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An Investigation of Secondary Pupils' Misconception about Electric Current and Voltage Concepts

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Abstract

The current study intends to identify Moroccan pupils' level of understanding of electric current and voltage concepts and their numerous misconceptions about these two concepts. The targeted sample was collected using a purposive sampling technique, and the sample size attained 172 pupils from three Moroccan secondary schools. The research followed a non-experimental approach with a quantitative research method. The data was gathered with a questionnaire administered to pupils in the first year of the baccalaureate. The results revealed that most students had a low level of understanding of electricity concepts due to various misconceptions. Specifically, nearly three-quarters of the pupils confused electric current with voltage, and almost half demonstrated sequential reasoning. For the nature of electric charge, third of the pupils perceived electricity as a material that is consumed. Additionally, the current consumed misconception was significantly more prevalent among males than females. Regarding the pupils' views, several barriers to learning electricity have been identified, including lack of sufficient learning activities, perceived inadequacy of the teaching methods used and the absence of motivation for learning electricity. These findings provide insights for future research to investigate whether serious games, as an innovative teaching tool, can improve learning outcomes and eliminate misconceptions.

Keywords: Electric Current, Misconceptions, Moroccan Pupils, Voltage.

Introduction

Understanding natural phenomena and problem-solving about daily life situations is principally based on mastering physics laws and various fundamental concepts (1), such as force, movement, Newtonian laws, and electric current. However, some research related to physics learning has identified that learners have particular difficulties in assimilating scientific concepts, and their explanations appear as misconceptions or pre-existing knowledge (2, 3). The term "misconception" refers to all ideas inconsistent with scientific explanation (4, 5), and is considered a barrier to the learning process for students trying to construct new knowledge. However, it should be recognized that pupils' misconceptions may include both right and wrong answers. In terms of classification, each misconception is characterized by the degree of its persistence. Indeed, some resist change in acceptable ideas (6), resulting in a wide gap between learning objectives and learners' actual knowledge (7). To construct knowledge in light of misconceptions, the Piagetian views followed an approach of three mechanisms to easily change pre-existing knowledge: assimilation, accommodation, and equilibration (8). Indeed, students use schemes or mental patterns to guide their cognitions or behaviours and interpret material or new experiences about the existing mental schemes (8). The behaviours of natural phenomena are described in mathematical formulas and represent specific physical laws. In this respect, the fundamental role of mathematics is to solve physics problems and clearly define the relationship between physical parameters. Therefore, without a sufficient background in mathematics, the scientific content in physics textbooks is incomprehensible. In this light, the learning difficulties not only depend on the learners' alternative misconceptions. In other words, mathematical skills, along with other factors, have a significant influence on learning performance. According to a study conducted in the USA (9), three main categories of factors are responsible for the failure of learners' academic achievement: factors related to the learners that

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can be controlled, factors depending on the material itself, and factors related to the design of the course. In a study conducted in Singapore about teachers' perceptions regarding their teaching practices, they held the view that learners perceive physics as difficult. Furthermore, the learners were perceived to have a negative attitude toward physics science (10). In addition, research findings mentioned some basic skills that learners did not acquire to engage more in new scientific activities, such as problem-solving, equations/ formulas, conceptual/theoretical understanding, experimentation, and spatial reasoning (9, 10). As mentioned by some researchers (11), Physics science requires some mathematical skills, such as the ability to use geometry and algebra and to move from general to specific and back. Another study conducted in Nigeria about the factors contributing to learning difficulties revealed common factors consistent with the research findings, such as lack of motivation, poor attitude toward physics science, learning environment, inadequately resourced teaching, ineffective teaching methods, and poor mathematical ability (12, 13).

Recent studies have highlighted significant gender-related patterns in physics sciences. Research has shown that male and female students often demonstrate different patterns in their alternative conceptions of mechanics concepts (14). The STEAM-integrated approach utilizing Scratch has shown promising results in reducing gender gaps in electricity concept understanding, suggesting that interactive learning tools can help address gender disparities in physics sciences (15). Furthermore, studies on the conceptual survey of electricity and magnetism have revealed persistent gender gaps in understanding fundamental electrical concepts, though these gaps can be minimized through targeted instructional strategies (16). Additionally, research on electromagnetic induction has demonstrated that collaborative learning approaches can reduce the gap between genders in terms of conceptual understanding (17). Regarding the causes of gender differences, several researchers identified various mediating factors influencing gender-based performance differences, including prior exposure to electrical concepts, learning environment, and teaching methodologies (18).

In this sense, the purpose of this study is to identify misconceptions that were supported by some Moroccan pupils regarding their peers' concepts of electric current and voltage. In addition, the second objective of this research is to determine the percentage of each underlying factor that could be a source of learning obstacles.

Methodology

Research Design and Participants

This study adopts a quantitative method for constructing the quantifiable results that precisely measure the extent of learners' misconceptions regarding the principal DC circuits concepts and statistically highlight in percentage the possible factors that caused misconceptions, describing the results and providing an overview of the all identified misconceptions and links them with the underlying proposed factors to investigate which factor mainly produced the learning obstacles.

172 eleventh-grade learners aged between 16 and 19 were selected to participate in the test and belong to three secondary high schools. The test was distributed during the academic year 2023-2024. The targeted learners were composed of 54% female and 46% male learners, drawn from three Moroccan schools in Guercif city. To respect specific research criteria, the purposive sampling technique was followed in the research protocol; in this regard, this study was framed by two following principal criteria:

- We selected the 11th-grade level as learners have already studied and explored these concepts in previous years.
- Test was administered for learners who study physics as their main subject.
- Participation in this survey was not mandatory; it was voluntary.

Data collection – Instruments

The overall test used in this study was divided into two sections; the first section was composed of a series of questions with multiple-choice responses (closed responses). The focus of the items seeks to identify the level of understanding of the concepts of current and electrical voltage. The errors established in the test indirectly indicate the pupils' misconceptions about the concepts studied (19).

Based on The Resistive Electric Circuit Concepts Test (DIRECT) version 1.0 (20), we selected 13 questions that the learners had previously studied in earlier years. It is worth noting that the items in our questionnaire are based on a validated questionnaire (20). The electric current concept involved five items, whereas the voltage concept-related questions included nine items (20). The questions presented situations that highlight the comportment of the electric current through various circuit patterns materialized by two main elements (the generators and the bulbs) (20). As the Moroccan educational system adopted the French language in teaching physics sciences, the questionnaire was translated into French without any bias in the items' meaning. Three education experts revised the questionnaire to ensure the validity of the items.

The second section allows us to determine the difficulties faced by the pupils in learning electricity. It contains a single question with seven propositions. Once the pupils finished the inquiry, they were invited to select which factors negatively impacted their learning process. The physics teachers of the selected classes administered the questionnaire, and pupils commenced responding immediately after the teacher distributed the copies.

Data Analysis

The process of assessing the responses and selecting the categories of misconceptions was based on the taxonomic frameworks previously outlined by researchers (20). The learners' responses were converted into binary numbers using SPSS software, so wrong choices were coded as '0' and considered misconceptions, while correct choices were coded as '1'. Additionally, we have labelled a response as wrong for questions for which we do not have a response from the pupils.

The second step corresponds to the treatment of data to calculate the level of conceptual understanding for each pupil based on the specific criteria (21), as presented in the Table 1 below:

Table 1: Levels of Understanding

Percentage of Understanding	Levels of Understanding
0% < P ≤ 39%	Low
40% < P ≤ 65%	Moderate
66% < P ≤ 79%	High
80% < P ≤ 100%	Very High

The variable P represents the percentage of pupils' scores for each concept, calculated using the formula [1]:

$$P = \frac{Number\ of\ correct\ answers}{Total\ number\ of\ items} \times 100\% \qquad [1]$$

$$\% = \frac{A}{172} \times 100 \qquad [2]$$

Percentage of the category of pupils' misconceptions was obtained through the formula [2], where A indicates the number of pupils who supported the misconception probed.

Data analysis was carried out via Excel Statistical Package, which was used as an alternative to SPSS software in all treatment processes.

Results and Discussion

Levels of Understanding

Table 2 shows the categories and question numbers included in this test, as well as the percentages of correct answers. Meanwhile, the distribution of learners' understanding levels is presented in Figure 1.

Table 2: The Learning Objectives and Percentages of Correct Responses Related to Each Question

Categories	Question		Learning Objective	Effectives	Total Correct Answers (%)
Electric Current	1	a)	Understanding and apply conservation of charge to a variety of circuits.	100	58,72
	2			53	30,81
	3	b)	Explain microscopically the current flow in a simple circuit through the use potential differences, and the interaction of forces on charged particles.	29	16,86
	4			25	14,53

Voltage	5 6 7	c)	Apply the knowledge that the amount of current is influenced by the voltage or potential difference maintained by the battery and resistance in DC circuit.	64 61 120	37,2 35,46 69,76
	8 9 10 11 12	d)	Apply the knowledge that the amount of current is influenced by the voltage or potential difference maintained by the battery and resistance in DC circuit.	62 20 25 30 22	36,00 11,62 14,53 17,44 12,79
		e)	Apply the concept of voltage to various simple circuits including the knowledge that the voltage in a parallel circuit same while in a series circuit it remains the sums.		
Current and Voltage	13		objectives a and d	48	27,9

For six questions in this test (3, 4, 9-12), less than 20% of learners gave the correct answer, which may reflect very low conceptual literacy. The difficulty is not surprising since learners often get confused between voltages, current, how electrical charges work in a circuit, and adopt a sequential reasoning. Questions 1 and 7 have the highest percentage of correct answer index with a value of (58, 72%) and (69,76 %). However, the high rate of correct responses regarding these two questions means that even if they are wrong explanations for the most of electrical situations, more than 50% of them partially understand the properties of electric current as well as their relationship with voltage and resistor. These results are also relatively comparable to the findings of other study (22). Some researchers found out that 76% of the participating students in their study did understand the topics in electricity, while 25% manifested only a partial understanding (22). We grouped the number of pupils based on the level attained in relation to each category of questions in order to get a general idea of the level of learning of each concept.

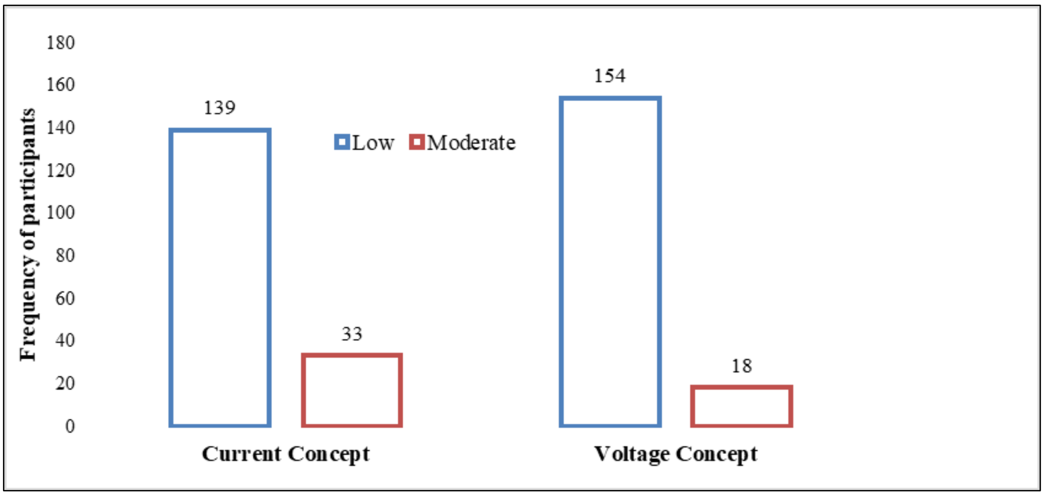

Figure 1: Number of Learners who obtained Low and Moderate Levels Corresponding to Each Concept

Based on the above criteria, the level of understanding P regarding each concept varied with a significant proportion between the law and moderate levels (21). Indeed, 139 students showed a low understanding of the current concept and 154 for the voltage concept. It can be seen from these findings that the majority of pupils have insufficient learning levels, falling below the medium. This diagnostic reveals in another manner that approximately 20% and 10% of pupils moderately understood the electric current and voltage concepts respectively. These percentages suggest that the voltage concept may be more abstract and less effectively grasped than electric current. the results are comparable to the previous findings. One such study demonstrated that only 17% of the pupils showed that they have a correct conception about electricity. The rest manifested misconceptions (23).

As revealed in this study, the concept of electric current is understood at twice the rate of the voltage concept. The reason for these non-concordance findings between the two concepts could be explained by the fact that some pupils viewed the voltage and electric current as possessing the same properties. In this context, the researchers discovered that numerous pupils struggle to make a clear physical distinction between the voltage and current concepts, often perceiving voltage as a type of current or something that flows (24). Additionally, many studies (24-26) reported unsatisfactory results for learners when they interpreted the behaviour of DC circuit elements (bulbs) in terms of brightness, which suggests a significative weakness concerning the conceptual understanding of those concepts. According to constructivism theory, this category of students has the pre-existing mental models for the electrical situations, which inconsistent to the scientifically interpretations (27). In this regard, constructivism posits that students construct their knowledge of the world through reflecting on those experiences and experiencing things (28). Overall, these results align with Moroccan middle school learners' performance in the TIMSS test in science (29). We see a decrease of 68 points (from 395 to 327 points). This result places Morocco 56th out of 58 countries.

Pupils' Misconceptions

Electric current and voltage are fundamental agents that help us qualitatively understand DC circuit laws. Many pupils do not have a profound understanding of the scientific meaning of these concepts and the relationship established between them. Therefore, the present research seeks to investigate each concept in turn.

Misconceptions Related to the Concept of Electric Current

Examining the various misconceptions probed by this test and linking them with principal objectives, each item yields a circuit pattern addressed from a particular objective (20). For the objective of understanding and applying the conservation of current in various DC circuits, several explanation models were highlighted by the DIRECT test. 34% of pupils were involved in the shared current model, as they predicted that current intensity decreases as it passes through the circuit elements (current is consumed). For example, a related study shows that students had a misconception that as electric current flows through a circuit, the bulbs in it consume the electric current (30). These findings are in line with previous studies (2, 20,30-32), where the flow of current decreases when it crosses such electrical elements. Sequential reasoning (the circuit elements influence the current flow) was highlighted in this study by 64,53% of pupils. The learner's misconceptions regarding DC circuits are not limited to secondary schools; even university students exhibit misconceptions such as sequential reasoning (33, 34). In line with this, various misconceptions have been identified and incorporated into specific circuit patterns (19, 20, 24, 35). For example, believing that a bulb near the battery is brighter than one farther away contradicts scientific ideas. Furthermore, two recent studies obtained similar results, with 35% and 38% of pupils, respectively, holding sequential reasoning in their responses (36, 37).

Additionally, pupils were confused about the terms "electric current" (I) and "voltage" (V); they held the viewpoint that electric current is caused by the potential difference (voltage) and not its consequence. This confusion was previously revealed (24). Other confusions highlighted by researchers (20, 37) include viewing resistance or voltage as current properties and perceiving electric energy and electric charge as having the same meaning for learners. Regarding the circuit elements, the notion of the battery takes an important place in electricity textbooks; in fact, it is considered a prominent element for the simple electric circuit (source of energy). Our analysis of this element shows that 41, 86% of students thought that the battery element behaves as a constant current source. Other study (24) conducted an empirical study on 145 high school students. Apart from other misconceptions, it mentioned that most students thought of the battery element as a source of constant current.

Generally, these results are in line with related research findings. Similar studies (32, 34), for instance, show that misconceptions such as 'current is consumed' and the 'local reasoning model' were common among their respondents. Meanwhile, the misconception that a battery is a constant current source was found to be prevalent (41.86%) in our study, whereas other studies reported this model as one of the least common misconceptions among students (1.9%) (32).

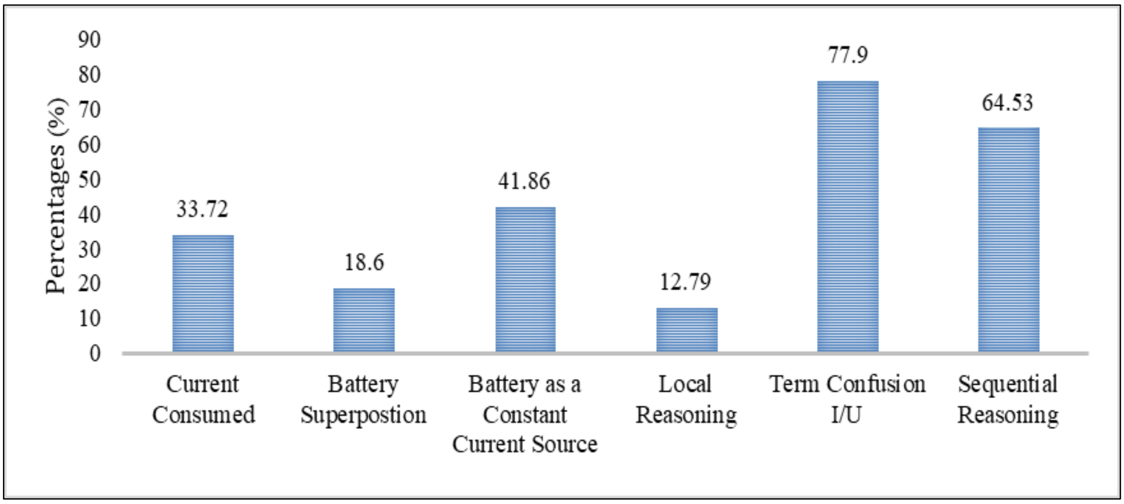

Figure 2: The Distribution of the Misconceptions Related to the Notion of Electric Current and Voltage

Misconceptions Related to the Concept of Voltage (Figure 2, 3)

The electric current and voltage represent the basic concepts in electricity, and it's impossible to describe such electrical situations without involving one of them. In this context, several studies emphasize the importance of these concepts in the curriculum (20, 24, 25). The aforementioned studies specifically focused on the misconceptions exhibited by students regarding the concept of voltage. The voltage concept was emphasized through nine schematic patterns. It seeks to reveal the various misconceptions supported by senior students. One of them is the battery superposition: 18, 6% of students thought that if one battery makes a bulb shine, then two batteries connected in parallel would make the bulb shine with higher intensity. The studies in this regard have already confirmed the exhibition of this typical misconception, even among college students (20, 38). The interpretation of the students' responses to this misconception probes a indiscrimination between circuit parallel and circuit series. Local reasoning is also highlighted in this study, with a few percentages (12, 79%). In this reasoning, pupils focus their attention on the behaviour of the electric current when it arrives at such a junction, completely ignoring whatever may be happening elsewhere. Several researchers investigated students' views concerning local reasoning, and they confirmed that it is involved least compared to other misconceptions (20, 24, 35).

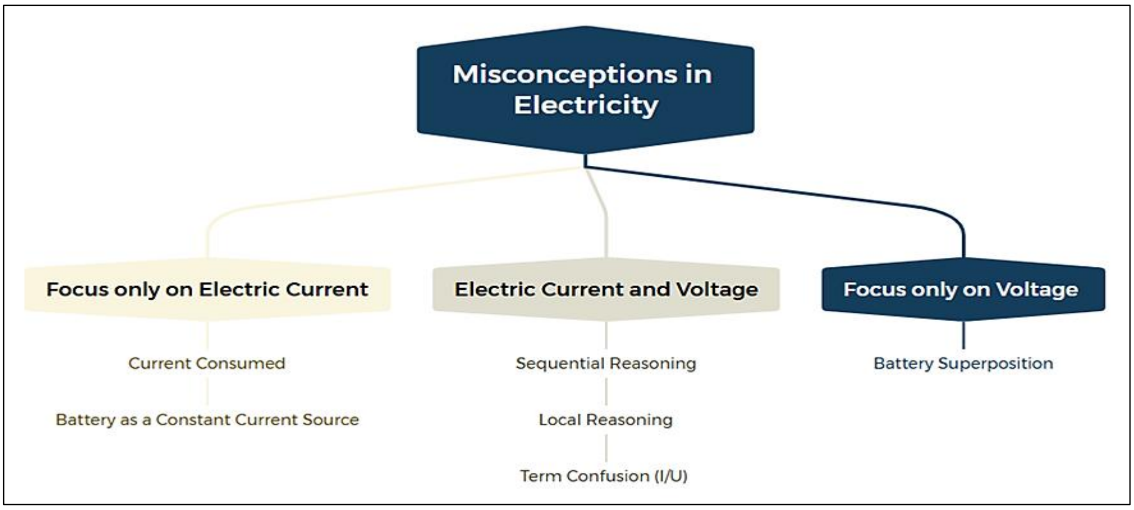

Figure 3: Mental Maps Revealed the Relationships between Various Electricity Misconceptions

Several causes can influence students' cognitive spheres, including the social environment represented by their peers and parents, who may perpetuate erroneous ideas, especially when electric devices continue to run. Most students consider that the electric current from these devices is consumed and not the electric energy (37, 39). In the whole, these aforementioned factors have an implicit implication on the learning perceptions. In fact, constructivists believe that learning is affected by the context in which an idea is taught as well as by students' beliefs and attitudes (40).

Influence of Gender Differences on Pupils' Misconceptions

Many studies which have been carried out to discover influence of gender differences on pupils' misconceptions have shown mixed results, Figure 4 shows the percentages about each reasoning model according to gender.

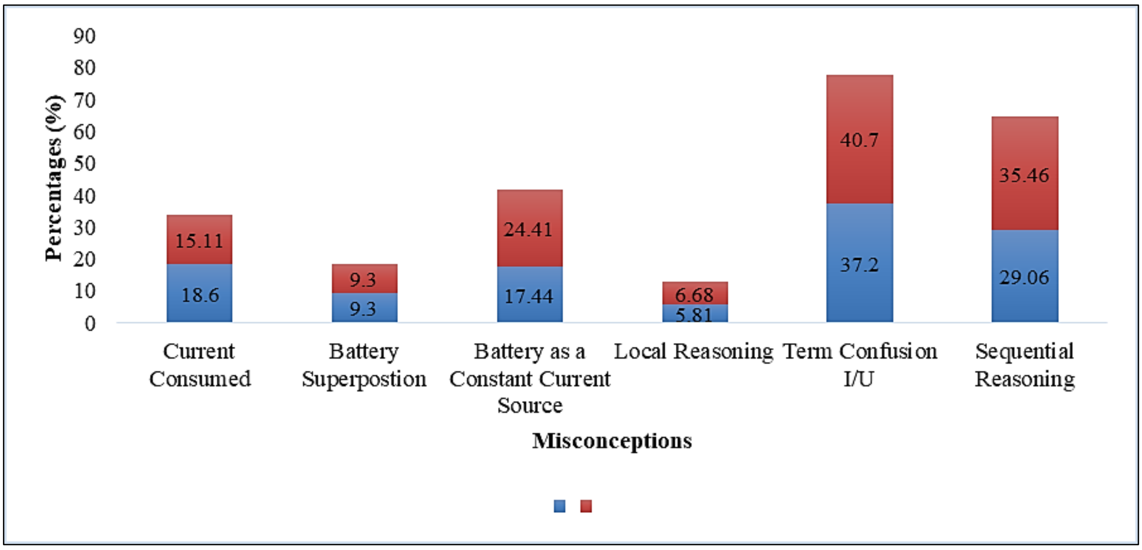

Figure 4: The Distribution of Misconceptions by Gender

Generally, gender factors have minimal influence on the resulting outcomes, and the percentages are pretty close between female and male students. However, analysis of the misconceptions by using the Chi-square test (used for the categorical variables) allowed us to conclude that:

There is a correlation between group sex and the factor ''Current Consumed Misconception''. Furthermore, Phi Cramer's V demonstrates a significant difference between groups and factors contributing to misconceptions ($p<0.05$); then, the males held significantly this misconception than the females.

Additionally, The Cramer's V value of .713 suggests a strong association between the variables being tested, as values closer to 1 indicate stronger relationships. The statistical significance ($p < .001$) indicates this association is unlikely to have occurred by chance. The other factors have a $p>0.05$, indicating no relationship between these factors and Sex. This result was consistent with another result, which found that electricity misconceptions depend on the context items when discussing them in terms of correlation with sex. In fact, research indicates that there was no significant gender difference between the total score's achievements and six theoretical items (18). However, the gender difference appeared when the questions asked were in a practical context. The gap difference in this study appeared only for the currently consumed misconception; the statistical difference in this kind of Misconception can be due to the socio-cultural backgrounds of the male students (41, 42). Numerous studies in this line have also demonstrated that the domain of electricity was one of the domains in which a gender difference was frequently highlighted (43, 44).

Difficulties Faced by the Pupils in Learning Electricity

The purpose of this section was to explore secondary school learners' difficulties with learning electricity. Indeed, this investigation is closely connected to the main focus of the study, which seeks to examine the different misconceptions held by the pupils regarding their peers' understanding of electric current and voltage.

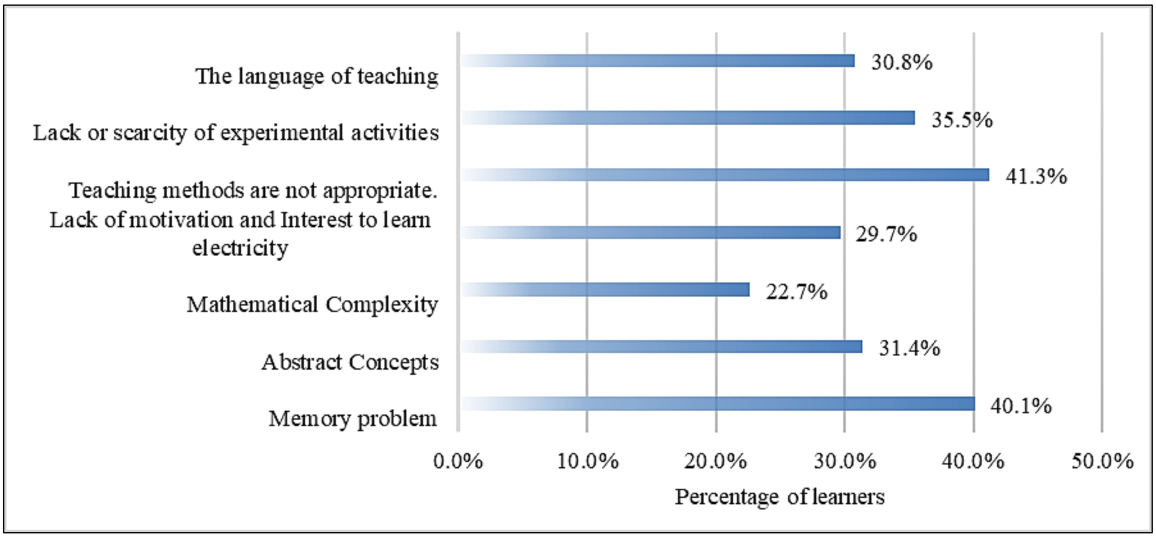

Figure 5: The Distribution of Difficulties Faced by the Pupils in Learning Electricity

Before discussing such difficulties, it is necessary to indicate that interest and motivation have been considered as the main conditions in which learners engage in learning situations (45). Figure 5 indicates that only 29.7% of pupils view electricity as uninteresting and lack motivation to engage in this physics area. The assumption that lack of motivation can reduce the learning rate has already been confirmed. Indeed, research found a positive correlation between motivation and learning achievement among high school pupils (46, 47). Understandably, both factors have a significant impact on learning outcomes. Additionally, other researchers concluded that students who are engaged and motivated in learning tend to obtain higher academic achievement and achieve satisfactory results compared to unengaged and unmotivated peers (48). Moreover, some barriers can indirectly affect the learning process and create resistance to receiving knowledge. Indeed, regarding communication, 30.8% of pupils claimed that the French language posed an obstacle to expressing and exchanging their ideas in the teaching-learning process. Regarding this point, some researchers have already demonstrated that learning by speaking in the mother tongue provides significant learning achievement compared to second-language students (49, 50). Additionally, among the difficulties encountered by learners is the problem of memorization. 40% of the pupils had a low memorization rate for scientific concepts. The high proportion is because the test we suggested is connected to their prior knowledge. Indeed, in order to complete the questionnaire, the pupils had to rely on their memory to recall what they had learned in prior years.

The use of mathematics to explain physical phenomena and the ability of pupils to translate the physical situation into a mathematical expression and simplified model undoubtedly facilitates physics learning. The relationship between mathematics and physics has been studied by several researchers (51, 52). Among the research findings on this point, the lack of mathematical skills is identified as a significant impediment to understanding physics phenomena, and the transition from describing phenomena to formalized mathematical language is considered a significant challenge (53). For this study, 22.7% of the pupils claimed to have poor mathematical skills. For instance, we can utilize Ohm's law to identify a resistance by dividing the voltage by the current, and a capacitor's discharge is represented by an exponential equation that depends on both the circuit's time constant and time. The perceptions of pupils towards mathematical skills have previously highlighted (54). It has been found from this study that 25% of the pupils perceived mathematics to describe physical phenomena as very difficult. Meanwhile, only 10% of the pupils saw "using math to solve physics problems" as very difficult.

According to the findings, 36% of pupils found that "lack or scarcity of experimental activities" provides an obstacle to comprehending electricity. Moreover, 32% described electricity as an abstract subject. Supporting this, another study demonstrated that meaningful learning related to physics sciences is achieved only when learners engage in experimental activities in their classrooms (54). The role of experiments in gaining meaningful learning in physics laws was profoundly emphasized (55). This study highlighted that experimental activities serve as a scientific inquiry method that creates cognitive activation for pupils. Some physics concepts, such as the diffraction phenomenon, dispersion phenomenon, and phenomenon of resonance, may be complex for learners to assimilate.

Teaching practices also play a vital role in learning achievement, as shown in Figure 5, where 41.3% of pupils were unsatisfied with the teaching methods. In this regard, several researchers (12, 31) have emphasized the potential of teaching methods to enhance learners' learning levels and their prominent role in dispelling learners' misconceptions.

Conclusion

After a thorough analysis of the results, several underlying conclusions have been selected. Concerning the level of understanding of both concepts studied, the vast majority of learners were weak in recognizing the electric current and voltage concepts. These findings are consistent with how Moroccan middle school pupils performed in the science category of the TIMSS test. This suggests that the misconceptions related to those concepts are widespread and pose significant challenges to learners. The study also enabled us to identify six categories of misconceptions. Among this, almost three-quarters of pupils confuse the terms "electric current" and "voltage". Moreover, more than half of the pupils employ sequential reasoning, mistakenly believing that current is consumed within a circuit. At the same time, approximately one-fifth of learners demonstrated misunderstandings regarding battery superposition, reflecting a lack of comprehension of how multiple batteries function together to increase energy in a circuit. On the other hand, there is no marked difference across genders, except there is a correlation between group sex and factor ‘’Current Consumed”; indeed, the males held significantly this misconception than the females. Regarding the difficulties learners encounter in learning electricity, there are several, namely, the lack of practical hands-on activities and experiments that can bridge the gap between theory and practical understanding, teaching methods that are not well-suited to addressing diverse learning needs, and poor communication between teachers and pupils. These obstacles create an unfavourable learning environment that needs to be revised for better pupil outcomes in physics education overall.

In light of these results, several recommendations can be made, including: We must rethink constructive activities and instruments for teaching electricity and investigate new ones that engage and motivate pupils, like serious games (56). We must rely on the experimental approach to facilitate and contextualize learning.

Limitation of the Study

The study was conducted during the 2023-2024 academic year and was limited to three high schools located in Guercif city. The sample size was restricted to 172 science students. Therefore, the results of this research cannot be generalized. Additionally, only nine factors proposed in this study were considered regarding the possible causes of learning difficulties. Another limitation of this study is the formulation of the questions, which may have led to errors in students' understanding.

Abbreviation

None.

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Author Contributions

This study was carried out through the collective effort the authors. Responsibilities encompassed: conceptualizing and designing the study; gathering, analyzing, and interpreting the data; and drafting and revising the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethics Approval

This study involved humans as respondents to the interviews (non-interventional study). No experiments or clinical trials were conducted. All participants provided written informed consent prior to engagement in this study.

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