Students’ understanding of physical components of electrical circuits

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Abstract. In many cases, the teaching of electricity starts from the basic use of ohms law and its mathematical interpretations. Less is done in terms of defining and explaining qualitatively the role of the electric circuit elements like a resistor, a conductor, a switch and lastly a battery. Since the learning of electricity is predominantly conceptual, it is perceived as difficult because it cannot be physically touched or seen, and those physical components are less dealt with qualitatively. The physical components are used during representations to explain the conceptual interactions of what takes place in each component in terms of current, resistance and potential difference. This research is aimed at determining how students define and explain the role of some basic electric circuit elements, that is, resistors, conductors, batteries and a switch. In addition, this work aims to determine how the knowledge of these physical components can enhance the understanding of electricity.

1. Introduction and theoretical background

In many cases, teaching electricity begins with the basic application of Ohm's law and its mathematical interpretation. Less is done to define and qualitatively explain the role of the electrical circuit elements such as resistor, conductor, switch and finally a battery. Since learning electricity is predominantly conceptual, it is found to be difficult in that it cannot be physically touched or seen, and these physical components are treated in a less qualitative manner. Students' understanding of electricity is usually poor and dominated by misunderstandings [1]. To bridge the gap, a suggestion was made to review teaching strategies. Furthermore, literature advised physics teachers in secondary or high school to take a concrete action by involving the students to empirical learning experience [2].

The grand challenge identified in science education is to improve students’ conceptual development of scientific concepts [3], while at the same time, the ongoing agenda is to help students to obtain high quality learning [4]. To improve students’ conceptual development of scientific concepts, this research adopted the back to basic approach consisting of two parts, namely: identifying students’ knowledge of physical components and their roles in electric circuit, which function as a system and is usually overlooked [5]. These physical components were a battery, a bulb, a conductor, and a switch. The second part focussed on how students use the knowledge of the physical components to answer questions dealing with electric circuit. Literature grounded by constructivism recommended the teachers’ awareness of students' prior knowledge and possible misunderstandings [1] as a key in planning for designing classroom activities to enhance conceptual development.

Guided by the phenomenographically approach on classifying students’ understanding, this research aims to present how students define and explain the role of some basic electrical circuit elements, i.e., resistors, conductors, batteries, and a switch. In addition, this work aims to determine whether the knowledge of these physical components has an impact on students' understanding of electricity.

2. Research Design and procedures

The research was a qualitative pre-post instruction design in which interventions were conducted using a whole class discussion of the physical components of electrical circuits: battery, conductor, resistor, and the switch, followed by an introduction of the field model as a strategy of explaining the dynamics of electrical circuits. A pre-post instruction study measures the occurrence of an outcome before and after a particular intervention is implemented [6]. The field model explains the movement of charges in a circuit under the influence of electric field created when charges are separated in a battery. Students' knowledge and understanding were assessed by phenomenography both before and after the intervention. The phenomenographically method was considered as a good way to assess students' understanding of scientific concepts and to identify sources of misunderstandings. One of the advantages of phenomenography method is that the phenomenographic data not only provide rich and contextual descriptions of students' understanding but are also capable of holistic understanding to unpack into different patterns of consciousness and non-consciousness of components [4]. Follow-up treatment took place after 8 weeks.

2.1 Participants and instruments used for data collection.

The participants were Bachelor of Education (B.Ed) second year preservice students (44 wrote pre-intervention: 42 post-intervention) who were deliberately chosen considering that they had learnt the subject in high school and the subject was about to be repeated at tertiary level. Being guided by phenomenography, pre-instructional data were collected using a semi-structured, open-ended questionnaire [4] with an additional confidence question. The semi-structured questionnaire was chosen because of its convenient deployment and allows a wider range of experiences with a phenomenon to be captured. Post-test instrument had no confidence question. The questions were divided into two parts, namely:

Part 1: Pre-instruction questions targeting students' knowledge of the physical components and their roles as follows:

The diagram in figure 1 represents a longitudinal cross area of a torch with different parts labelled A to D.

1.1 *Name the parts labelled A to D and their roles in electric circuit*

1.2 How confidence are you about the answers you gave in 1.1? Select from the following:
A: Very Confident with the name and the explanation of the role
B: Very Confident with the explanation but not sure about the role
C: Very confident with the role but not sure about the explanation of the role
D: I guess all
E: I don't have a clue

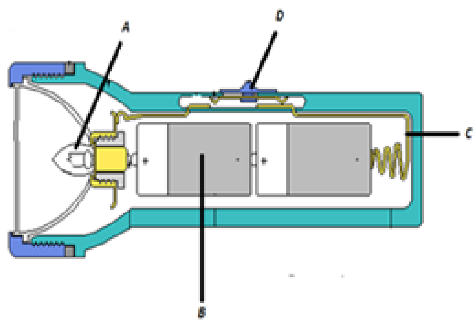

Figure 1: Longitudinal section of the torch

Part 2: Post instruction questions to determine if the knowledge of the physical components and their roles has an impact on their conceptual understanding of electricity circuit dynamics.

The post-intervention questions were aimed at understanding how students use their knowledge of physical components to answer conceptual understanding questions. Conceptual questions require students to understand how both physical and conceptual components work as a system to fulfil a specific role. Questions were the following:

2. Use the diagram in figure 2 to answer the following questions.

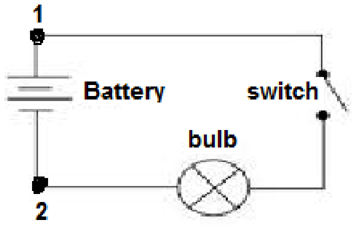

Figure 2: Electric circuit 1

2.1 What causes the bulb to glow in figure 2 when the switch is on? Explain.

2.2 What will happen to the resistance of the bulb if another battery is added in series in figure 2?

2.3 Why bulbs in our lecture room glow almost at the same time when the switch is put on?

3. The diagram in figure 3 shows an electric circuit with three different light bulbs X, Y and Z. When the switch is on, bulbs X and Y were glowing, but bulb Z was not glowing. From the following options, select the reason why bulb Z is not glowing. Explain your choice.

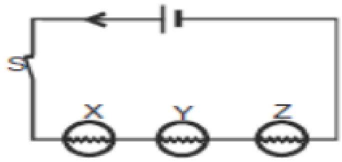

Figure 3:Electric circuit 2

A. the resistance of Z is too low
B. the resistance for Z is too high
C. the current is too weak by the time it reaches Z
D. bulb Z is nearer the negative terminal

3. Data analysis

The main goal of the study is to identify several qualitatively distinct categories that represent variations in individual experience [4] of parts of an electrical circuit and their roles. The phases used in data analysis were as follows: identification, sorting, comparison, and categorisation [7]. Both questions from parts 1 and 2 were phenomenographically analysed after Google form data collection. The first question was just to name the physical object (part) of the torch and the role of each. The answers to the role of each part were then sorted and categorized to explain the students' knowledge of the role of each part. Finally, the students' confidences were compared to their explanations of the role of each component.

4. Results and discussions

The presentation and discussion of the results takes place in two parts. Part 1 will be the result of students' knowledge of the physical components and their roles, while Part 2 focuses on whether knowledge of the physical components has an impact on their conceptual understanding of basic electrical circuitry.

4.1 Part 1: Results and discussions.

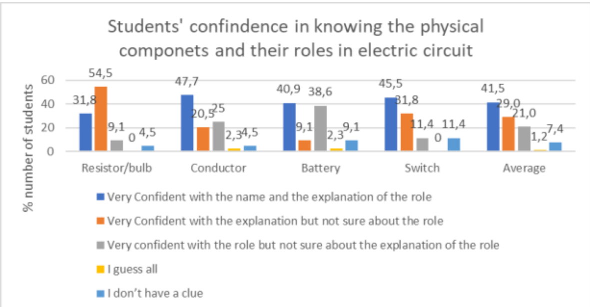

Figure 4: Students' confidence

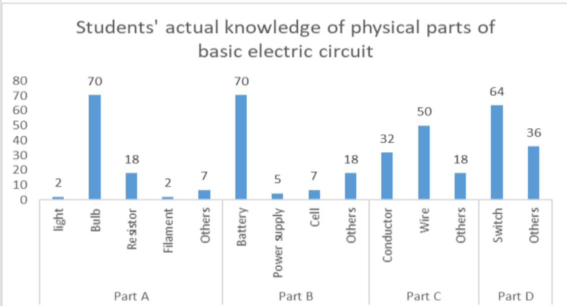

Figure 5: Students' knowledge of the physical components

Figure 4 shows that 31.8% of students are very confident with naming and explaining the role of resistor. While 54.5% of the students are very confident with the explanation, they are unsure about the role of the resistor. However, the average of student confidence across the components shows that student confidence levels are less than 50%. This result shows that many students still had misconceptions or were unaware of the physical components and their role in the circuit.

Figure 5 shows positive results from more than 50 % of the students in each part, correctly naming the physical parts of the circuit. There are still a handful of students who confuse the lightbulb and the resistor, affecting their confidence in naming and explaining the roles of the physical parts.

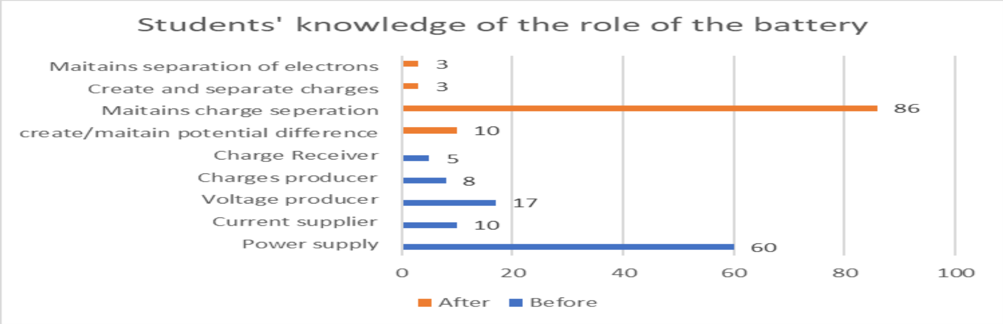

Figure 6: Students' knowledge of the role of the battery before and after intervention

Figure 6 shows that after the intervention, students greatly improved their knowledge of the role of the battery. The most appropriate role of the battery, which helps explain circuit dynamics, is to maintain charge separation, since an electric field is created the moment charges are separated. This idea combines static electricity with electrodynamics, which saw the field model as a powerful tool to meet the great challenge in electricity [8].

Part 2: The impact of students' knowledge of physical components on their conceptual understanding.
To determine if students' knowledge of the physical components affects how they answer qualitative questions about basic electrical circuits, the following results per questions are presented.

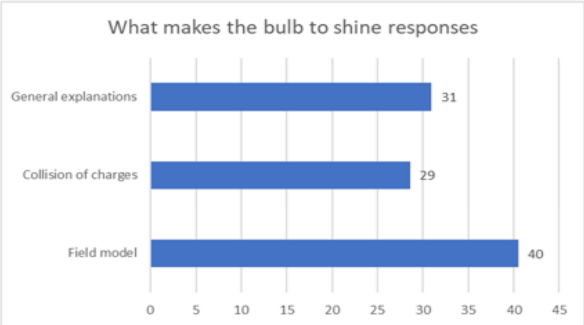

Figure 7: Question 2.1 responses

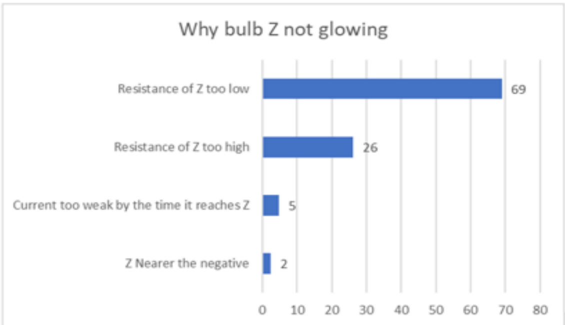

Figure 8: Question 2.2 responses

2.1 What causes the bulb to shine when connected to electric circuit?

Two questions related to the causes of the glow of the lightbulb in a circuit. The first question only referred to an incandescent bulb connected in series with the battery and switch. Students' answers to the question of what makes the light bulb glow or not glow are shown. Common explanations were those that were not 100% scientifically based, for example: "*It is lit because the circuit is on*". This type of explanation is not helpful in assessing understanding when presenting just one idea among many. Those who used collisions of charges correctly explained and showed their understanding of the difference between a conductor and a resistor. Some of the misconceptions identified:

"*The bulb glows when electric current interacts with the resistance of the bulb" and "The resistor converts current to electricity."*

One of the promising answers given by student, was based on the field model as follows:

"When the switch is on, *electric field are established throughout the circuit at approximately the speed of light*, the electric fields are directed from positive terminal and negative terminals separated by the battery through the conductor and at this moment charges start to move *creating current and potential difference simultaneously*, the electric field are closer to each other in the resistor meaning *the electric field force is stronger*. According to Newton's second law of motion, the charges gain more acceleration causing them to move *faster colliding with each other and the particles of the filament*, due to this collision the average kinetic energy increases and according to collision theory the *temperature will also increase*, thus converting electrical energy to heat energy which is later dissipated as light."

Knowing the role of each physical component helped students re-explain, including using mechanical concepts (Newton's second law) to show why the temperature increases and ultimately why the lightbulb glows.

Another explanation by student:

"As soon as the circuit is closed and *there's charge separation in the battery,* potential difference is established instantaneously then the charges will start to move. When the charges reach the bulb, there is a *filament in the bulb that acts as a resistor and since it is very thin* the rate at which the charges will move, and kinetic energy will also increase as *the electric field lines are close to one another and the increase in kinetic energy will lead to an increase in temperature* hence heat and light will be produced that's where the bulb shines"

The statements above prove that the students used the knowledge of the role of the battery and the resistor to explain why they emit light, therefore this knowledge enabled them to explain how the light bulb in a circuit glows.

Figure 9 and figure 10 show the results of question 2.2 and question 2.3 that will be discussed in the next sections.

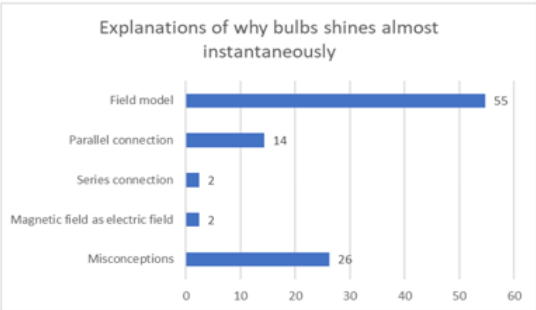

Figure 9: Question 2.3 responses

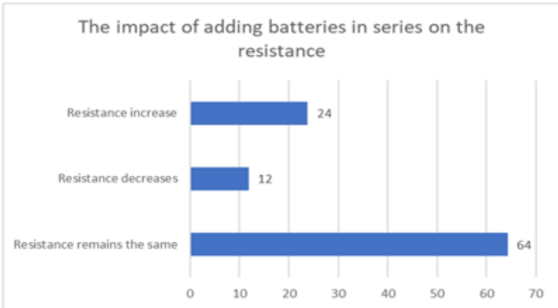

Figure 10: Question 3 responses

Question 2.2: Bulbs in the lecture room shining at the same time.

In general, students think that charges travel at the speed of light, which is why light bulbs glow almost simultaneously. Most students explained using the field model (The battery maintains the separation of charges during the process, an electric field is built up throughout the circuit at almost the speed of light, that's why the charges start moving almost simultaneously: that's why the light bulbs shine at the same time). Once students understand the battery's role as that of maintaining charge separations, it becomes easier to explain using the field model. The common misconception has been that charges travel at the speed of light and that non-distinction between the magnetic field and electric field will be treated with the concept substitution strategy in the future [9]. The fact that most students (55%) explained using the field model is also a positive contribution towards teaching electricity using the field model as advocated by Stocklmayer [8].

Question 2.3: The impact of adding the number of batteries in series on the resistance of the bulb.

During the intervention, the roles of each physical component were discussed, for example, resistance was also discussed as a physical component with predefined resistance. The chart above (Figure 10) shows that most students (27) 64% retained the role discussed in class. Some examples of explanations that show the improved understanding in terms of students' knowledge of the role of each physical component are as follows:

Student 1: The resistance of an electrical component of a circuit is fixed immediately after the component is manufactured at the store and it is never affected by anything happening in the circuit, thus it remains the same regardless of the times and seasons.

Student 2: The bulb is manufactured to have a specific resistance; hence it will not be affected by the emf the battery can supply.

The students' reasoning above shows that their understanding of the role of resistance allowed them to answer questions correctly without applying Ohm's law. However, some students retained their misconceptions and explained incorrectly using Ohm's law as their justification as follows:

Student 3: Resistance is directly proportional to the voltage. Increasing the number of cells increases the voltage and hence increases the resistance.

Student 4: If the total potential difference in the circuit increases it will reduce the resistance of the bulb when the switch is ON because when the switch is ON the current is produced due to the movement of the charges, since resistance is indirectly proportional to the current flowing in the circuit it will decrease when the current increases.

The two sample answers imply that some of the students do not understand Ohm's law correctly. Similar results where Ohm's law was misinterpreted correctly was previously reported [10].

4 Conclusion

Many students do not know the names and roles of the physical parts of electrical circuits but are expected to know the conceptual elements. That explains why electricity is difficult. In this research, phenomenography was helpful in showing how students understand the names and roles of parts in the basic electrical circuit, and misunderstandings were identified and presented to share with others. Based on the explanation given by most students when answering Part 2, the study claimed that knowledge of the physical components: battery, resistor, conductor, and switch can have a positive impact on students' understanding of basic DC circuits. However, further exploration is required to investigate other topics in an attempt to reach the goal of the science agenda [3] and to continuously tackle the great challenge [4] in science teaching and learning.

Implications: Before teaching the concepts of current, resistance, and potential difference, teachers should first ensure that students know and understand the role of the physical parts of the circuit. This can be done using a phenomenographic approach, classifying students' experiences with the phenomenon.

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