive force, series and parallel circuits, as well as microscopic models based on point charges, electric fields, electric potential, force, and charge motion (Liu et al., 2022). Macroscopic concepts describe observable characteristics and relationships among circuit variables, whereas microscopic models provide mechanistic explanations of how the observed phenomena occur, leading to deeper conceptual understanding of electric circuits.

In general, the topic of direct current electric circuits includes Ohm's law (current, voltage, and resistance), electrical measuring instruments, and series and parallel circuits (Giancoli, 2001). Although these concepts may appear straightforward, many students still experience difficulties and misconceptions in understanding electric circuits. In particular, students frequently misunderstand the concepts of electric current and potential difference in series and parallel circuits (Balta & Logman, 2022). For example, some students believe that increasing the number of batteries connected in parallel will increase the potential difference. Other students assume that electric current produced in a circuit remains constant under all conditions (Bauman et al., 2024). To illustrate the basic configurations of electric circuits commonly introduced in this topic, Figure 1 presents examples of a simple series circuit with a single bulb and a parallel circuit with two bulbs connected to a battery.

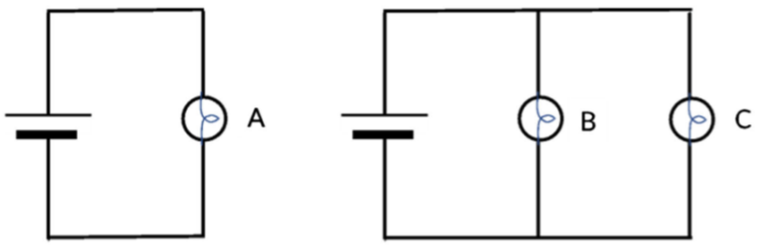

Figure 1. Simple electric circuits: a battery connected to a single bulb in series and a battery connected to two bulbs in parallel.

Understanding first-year university students' conceptions is important because this stage represents the transition from secondary school to higher education. Such information is essential for instructors in designing effective learning experiences. Students often enter university with diverse educational backgrounds and learning experiences. Some students studied physics for three years in secondary school, while others only studied it for one year. Consequently, students' initial conceptual understanding varies substantially.

For example, students enrolled in introductory physics courses may have highly diverse experiences: some have never conducted laboratory experiments, some primarily learned physics through textbooks and mathematical equations, while others possess incomplete conceptual understanding. Therefore, it is necessary to analyze students' conceptual understanding using one important physics topic, namely direct current electric circuits. This topic provides a fundamental basis for learning subsequent courses such as General Physics II, Electricity and Magnetism, Electronics, and even experimental physics courses. Accordingly, the purpose of this study was to analyze in depth students' understanding of simple direct current electric circuits related to electric current, voltage, and electric circuit configurations.

METHOD

This study employed a descriptive survey with qualitative explanation (Creswell & Creswell, 2018). Quantitative data consisted of students' selected answers, whereas qualitative data were obtained from students' written explanations for their choices. The study involved 107 first-year students enrolled in Physics Education and Chemistry Education programs who had previously studied physics in secondary school. Direct current electricity is included as part of the General Physics course in both programs.

To assess students' conceptual understanding, a four-option multiple-choice test consisting of three items accompanied by written reasoning was administered. The items focused on bulbs connected in parallel, batteries connected in parallel, and short circuits. The instrument was adapted from standardized conceptual tests on direct current electricity (Balta & Logman, 2022; Bauman et al., 2024). The test was first translated and subsequently validated by two university lecturers to ensure translation accuracy, appropriate physics terminology, and clarity of wording.

The test was administered to students during the first semester at the beginning of the course, and students completed it within approximately 20 minutes. Students' responses were then analyzed by calculating the number and percentage of students selecting options A, B, C, and D. Students' written explanations were grouped and analyzed using thematic analysis (Creswell & Creswell, 2018; Merriam & Tisdell, 2015).

RESULTS AND DISCUSSION

Students' conceptual understanding of direct current electric circuits was assessed using three four-option multiple-choice items accompanied by written explanations. The items examined students' understanding of current, voltage (potential difference), and electric circuits in three situations: bulbs connected in parallel to a battery, batteries connected in parallel to a resistor, and bulbs connected to a battery where one bulb was short-circuited.

Bulbs Connected in Parallel

The first item involved two identical bulbs connected in parallel to a battery, as shown in Figure 2. Students were asked to predict what would happen if one bulb (Bulb 2) was removed and to provide reasoning for their answer choices. The response options concerned the brightness of the remaining bulb and the potential difference between points C and D.

Perhatikan gambar rangkaian listrik di bawah ini. Sumber tegangan ε tidak memiliki hambatan dalam. Kedua bola lampu 1 dan 2 identik (sama) dan menyala. Apa yang terjadi Jika lampu 2 dilepas?

a. Bola lampu 1 akan menyala lebih terang
b. Beda potensial antara C dan D menjadi nol
c. Beda potensial antara C dan D tidak berubah
d. Beda potensial antara C dan D akan bertambah

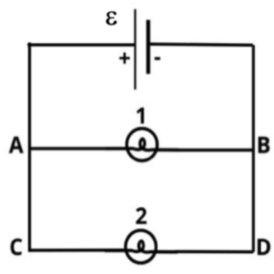

Figure 2. Question on bulbs connected in parallel

The analysis showed that 50% of students selected the option stating that Bulb 1 would become brighter. Meanwhile, 21% of students chose the option that the potential difference between points C and D would become zero, and another 21% selected the option that it would remain unchanged. Only 7% of students stated that the potential difference between points C and D would increase. The distribution of students' responses and the underlying reasons for each option are presented in Table 1.

Table 1. The percentage and reasons of students regarding bulbs connected in parallel circuits.

Options	Number n=107	Reasons
A	53(50%)	• Electric current through bulb 1 increases • The electric current flows only bulb 1. • The bulb 1 receives a greater voltage supply. • The electrical energy is not distributed among the components. • The electrical resistance decreases.
B	22(21%)	• No electric current flows through that point. • The electric current is interrupted.
C	23(21%)	• According to Ohm's Law, voltage is directly proportional to electric current; therefore, no change occurs. • Since the circuit is arranged in parallel, the electrical energy is distributed equally across the branches.
D	8(7%)	• An electrical disconnection occurs, resulting in an increase in the potential difference. • The potential difference between points A and B is independent of the potential difference between points C and D; therefore, the potential difference across C and D increases.

The correct answer was that the potential difference between points C and D remains unchanged even after one bulb is removed. Students who selected this answer generally reasoned that the circuit was connected in parallel and related their reasoning to Ohm's law, arguing that voltage is proportional to current. These students correctly identified the parallel configuration and recognized that potential difference remains the same across parallel branches.

An interesting finding was that half of the students believed that Bulb 1 would become brighter. Their explanations included statements such as "the electric current increases," "electrical energy is no longer divided," and "the resistance decreases." These responses suggest that students relied heavily on intuitive reasoning: when one object (a bulb) is removed, another quantity (current) must increase. Such intuitive reasoning is often compelling because it aligns with everyday experiences, consistent with findings reported by Balta and Logman (2022).

Students appeared to pay insufficient attention to the parallel arrangement of the bulbs or failed to apply Ohm's law appropriately before selecting their answers. As future teachers, however, students are expected to possess sufficiently deep conceptual understanding to provide accurate scientific explanations (Lin, 2017). Additionally, 21% of students stated that the potential difference between points C and D would become zero because no electric current flows through those points. These students failed to recognize that points A and C are directly connected, as are points B and D.

Batteries Connected in Parallel

The second question, shown in Figure 3, involved batteries connected in parallel, with one branch connected to a switch and an ammeter placed before the resistor. This item examined students' understanding of changes in electric current after the switch was closed.

Perhatikan gambar rangkaian listrik di bawah ini. Bagaimana perubahan angka yang ditunjuk pada amperemeter (A) ketika saklar ditutup?. Hambatan dalam baterai dianggap nol.

a. Tetap
b. Makin besar
c. Makin kecil
d. Nol

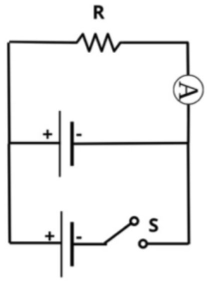

Figure 3. Question on batteries connected in parallel

The analysis showed that 39% of students correctly answered that the current would remain unchanged after the switch was closed. However, the explanations provided were generally weak. Some students stated that "the current path through the switch is different from the path through the ammeter," while others simply mentioned that "electron flow remains constant."

Most students did not relate their reasoning to the principle that batteries connected in parallel maintain the same potential difference, resulting in unchanged current. This finding is consistent with Kokkonen and Mäntylä (2018), who reported that university students often struggle to explain series and parallel battery arrangements.

Approximately 60% of students selected incorrect responses. About 36% believed that the current would become zero because the switch would "block" or "stop" the current. Some students also assumed that closing the switch prevents the circuit from functioning. These responses indicate that many students still misunderstand the role of switches in electric circuits, despite having studied them since elementary or secondary school (Ivanjek et al., 2021).

Furthermore, 13% of students stated that the current would decrease because "the current splits into two paths," whereas 11% believed that the current would increase because "energy and voltage increase."

Students frequently referred to everyday experiences, such as the idea that using more electrical appliances results in greater current flow. However, they failed to consider the specific configuration of the voltage source, namely batteries connected in parallel. This suggests that students activated prior intuitive knowledge resources that were applied inappropriately to the context (Robertson et al., 2025). The distribution of students' responses and the reasoning underlying each selected option are presented in Table 2.

Table 2. The percentage and reasons of students regarding batteries connected in parallel

Options	Number n=107	Reasons
A	42(39%)	• The electric current flowing through the switch and the ammeter is different; therefore, it does not affect the ammeter reading. • The electron flow remains constant.
B	12(11%)	• The voltage increases. • The electrical energy increases. • When the switch is closed, the current paths merge. • Greater electrical power consumption results in a larger current, as exemplified by the use of electrical appliances in households.
C	14(13%)	• The electric current is divided among the branches. • The total current remains constant; therefore, when the switch is closed, the electric current decreases. • Previously, the current flowed through only one path, whereas now it flows through two paths.

Options	Number n=107	Reasons
D	39(36%)	• The resulting voltage decreases. • When the switch is closed, the electric current ceases to flow. • When the switch is closed, the electric current is obstructed by the switch, causing the current to stop. • When the switch is closed, the electrical circuit is no longer operating. • No electric current flows through the circuit.

Short Circuit

The third question presented two simple electric circuits, as shown in Figure 4. The first circuit consisted of two bulbs, A and B, where Bulb B was short-circuited, while the second circuit contained a single bulb, C. Students were asked to determine the relative brightness of the three identical bulbs, assuming the batteries were also identical.

Perhatikan gambar rangkaian listrik di bawah ini. Lampu A,B, dan C identik (sama). Bagaimana tingkat kecerahan ketiga lampu?

a. Lampu C lebih terang dari lampu A dan lebih terang dari B
b. Lampu A=B=C (ketiga lampu sama terang)
c. Lampu A sama terang dengan lampu C dan lampu B mati
d. Lampu A sama terang dengan lampu B dan lebih redup dari lampu C

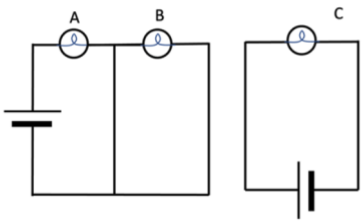

Figure 4. Question on short circuits

The results showed substantial variation in students' responses, ranging from 15% to 38% across the four options. The largest proportion of students (38%) incorrectly stated that bulbs A, B, and C would have equal brightness because "the electric current is the same" and "the bulbs are identical." These students appeared to assume that bulbs A and B were connected in series.

Students failed to recognize the branch between bulbs A and B and overlooked the fact that both terminals of Bulb B were directly connected, creating a short circuit. This misunderstanding may have been influenced by the visual representation of the circuit, which resembled the common textbook presentation of bulbs arranged sequentially. Therefore, circuit representation and visualization strongly influence students' understanding of electric circuits (Wang & Wei, 2024).

Additionally, 28% of students stated that bulbs A and B would have equal brightness because they considered the bulbs to be connected in series. These findings indicate that many students were unable to distinguish between different circuit configurations and their underlying principles. Similar findings have been reported by Liu et al. (2022) and Grob et al. (2026). To better understand the specific reasoning behind these misconceptions, students' response distribution along with their explanations for each answer option are presented in Table 3.

Table 3. The percentage and reasons of students regarding short circuit

Options	Number n=107	Reasons
A	16(15%)	• Bulb C operates independently and does not share the electrical load. • Bulbs A and B are connected in parallel, whereas bulb C is not. • The resistance of bulbs A and B is greater than that of bulb C. • The electric current through bulbs A and B is divided.

Options	Number n=107	Reasons
		• The voltage source is distributed between bulbs A and B, whereas the entire voltage is supplied to bulb C.
B	41(38%)	• The same electric current is supplied to each bulb. • This occurs because the bulbs are identical.
C	20(19%)	• No electric current flows through Lamp B. • Bulb B does not receive a voltage supply from any source.
D	30(28%)	• The electrical energy supplied from the source to bulb C is greater than that supplied to bulbs A and B. • The electric current flowing through bulbs A and B is equal. • Bulbs A and B receive the same voltage supply. • Bulbs A and B are connected in series.

CONCLUSION

Direct current electric circuits constitute an essential topic taught from elementary school through higher education. Therefore, analyzing students' conceptual understanding is important for designing effective instructional approaches. The findings of this study showed that more than 50% of first-year university students were unable to correctly answer questions related to direct current electricity, including bulbs connected in parallel, batteries connected in parallel, and short circuits. These findings indicate that students continue to experience substantial difficulties in understanding DC electric circuits despite repeated exposure to the topic throughout their education. Common misconceptions identified in this study included the belief that batteries produce constant current, that batteries connected in parallel increase voltage, and difficulties in distinguishing between series and parallel bulb arrangements. The implications of this study suggest that educators should design instructional approaches that challenge students' intuitive reasoning through conceptually oriented instruction, experiments, and interactive simulations to support the development of scientifically accurate understanding of direct current electricity.

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