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Research Article

Uncovering the Undergraduate Physiotherapy Students' Conceptual Understanding Levels and Misconceptions of Simple Electric Circuits from 2018 to 2023

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Abstract – This study aimed to investigate undergraduate physiotherapy students' conceptual understanding levels of simple electric circuits and the misconceptions they brought to introductory physics courses, over five years, from 2018 to 2023. This retrospective study adopted an exploratory research methodology. Using purposive sampling, undergraduate students majoring in physiotherapy and rehabilitation and attending the Physics II course at a private university from 2018 to 2023 were selected as participants. In total, the results of the Simple Electric Circuit Diagnostic Test (SECDT) voluntarily taken by 296 students (209 females and 87 males) aged 18 to 22 were included in the study. The students' responses in the SECDT were analyzed using MS Excel and further analysis with IBM PASW18. The researcher calculated the frequency of each misconception category by adding up the students' responses to all questions related to that category. The independent samples Kruskal Wallis test with post-hoc analysis (pairwise comparisons) was conducted to determine whether student groups in different academic years were statistically different regarding SECDT scores. The results showed that students held five common misconceptions over five years: clashing current model, short circuit misconception, power supply as constant current source model, sequential reasoning, and local reasoning. Moreover, the study revealed a peak in 2021-2022 regarding students having better conceptual understanding levels than other years. Five-year data showed that minimal changes have occurred, and that prevalent misconceptions did not change over time. These findings can help educators when designing their courses, explicitly focusing on these misconceptions to promote a better conceptual understanding of electricity.

Keywords: Physics for non-physicists, non-physics science majors, conceptual understanding levels, health sciences, misconception, physiotherapy, simple electric circuits.

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Introduction

Physics is often perceived as abstract and disconnected from students' everyday experiences (Kollöffel & de Jong, 2013; Ramma et al., 2017). Research in physics education has revealed that many introductory physics students struggle to grasp physics concepts (Neidorf et al., 2020). Developing these concepts is intricate and influenced by individuals' perceptions, experiences, and information acquisition habits. Life experiences differ from person to person, resulting in varying interpretations of the same subject. Language used in the classroom, textbooks, and even teachers can be primary sources of misconceptions (Hammer, 1996). It is crucial for instructors to identify and address these misconceptions to foster student engagement and facilitate a better grasp of scientific principles (Uwamahoro et al., 2021).

One abstract concept that deserves attention is electricity. Although invisible, it is omnipresent and essential to numerous crucial processes, such as powering electronic devices and enabling medical equipment. Understanding electricity is fundamental across all educational levels in physics, as it establishes a strong foundation for comprehending more complex subjects (Mbonyiryivuze et al., 2019; Mulhall et al., 2001). Studies in science education have focused on grasping conceptual understanding, particularly in simple electric circuits, both in practical and theoretical contexts (Ünal, 2022). Earlier studies have identified misconceptions about electricity (Chambers & Andre, 1997; Engelhardt & Beichner, 2004; Peşman & Eryılmaz, 2010; Shipstone, 1984).

It is important for students to have a good understanding of electricity, as it plays a significant role in various fields such as engineering, technology, and medicine (Melzer et al., 2012). The fundamental principles of electric circuits are crucial, as they form the basis for students' comprehension of technology (Önder et al., 2017). In this regard, physics courses designed for health science students should aim to provide essential conceptual understanding, building on their existing knowledge of physics, as argued by Özmen (2024). Physics is a fundamental science relevant to numerous professions (Ozdemir et al., 2020). Professionals such as physiotherapists rely on a foundational understanding of electricity (Espejo-Antúnez et al., 2022; Kollöffel & de Jong, 2013; Martellucci, 2015). This knowledge helps them use electrical modalities safely and effectively, comprehend the bioelectrical functions of the human body, keep up with technological advancements, and collaborate efficiently in healthcare settings (Melzer et al., 2012). Ultimately, this understanding contributes to improved patient care and treatment outcomes. Accordingly, this study aimed to investigate the misconceptions undergraduate physiotherapy students brought to introductory physics courses over five years, from 2018 to 2023.

This paper focuses on the conceptual understanding levels of physiotherapy and rehabilitation (PR) students related to simple electric circuits and investigates the following research questions:

i. How did PR students' conceptual understanding levels of simple electric circuits change between 2018 and 2023?
ii. Which misconceptions about simple electric circuits persisted among PR students between 2018 and 2023?
iii. Were there any significant differences between PR students' conceptual understanding levels and misconceptions of simple electric circuits over five years?

Background of the Study

Understanding key electrical concepts and the distinction between short and open circuits is essential for grasping the workings of simple electric circuits. The literature contains ample evidence of misconceptions about simple electrical circuits, common even among students who have received formal instruction in the relevant material (Quezada-Espinoza et al., 2023). Many students often deem electric circuits complex and abstract, with several studies highlighting their learning challenges (Taslidere & Yıldırım, 2023). Consequently, extensive research has identified misconceptions surrounding simple electric circuits (Chambers & Andre, 1997; Peşman & Eryılmaz, 2010; Turgut et al., 2011). Early research on the subject demonstrated that students struggle with the concept of electricity (Chambers & Andre, 1997; Shipstone, 1984).

Previous research has extensively documented several common misunderstandings about simple electric circuits. For instance, students often incorrectly assume that electric current is used up as it travels through a circuit, which can hinder learning about current conservation and the Kirchhoff's laws (Shipstone, 1984). Another prevalent misconception is that batteries provide a constant current rather than a constant voltage, which can confuse students when analyzing circuit behavior under various loads (McDermott & Shaffer, 1992). Confusion about the direction of current flow, particularly the difference between conventional current (positive to negative) and electron flow (negative to positive), is also widespread (Dupin & Johsua, 1987).

Students often misunderstand the role of a voltage source, thinking that it pushes the current through a circuit without realizing that it actually establishes a potential difference driving the current (Fredette & Lochhead, 1980). Many students incorrectly assume that the voltage is the same at all points in a circuit, failing to recognize that the potential difference between two points which drives the current flow. Misconceptions about series and parallel circuits are also common, especially regarding the voltage and the current distribution.

Students frequently fail to understand that the voltage across each branch is the same in parallel circuits, while in series circuits, the current through each component is identical (Cohen et al., 1983). In parallel circuits, they may fail to understand how the current is divided among branches, affecting each branch's total resistance and their individual currents (Chambers & Andre, 1997). Researchers have also reported specific misconceptions about electricity and electric circuits in the literature (Engelhardt & Beichner, 2004; Peşman & Eryılmaz, 2010).

In their review, Duman and Avcı (2014) examined the studies that identified the misconceptions of secondary school students and pre-service science and technology teachers in science education between 2003 and 2013 in Türkiye-based university journals available electronically. They detected two studies related to misconceptions: about simple electric circuits (Ateş & Polat, 2005) and about the electric current (Yıldırım et al., 2008). In a similar study, Yeltekin-Atar et al. (2021) examined the studies on misconception and conceptual understanding in physics education published between 2010 and 2019 within all volumes of the faculty of education journals. The results showed that “electricity and magnetism” is the third most common physics content in misconception and conceptual understanding studies (in 13 out of 90 studies).

However, previous studies differ in their prevalence of common misconceptions related to simple electric circuits. Ateş and Polat (2005) identified the following misconceptions in their study with university students: sequential reasoning (41%), the power supply as a constant current source model (38%), the shared current model (27%), the attenuation model (7%), the unipolar model (4%), and the clashing current model (5%). Another study by Yıldırım et al. (2008) focused on 6-8th-grade students and their understanding of electricity. It revealed that most students had misconceptions about electric currents, consistently across all three grades, and that students often struggled with basic and abstract concepts of current and voltage. Additionally, when changes were made to electric circuits, such as adding a resistance, students had difficulty in distinguishing between equivalent current and voltage concepts. They also faced challenges in grasping the effects of resistance on current and voltage, leading to misconceptions.

Looking at the studies in the literature, Çepni and Keleş (2006) listed the most common misconceptions as: the power-consumption model, the clashing currents model, and the attenuation model. In a study conducted with pre-service science teachers, Altun (2009) reported that short circuit, shared current, attenuation, and clashing currents models are the most common misconceptions. Peşman and Eryılmaz (2010) found the shared current model, the clashing current model, short circuit misconception, power supply as a constant current source, and the local reasoning model as the most common misconceptions.

In Karakuyu and Tüysüz's (2011) study involving tenth-grade students, one common misconception was the belief that adding or removing a resistance from the circuit would always increase or decrease the total resistance, regardless of how the resistors were connected.

Another extensive study conducted by Eryılmaz et al. (2016) aimed to assess misconceptions across different regions in Türkiye by administering the Simple Electric Circuits Diagnostic Test (Peşman, 2005) to a large sample of high school students (N=11550). The study revealed that the most prevalent misconception (31%) among students regarding simple electrical circuits was the clashing current model.

In a study conducted with students in physiotherapy and rehabilitation major, the clashing current and the local reasoning models were found to be more common misconceptions (Özmen, 2019). Similarly, in Özmen's (2022) study, the most common misconceptions among the students in audiology major were the clashing current and the local reasoning models, where the students consider the electric circuit locally ignoring that the events in the whole circuit coincide.

These misconceptions can significantly impact learning, leading to difficulties in understanding more advanced topics and applying theoretical knowledge in practical situations (Reiner et al., 2000). Misconceptions can persist despite instruction, suggesting that traditional teaching methods may be ineffective in addressing these issues (Özmen, 2024; Vosniadou, 1994). Previous research has shown that misconceptions about electric circuits are resistant to change because they are often based on intuitive but incorrect interpretations of physical phenomena (Reiner et al., 2000). Therefore, it is crucial for educators to identify these misconceptions early and address them through targeted instructional interventions.

Educators can develop more effective teaching strategies that enhance student learning and comprehension in introductory physics courses by understanding the most frequent misconceptions related to simple electric circuits.

Assessment of Misconceptions with Multiple Choice Diagnostic Tests

Multiple-choice tests are commonly used in educational assessments as they evaluate the knowledge of the students and pinpoint misunderstandings (Kaltakci-Gurel et al., 2015). To address these misunderstandings, researchers have developed one, two, and three-tier multiple-choice tests, each providing varying levels of diagnostic precision. One-tier multiple-choice tests are the most conventional type, consisting of a single question and several answer choices. These tests are efficient and straightforward to administer, making them popular in large classroom settings. However, one-tier tests often do not fully uncover the reasoning behind students' choices. While they can identify incorrect answers, they do not offer insight into the misconceptions that led to those answers (Haladyna, 2004).

Two-tier multiple-choice tests were created to tackle this limitation. The first tier comprises a traditional multiple-choice question, while the second tier requires students to explain their choice. This format enables educators to gain insight into the students' thought processes and pinpoint specific misunderstandings. For example, when assessing understanding of Ohm's Law, the first tier might inquire about the current through a resistor given a certain voltage and resistance, while the second tier would request the student to explain their reasoning (Treagust, 1988). This additional layer of questioning helps differentiate between different types of misunderstandings and provides more detailed diagnostic information.

Three-tier multiple-choice tests add another layer of depth by incorporating a confidence rating. After answering the initial question and providing a reason, students indicate their confidence in their answers. This tier helps to identify not only the presence of misunderstandings but also the students' certainty in their incorrect beliefs (Caleon & Subramaniam, 2010; Peşman & Eryılmaz, 2010). For instance, in a three-tier test on electric circuits, a student might select an incorrect answer about parallel circuit behavior, provide a flawed explanation, and then rate their confidence as high. This combination of responses indicates a strong and potentially resistant misconception that requires targeted instructional intervention.

Method

Research Design

This retrospective study used exploratory research methodology in a longitudinal manner. Longitudinal studies involve collecting continuous or repeated data to track specific individuals over long periods (Caruana et al., 2015). These studies are typically observational, as researchers gather quantitative and/or qualitative data on various exposures and outcomes without introducing any external influence (Rezigalla, 2020). Longitudinal research can take various forms and this study adopted a "repeated cross-sectional" research design, where participants differed entirely on each sampling occasion.

Participants

Using purposive sampling, the study retrospectively analyzed the results of the Simple Electric Circuit Diagnostic Test (SECDT) voluntarily taken by undergraduate students in physiotherapy and rehabilitation major enrolled in the Physics II course at Başkent University from 2018 to 2023. In total, 296 students were included in the study, with 209 females and 87 males. Table 1 presents the distribution of participants by gender over the five-year period.

Table 1 The Gender Distribution of the Participants across Five Years

Year	Female N (%)	Male N (%)	Total N (%)
2018-2019	50 (84.7)	9 (15.3)	59 (19.9)
2019-2020	39 (72.2)	15 (27.8)	54 (18.2)
2021-2022	55 (82.1)	12 (17.9)	67 (22.6)
2022-2023	23 (60.5)	15 (39.5)	38 (12.8)
2023-2024	42 (53.8)	36 (46.2)	78 (26.4)
Total	209 (70.6)	87 (29.4)	296 (100)

Instrument

The Simple Electric Circuit Diagnostic Test (SECDT) was utilized in this study to evaluate students' conceptual understanding level. The SECDT is a three-tier diagnostic test developed by Peşman (2005) that measures 11 misconception models related to simple electric circuits through 12 questions (p. 157). The first set of questions consists of multiple-choice queries with typically two or three options. The subsequent set requires justifications for the chosen answer from the first tier, and the final set evaluates the students' confidence in their responses to the previous questions. By combining answers from the first and second tiers and responding to "sure" in the third tier, specific misconception models based on the answers are represented. These models include the sink model (M1), the attenuation model

(M2), the shared–current model (M3), the clashing current model (M4), the empirical rule model (M5), the short circuit model (M6), the power supply as a constant current source model (M7), the parallel circuit model (M8), the sequential reasoning model (M9), the local reasoning model (M10), and the current flow as water flow model (M11). For a comprehensive understanding of the SECDT structure, it is advisable to refer to Table 1 in Peşman and Eryılmaz's (2010) study (p. 212). The reliability coefficient of the test provided in the original research was calculated to be 0.33 for misconception scores and 0.69 for correct scores using the Cronbach's alpha. For the current study, the reliability coefficient is calculated as 0.41 for misconception scores; and as 0.70 for correct scores. The reliability coefficients computed from the misconceptions scores are typically lower than those calculated from the correct scores (Kaltakci-Gurel et al., 2017). The reliability coefficients in this study are similar to those in Peşman (2005) , representing the nature of misconception tests (Arı et al., 2017).

Data Collection

The study was approved by the Başkent University Institutional Review Board and Ethics Committee (Project no: KA23/284) and supported by the Başkent University Research Fund. Data collection occurred yearly at the beginning of the spring semester during the second week of the Physics II course. Students were informed about the study during the first week of the course, and additional (bonus) points were given to students who participated voluntarily. Data collection was completed within a 50-minute lecture. Data was not collected during the 2020-2021 spring semester because the author was on maternal leave. Additionally, due to February 2023 Kahramanmaraş earthquakes, the data collection was conducted online during the 2022-2023 spring semester. A low response rate was noted due to the Council of Higher Education's (CoHE, 2023) declaration that made the participation in online courses non-mandatory.

Data Analysis

The students' responses in the SECDT were analyzed using the MS Excel and the IBM PASW18. The researcher calculated the frequency and percentage of each misconception category by adding up students' responses to all questions related to that category. Any misconception with a rate of 10% or higher is regarded as a serious misconception in this study, as Caleon and Subramaniam (2010) recommended. Since the assumption of normal distribution for the dependent variables was violated, the independent samples Kruskal Wallis test with post-hoc analysis (pairwise comparisons), a non-parametric test, was conducted to determine whether student groups (clusters) in different academic years were statistically different in terms of SECDT scores.

Results

Descriptive Results of PR Students' Responses to the SECDT

The descriptive statistics of SECDT across different academic years indicate variations in students' performance (Figure 1). The mean scores varied, with the lowest in 2019-2020 at 3.76 and the highest in 2021-2022 at 5.91. The maximum score varies slightly between 9 and 10 within years, except the peak at 12 in 2021-2022. The data suggests varying student performance levels across different years, with notable improvements in certain periods and declines in others.

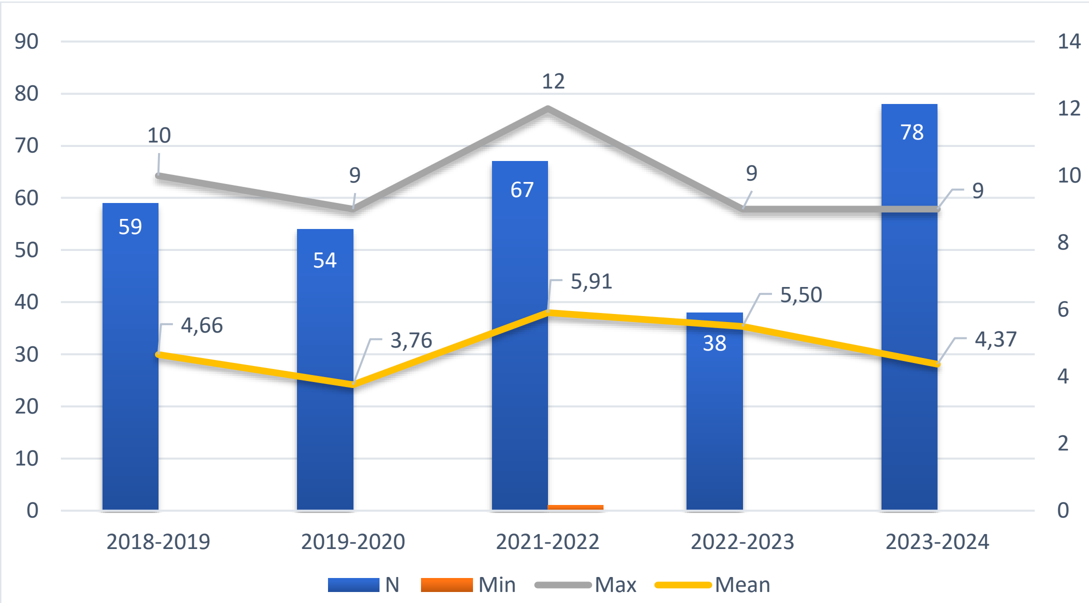

Figure 1 Descriptive Statistics of the SECDT scores from 2018 to 2023

Table 2 outlines the percentage of correct responses students gave in the SECDT. Out of 12 questions, students had a correct response rate of less than 30% in five questions (Q2, Q3, Q5, Q9, and Q10).

Table 2 Percentage of Students' Correct Responses for Each Question in SECDT

Question No.	Correct responses - percentage (%) 2018-2019	2019-2020	2021-2022	2022-2023	2023-2024
Q1	42.4	42.6	**70.1**	44.7	39.7
Q2	**8.5**	7.4	1.5	5.3	5.1
Q3	**15.3**	14.8	10.4	13.2	9.0
Q4	50.8	42.6	82.1	**86.8**	67.9
Q5	5.1	0.0	6.0	**7.9**	2.6
Q6	59.3	51.9	**86.6**	76.3	65.4
Q7	64.4	53.7	77.6	**84.2**	61.5
Q8	**59.3**	38.9	58.2	44.7	43.6
Q9	23.7	16.7	26.9	**28.9**	12.8
Q10	10.2	7.4	13.4	**15.8**	14.1
Q11	67.8	64.8	**85.1**	81.6	67.9
Q12	61.0	35.2	**73.1**	60.5	52.6

*Boldface numbers refer to the highest percentages within year clusters.

Q2 analyzes a parallel circuit to determine the current flowing through each branch. Q3 examines how the magnitude of electric current changes in a series of bulb connections. Similarly, Q5 requires students to compare the magnitude of electric current when a new bulb is connected in parallel to a simple electric circuit. In Q9, students are asked to compare the brightness of a bulb connected with two identical resistors in series (10Ω-bulb-10Ω). This is done by increasing the resistance of one resistor in the electric circuit (10Ω-bulb-20Ω) and changing the location of resistors (20Ω-bulb-10Ω). Lastly, Q10 inquires whether a bulb gives light if one point of the bulb touches the current-carrying wire.

Distribution of Misconception Models Related to Simple Electric Circuits

The distribution of the sink model misconception (M1) across different academic years is detected by three alternative responses given to Q1 and Q10 (M1_1: 1.1 a, 1.2 a, 1.3 a; M1_2: 10.1 a, 10.2 b, 10.3 a; M1_3: 10.1 b, 10.2 b, 10.3 a). Q1 asks whether a lamp will give light if it is connected to the positive terminal of a battery with a connecting wire. On the contrary, the same question is asked in Q10 when a wire is connected to a battery's negative and positive terminals while the lamp touches the wire. If a student believes that a lamp will light up when connected to the positive terminal of a battery with a wire, they might have the sink model misconception. Similarly, if a student confidently explains that the lamp will or will not light up because "the bulb is connected to the positive terminal," they may also have the sink model. Occurrences of the misconception were relatively low. However, the frequency and percentage of M1_3 increased considerably over time, reaching 14.1% in

2023-2024. The data underscores the persistence and increase of specific misconceptions about the sink model among students over the years (see Appendix).

The attenuation model misconception (M2) across different academic years was measured with two alternative responses to Q4 in the SECDT (M2_1: 4.1 c, 4.2 c, 4.3 a; M2_2: 4.1 b, 4.2 c, 4.3 a.). In Q4, two identical bulbs are connected with a battery in series, and the magnitudes of currents in each connection and the brightness of the bulbs are compared. If the students confidently explain that the magnitude of electric current will decay as the bulbs consume it, they may hold the attenuation model misconception. M2_1 shows a gradual increase in occurrences, from 1.7% in 2018-2019 to 7.7% in 2023-2024, indicating a rising trend in this alternative response over the years (see Appendix). However, the findings suggest that this misconception has either been non-existent or has not been effectively addressed recently.

The shared current model misconception (M3) across different academic years was measured by five alternative responses to Q3, Q4, and Q5 (M3_1: 3.1 b, 3.2 c, 3.3.a; M3_2: 3.1 a, 3.2 c, 3.3 a; M3_3: 4.1 d, 4.2 c, 4.3 a; M3_4: 5.1 b, 5.2 c, 5.3 a; M3_5: 5.1 a, 5.2 c, 5.3 a). In these questions, students have a misconception that electrical devices equally share an electrical current independent of how they are connected. The occurrence of the misconception varied slightly over the years, especially for M3_1, M3_2, and M3_5 (see Appendix). For example, M3_2 shows notable fluctuations, peaking at 10.5% in 2022-2023.

The distribution of the clashing current model misconception (M4) across different academic years is presented in Table 3. This model is detected by two alternative responses to Q1 and Q10 (M4_1: 1.1 b, 1.2 b, 1.3 a; M4_2: 10.1 a, 10.2 a, 10.3 a). If students respond to these questions that positive and negative charges should meet in the bulb to give light, they may have a clashing current model. M4_1 shows a marked increase over the years, beginning at 27.1% in 2018-2019 and rising to 48.7% in 2023-2024, indicating a growing prevalence of this misconception among students. Similarly, M4_2 began at 10.2% in 2018-2019, dropped to 3.7% in 2019-2020, then surged to 11.9% in 2021-2022, peaking at 21.1% in 2022-2023 before slightly declining to 7.7% in 2023-2024. These trends highlight a persistent challenge with the clashing current model misconception, with particularly high occurrences of M4_1.

Table 3 Distribution of Clashing Current Model Misconception (M4)

Year	M4_1		M4_2	
	f	%	f	%
2018-2019	16	27.1	6	10.2
2019-2020	13	24.1	2	3.7
2021-2022	16	23.9	8	11.9
2022-2023	18	47.4	8	21.1
2023-2024	38	48.7	6	7.7

*M4_1: 1.1 b, 1.2 b, 1.3 a; M4_2: 10.1 a, 10.2 a, 10.3 a.

The empirical rule model misconception (M5) was assessed through three different responses to Q4, Q7, and Q12 (M5_1: 4.1 b, 4.2 a, 4.3 a; M5_2: 7.1 b, 7.2 b, 7.3 a; M5_3: 12.1 a, 12.2 b, 12.3 a). The questions inquire how students perceive the brightness of bulbs when they are connected in series (Q4), connected in parallel (Q7), and connected in parallel with a conductive wire (Q12). Students who hold empirical rule model respond to these questions as the bulb will shine brighter if it is positioned near the battery in a circuit. The responses for M5_1, M5_2, and M5_3 consistently remained low (see Appendix). Overall, it seems that empirical model misconceptions are less frequent compared to other misconceptions.

The distribution of misconceptions about short circuits (M6) among students in different academic years is presented in Table 4. The model is identified through four responses to questions 8, 10, and 12 (M6_1: 8.1 b, 8.2 b, 8.3 a; M6_2: 8.1 c, 8.2 c, 8.3 a; M6_3: 10.1 a, 10.2 c, 10.3 a; M6_4: 12.1 b, 12.2 d, 12.3 a). Students who hold short circuit misconception responds to these questions without recognizing the conductive wire connections in an electric circuit. M6_1 is the most commonly chosen alternative, with occurrences rising significantly from 11.9% in 2018-2019 to a peak of 19.2% in 2023-2024. M6_2 remains consistently low with minimal variation. On the other hand, M6_3 showed fluctuations, reaching a notable high of 15.8% in 2022-2023. Similarly, M6_4 also displayed variations, peaking at 9.0% in 2023-2024. These trends indicate that while M6_2 is less common, M6_1 and M6_3 are more frequently observed, signaling ongoing challenges in students' comprehension of the short circuit concept.

Table 4 Distribution of Short Circuit Misconception (M6)

Year	M6_1		M6_2		M6_3		M6_4	
	f	%	f	%	f	%	f	%
2018-2019	7	11.9	2	3.4	1	1.7	3	5.1
2019-2020	10	18.5	2	3.7	3	5.6	2	3.7
2021-2022	9	13.4	3	4.5	7	10.4	1	1.5
2022-2023	3	7.9	4	10.5	6	15.8	3	7.9
2023-2024	15	19.2	2	2.6	10	12.8	7	9.0

*M6_1: 8.1 b, 8.2 b, 8.3 a; M6_2: 8.1 c, 8.2 c, 8.3 a; M6_3: 10.1 a, 10.2 c, 10.3 a; M6_4: 12.1 b, 12.2 d, 12.3 a.

Table 5 provides an analysis of the distribution of the power supply as constant current misconception (M7) across five academic years by four alternative responses to Q3, Q5, and Q9 (M7_1: 3.1 c, 3.2 a, 3.3 a; M7_2: 3.1 a, 3.2 a, 3.3 a; M7_3: 5.1 c, 5.2 e, 5.3 a; M7_4: 9.1 d, 9.2 d, 9.3 a). The data reveals a varying prevalence of these misconceptions over the years. M7_1 gradually increased from 11.9% in 2018-2019 to 32.1% in 2023-2024, peaking at 34.3% in 2021-2022. M7_2 and M7_4 responses were consistently low. M7_3 showed a significant rise, starting from 37.3% in 2018-2019, peaking dramatically at 77.6% in 2021-2022, before slightly declining to 50.0% in 2023-2024. Overall, the data highlights persistent and fluctuating trends in misconceptions about constant current in power supplies, with M7_1 and M7_3 being notably prevalent, while M7_2 and M7_4 remained relatively uncommon.

Table 5 Distribution of Power Supply as Constant Current Misconception (M7)

Year	M7_1		M7_2		M7_3		M7_4	
	f	%	f	%	f	%	f	%
2018-2019	7	11.9	0	0.0	22	37.3	0	0.0
2019-2020	6	11.1	0	0.0	12	22.2	0	0.0
2021-2022	23	34.3	1	1.5	52	77.6	2	3.0
2022-2023	13	34.2	0	0.0	21	55.3	0	0.0
2023-2024	25	32.1	1	1.3	39	50.0	5	6.4

*M7_1: 3.1 c, 3.2 a, 3.3 a; M7_2: 3.1 a, 3.2 a, 3.3 a; M7_3: 5.1 c, 5.2 e, 5.3 a; M7_4: 9.1 d, 9.1 d, 9.3 a.

One response alternative to Q5 in SECDT measured the parallel circuit misconception (M8) distribution (M8_1: 5.1 a, 5.2 a, 5.3 a.). The findings indicated that this misconception was not very common among students (see Appendix).

Table 6 displays the distribution of misconceptions related to sequential reasoning (M9) over five academic years, considering two alternative responses to Q9 (M9_1: 9.1 a, 9.2 a, 9.3 a; M9_2: 9.1 c, 9.2 b, 9.3 a). The data reveals consistent and fluctuating patterns in misconceptions about sequential reasoning with M9_1, while M9_2 remained relatively uncommon.

Table 6 Distribution of Sequential Reasoning Misconception (M9)

Year	M9_1		M9_2	
	f	%	f	%
2018-2019	4	6.8	1	1.7
2019-2020	7	13.0	0	0.0
2021-2022	16	23.9	0	0.0
2022-2023	6	15.8	6	15.8
2023-2024	15	19.2	2	2.6

*M9_1: 9.1 a, 9.2 a, 9.3 a; M9_2: 9.1 c, 9.2 b, 9.3 a.

In Table 7, the distribution of local reasoning misconception (M10) is displayed across different academic years by three alternative responses to Q2, Q5, and Q12 (M10_1: 2.1 a, 2.2 a, 2.3 a; M10_2: 5.1 a, 5.2 b, 5.3 a; M10_3: 12.1 a, 12.2 c, 12.3 a). The response to M10_1 is quite prevalent throughout the years, peaking at 85.1% in 2021-2022. However, the prevalence of responses to Q5 and Q12 are quite low when compared to the M10_1 response given for Q2.

Table 7 Distribution of Local Reasoning Misconception (M10)

Year	M10_1		M10_2		M10_3	
	f	%	f	%	f	%
2018-2019	29	49.2	1	1.7	0	0.0
2019-2020	32	59.3	4	7.4	2	3.7
2021-2022	57	85.1	2	3.0	4	6.0
2022-2023	30	78.9	1	2.6	0	0.0
2023-2024	60	76.9	3	3.8	2	2.6

*M10_1: 2.1 a, 2.2 a, 2.3 a; M10_2: 5.1 a, 5.2 b, 5.3 a; M10_3: 12.1 a, 12.2 c, 12.3 a

Lastly, the current flow as water flow misconception model (M11) was measured by three alternative responses to Q6, Q7, and Q11 (M11_1: 6.1 a, 6.2 a, 6.3 a; M11_2: 7.1 c, 7.2 a, 7.3 a; M11_3: 11.1 a, 11.2 b, 11.3 a). The analysis revealed that this misconception was not very common among students (see Appendix).

To sum up, over five years, the results indicated that students held five common misconceptions that they might bring from K-12 education and/or their daily life experiences: the clashing current model (M4), the short circuit misconception model (M6), the power supply as constant current source model (M7), the sequential reasoning (M9), and the local reasoning model (M10).

Comparison of PR Students' Conceptual Understanding Levels of Simple Electric Circuits Across Five Years

The student responses to the SECDT were coded as correct (i.e., 1st tier: correct, 2nd tier: correct, 3rd tier: sure), as misconception (specific combinations of tiers as reported by Peşman and Eryılmaz (2010)), and as incorrect (e.g. all "not sure" responses to 3rd tier, any response does not fit into misconception category but incorrect, neglecting confidence level). Incorrect answers also indicate "lack of knowledge" about the electricity concept.

Kruskal-Wallis tests indicated that there were significant differences in PR students' correct response scores (χ^2 (4, 296) = 30.146, $p < .001$), incorrect response scores (χ^2 (4, 296) = 50.570, $p < .001$), and misconception scores (χ^2 (4, 296) = 49.368, $p < .001$) across different academic years. Post-hoc comparisons are conducted by using the Bonferroni correction for multiple tests, indicating the mean rank of students' correct responses, incorrect responses, and misconception scores in the SECDT. The pairwise comparisons for correct, incorrect, and misconception scores across academic year clusters are displayed in Figure 2.

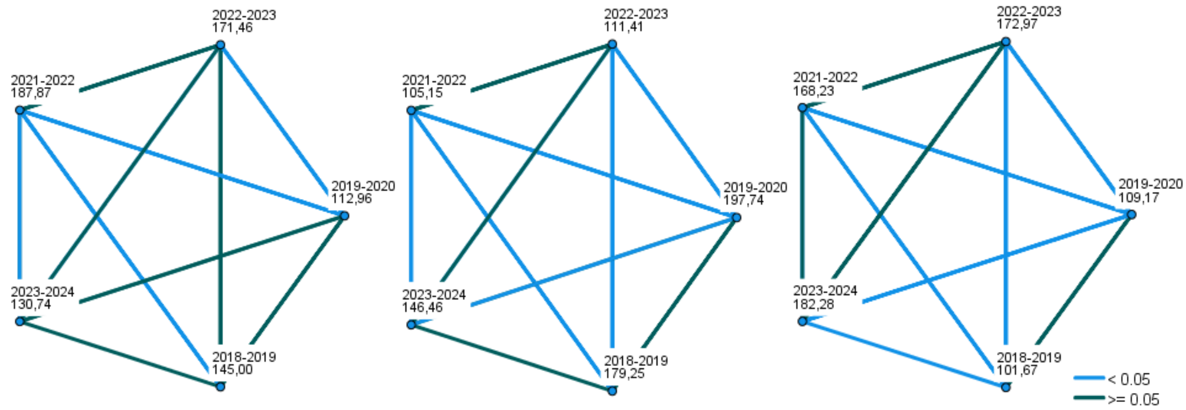

Figure 2 Pairwise Comparisons Across Years of PR Students' (a) Correct Response Scores, (b) Incorrect Response Scores, and (c) Misconception Scores in the SECDT.

The SECDT correct response scores of PR students enrolled in the 2021-2022 academic year were significantly higher than those of students enrolled in the 2018-2019 cluster, $p = 0.047$, students enrolled in 2019-2020, $p < .001$, and students enrolled in 2023-2024, $p < .001$. On the other hand, the SECDT incorrect response scores of PR students enrolled in the 2021-2022 academic year were significantly lower than those of students enrolled in the 2018-2019 cluster, $p < .001$, students enrolled in 2019-2020, $p < .001$, and students enrolled in 2023-2024, $p = 0.035$. Even though PR students in the 2021-2022 cluster have higher correct and lower incorrect responses in the SECDT, their misconception scores were significantly higher than those of students enrolled in the 2018-2019 cluster, $p < .001$, and students enrolled in 2019-2020, $p < .001$.

The SECDT correct response scores of PR students enrolled in the 2022-2023 academic year were significantly higher than those enrolled in the 2019-2020 cluster, $p = 0.047$. Conversely, the SECDT incorrect response scores of PR students enrolled in the 2022-2023 academic year were significantly lower than those of students enrolled in the 2018-2019 cluster, $p = 0.001$, and students enrolled in the 2019-2020 cluster, $p < .001$. When the SECDT misconception scores of PR students enrolled in the 2022-2023 academic year were considered, they were significantly higher than those of students enrolled in the 2018-2019 cluster, $p < .001$, and in 2019-2020, $p < .001$.

Discussions and Suggestions

The current study tracked health science students' conceptual understanding levels of simple electric circuits within five academic years to determine the trend of prevalent misconceptions brought to the university level. The results revealed a peak in 2021-2022 regarding better conceptual understanding level (see Figure 1 and Figure 2a). This might imply that these students were positively affected by the school closures during the COVID-19 pandemic. Attending online classes can create a sense of being in a physical classroom. When instructors use a video camera, students feel more motivated, and watching the instructor explain the topics helps them concentrate better (Al-Kumaim et al., 2021). Gökbulut (2021) identified a moderate positive association between the level of educational perception among higher education students and their readiness for mobile learning. This association was attributed to the fact that individuals can access information through mobile devices at any time, regardless of their location, thereby taking advantage of the benefits of distance education. The current study showed that this temporary effect due to a novelty (online education) has declined throughout the years. Moreover, the same effect was not observed for the 2022-2023 cluster affected by online education due to the Kahramanmaraş earthquakes. The difference may stem from the attendance not being mandatory.

However, considering misconception scores across the years (see Figure 2c), students of the 2018-2019 and 2019-2020 groups, who were not exposed to online education during high school, have fewer misconceptions than the other groups. Similarly, according to Koto and Ilhami (2023), students have been found to develop misconceptions about dynamic fluids following the shift to online learning during the COVID-19 pandemic. This can be attributed to reduced interaction between students and teachers, technical issues, and difficulty grasping key concepts.

The SECDT questions that were rarely answered correctly (Q2, Q3, Q5, Q9, and Q10) within five years indicate that students did not have a sound conceptual understanding related to how electric current flows through the series or parallel circuits, how the magnitude of electric current changes in a series of bulb connections, how the magnitude of electric current affected when changing the place of circuit elements, and lastly, how a bulb should be connected with a conducting wire and a cell to give light.

There is a thin line between having a good conceptual understanding and holding less misconception, and it cannot be stated that there is a linear relationship between them. The results of pairwise comparisons of PR students' performances over five years (see Figure 2) provide evidence for this. When the students' performances are evaluated from a misconception point of view, 7 out of 11 misconception models diagnosed by the SECDT were rarely detected within five years. These are the unipolar/sink model (M1), the attenuation model (M2), the shared current model (M3), the empirical model (M5), the parallel circuit misconception (M8), and the current flow as water flow misconception (M11). Even though students did not have a sound conceptual understanding of electric current, the aforementioned misconception models were not prevalent among students in different year clusters. We can conclude that students lack knowledge of these concepts.

In a prior analysis, Mackay and Hobden (2012) utilized diagrams to explore the preconceived notions of South African university students regarding electric circuits. The findings revealed that 34% of the "errors" stemmed from unipolar thinking. The researchers discussed that the unipolar model tends to resist prolonged instruction. However, in the current study, the percentage of PR students in each academic year cluster holding the unipolar/sink model was apparently lower than that proposed by Mackay and Hobden's (2012) findings. Tsai et al. (2007) suggested that the variation among studies might have resulted from various researchers' use of different diagnostic tools.

The study detected five prevalent misconception models between 2018 and 2023 clusters with percentages of more than 10%: the clashing current model (M4), the short circuit misconception (M6), the power source as constant current source model (M7), the sequential reasoning model (M9), and the local reasoning model (M10). Similar findings were reported in Manunure et al.'s study (2020), which identified the secondary students' misconceptions. Pretest results on the SECDT of control and experimental groups showed that the clashing current and short-circuit misconception models were the most prevalent misconceptions among students.

Moreover, these results are comparable to Peşman and Eryılmaz's (2010) and Aligo et al.’s (2021) findings. Peşman and Eryılmaz (2010) reported the most common misconception models among high school students as the shared current (M3), clashing current (M4), short circuit (M6), power supply as a constant current source (M7), and local reasoning (M10) models. In the current study, the shared current model was uncommon among students except for the 2022-2023 cluster (10.5%). As the trend of M3 declines through the following year, it is difficult to note that the shared current model is prevalent among PR students. In the latter study, the most common misconception model among high school students was found as the clashing current model (M4), which is followed by short circuit (M6), empirical rule (M5), shared current (M3), local reasoning (M10), and current flow as water flow (M11) models. In the same study, researchers examined the prevalence of misconceptions among science teachers of these high school students and found that the short circuit model (M6) was the most common misconception, followed by current flow as water flow (M11), clashing current (M4), shared current (M3), local reasoning (M10), and parallel circuit (M8) misconception models. This finding may be projected in the current study, which shows that potential source of common misconceptions might be the K-12 teachers’ misconceptions. Further research may focus on longitudinal studies to update the sources of alternative conceptions starting from early years in new era.

Taslidere and Yıldırım (2023) found that many university students held onto the misconception of the clashing current model (M2) before and after receiving instructions. The researchers concluded that providing conceptual change texts enhanced with concept cartoons could improve primary preservice teachers’ understanding of simple electricity. However, even after instruction, students were still inclined to think that the clash between positive and negative electricity in an electrical device made it operate. The current study's findings also showed that, over the years, the clashing current model has been quite persistent among students, implying that this might not have been addressed adequately through K-12 education. These results might also imply that there is not a single solution to remediate each misconception, and that new teaching strategies should be developed and implemented in the early stages of education, especially for the clashing current model.

In conclusion, PR students hold various misconceptions that might impede their practical work, which should be addressed in introductory physics courses. Five-year data shows minimal changes occurred, and the prevalent misconceptions did not change over time. These findings can help educators in designing their courses by explicitly focusing on these misconceptions to promote a better conceptual understanding of electricity.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

The author declares no competing interests.

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CRediT author statement

This study has a single author, and according to ethical rules, the responsible author carried out all research processes.

Research involving Human Participants and/or Animals

This retrospective research was conducted in accordance with ethical principles and rules. It was approved by the Başkent University Institutional Review Board and Ethics Committee (Project no: KA23/284).

Fizyoterapi Lisans Öğrencilerinin Basit Elektrik Devrelerine İlişkin Kavramsal Anlama Düzeylerinin ve Kavram Yanılgılarının 2018-2023 Döneminde İncelenmesi

Özet:

Bu çalışmanın amacı, 2018-2023 yılları arasında, fizyoterapi lisans öğrencilerinin basit elektrik devreleri ile ilgili kavramsal anlama düzeyleri ile fizik derslerine getirdikleri kavram yanılgılarının ortaya çıkartılmasıdır. Bu retrospektif çalışmada açıklayıcı bir araştırma metodolojisi benimsenmiştir. Katılımcılar, amaca uygun örnekleme yöntemi kullanılarak, 2018-2023 yılları arasında bir vakıf üniversitesinde Fizik II dersine kayıt olan fizyoterapi ve rehabilitasyon lisans öğrencilerinden seçilmiştir. Yaşları 18 ila 22 arasında değişen toplam 296 öğrenci (209 kadın ve 87 erkek) tarafından gönüllü olarak doldurulan Basit Elektrik Devreleri Tanı Testi (BEDTT) sonuçları çalışmaya dahil edilmiştir. Öğrencilerin BEDTT'ye verdikleri yanıtlar MS Excel programı kullanılarak analiz edilmiş ve IBM PASW18 programı ile ileri analizler yapılmıştır. Her bir kavram yanılgısı kategorisinin frekansı, öğrencilerin o kategoriyle ilgili tüm sorulara verdikleri yanıtları toplayarak hesaplanmıştır. Farklı akademik yıllarda oluşturulan öğrenci gruplarının BEDTT puanları açısından istatistiksel olarak farklı olup olmadığını belirlemek için bağımsız örneklem Kruskal Wallis testi ve post hoc analizi (ikili karşılaştırmalar) yapılmıştır. Sonuçlar, öğrencilerin beş yıl boyunca beş ortak kavram yanılgısına sahip olduğunu göstermiştir: Bunlar, çarpışan akımlar modeli, kısa devre kavram yanılgısı, sabit akım kaynağı olan güç kaynağı modeli, sıralı muhakeme (akıl yürütme) ve bölgesel muhakeme modelleridir. Ayrıca, çalışma 2021-2022 yıllarında öğrencilerin diğer yıllara kıyasla daha iyi bir kavramsal anlama düzeyine sahip olduklarını ortaya koymuştur. Beş yıllık veri, genel olarak kavram yanılgılarının çok az değiştiğini, yaygın kavram yanılgılarının ise zaman içinde aynı kaldığını göstermiştir. Bu bulgular göz önünde bulundurularak, eğitimcilerin derslerini tasarlarken özellikle bu kavram yanılgılarına odaklanarak elektrik konusunun kavramsal olarak daha iyi anlaşılmasını sağlamalarına yardımcı olabileceği düşünülmektedir.

Anahtar kelimeler: Fizikçi olmayanlar için fizik, fizik dışı bilim dalları, sağlık bilimleri, kavramsal anlama düzeyi, kavram yanılgısı, fizyoterapi, basit elektrik devreleri.

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