Investigation of pre-service teacher's understanding of Ohm's law

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Abstract

The incomplete understanding of Ohm's law is a phenomenon widely experienced in introductory physics courses and high school science. Nonetheless, lecturers and teachers may be unaware of student's inability to distinguish between the definition of resistance and Ohm's law describing constant resistance. Our study explores the development of understanding of Ohm's law amongst twenty four undergraduate students training to teach science in primary and junior secondary schools.

Our research found that some students demonstrated an inability to consider a circuit as a system. Furthermore, when the context was changed understanding was often lost. This could indicate operation on low cognitive levels which has serious implications for our future classrooms, not only regarding Ohm's law, but also for the teaching of science in general.

Introduction

Ohm's law is a popular topic in high schools as well as first year physics courses. Calculations require nothing more than straightforward algebra. For practical work, the equipment is the most basic and available even in poorly resourced classrooms. Learners/ students build circuits, measure, draws tables and graphs, calculate slopes and make neat conclusions. This is almost too good to be true. Teachers and lecturers may be unaware of student's inability to distinguish between the definition of resistance and Ohm's law describing constant resistance. There is a risk that neat formula R=V/I may become the centre of attention without paying attention to the context in which it is applied.

The aim of this paper is to explore the development of the understanding of the concept of constant resistance amongst pre-service science teachers during a one semester course. This group of students perform well on standard questions on Ohms law, and on potential division between resistors connected in series, but fail to apply this knowledge to new situations. This is in line with research done by Arons (1982), Mc Dermott and Shaffer (1992) and Shaffer and McDermott (1992) as cited in Arons (1997) who reported that students have the 'ability to solve conventional problems' but has a 'weak correlation with understanding of the physical phenomena taking place.'

Literature Survey

Almost thirty years ago, Johnstone and Mughol (1978) discussed learners' difficulties to understand the concept of resistance. During the same period, it was pointed out that some textbooks present the defining equation for resistance as Ohm's law, without mentioning or emphasizing that resistance is only constant for certain classes of conductors (O' Sullivan, 1980; Iona, 1979). Iona surveyed textbooks from junior high school to college level to compare different ways in which electrical resistance was taught, and found that the concept of resistance was often introduced from a mathematical perspective. Learners were then familiarized with the concept by giving problems where one of the three quantities V, I or R, had to be calculated when the other two were given. Iona advocated that textbooks should make a distinction between a defining equation and a physical law describing some property of natural phenomena. He also observed that some textbooks make statements like 'the current is inversely proportional to the resistance' while using the same equation to define resistance. O'Sullivan pointed out that students in introductory physics courses often conclude that 'Ohm's law is nothing more than the definition of resistance'. He suggested that once the concept of resistance has been introduced mathematically, Ohm's law could be expressed as a statement 'the resistance of a metallic conductor is constant at constant temperature.'

Although calculations of resistance and Ohm's law are not specifically included in the content for the GET phase of the RNCS (DOE, 2004), some of the grade 9 textbooks that have been published for the new curriculum do discuss Ohm's law, for example books by Davies, Lightfoot, Robinson & Wood (2001) and Cloete & Haverley (2001). The latter does not mention the class of resistor for which Ohm's law actually holds. This could lead to misunderstanding amongst teachers due to the fact that studies in both America (Hurd et al., 1980) and South Africa (Kruger, 1985) have found that science teachers depend heavily on the textbook as a teaching and learning aid as cited in Sanders (2002). Furthermore, headings referring to 'Ohm's law' are sometimes inappropriate, for example simple circuits with batteries and bulbs (Periago & Bohigas, 2005; Sugrue, Valdes, Schlackman & Webb, 1996).

Methodology

The study aimed to keep track of the development of students understanding of the concept of constant resistance developed during a semester. Twenty four students, training to teach the learning area Natural Science in the GET band, were involved. The course focuses on conceptual understanding, with a minimum of calculations. Four sources of data were used, namely a practical, worksheets, structured interviews and some of the questions in a semester test. The sample excluded students who were absent from either the practical, worksheet session or semester test.

Ohm's law was introduced during a lecture, with emphasis on the distinction between the definition of resistance and the concept of the constant resistance of metal conductors at constant temperature. This emphasis was crucial, as the textbook (Hewitt, Suchocki & Hewitt, 2003) introduces Ohms law as 'the current in a circuit is proportional to the voltage and inversely proportional to resistance…', but does not mention metals at constant temperature. Calculations were restricted to simple circuits to keep the focus on conceptual understanding.

During a practical, students were instructed to explore the relationship between the potential difference across a piece of nichrome wire and the current in the wire. They were supplied with a piece of nichrome wire, a standard circuit board set and a rheostat that would enable them to control the current by shifting the rheostat. The students were working in groups of not more than four, and each group had to submit a report on the practical.

Four weeks after the practical, the students were given two worksheets to assess the understanding of the concept of constant resistance. Students were working in pairs to give opportunity for peer interaction. In worksheet 1, the circuit simply consisted of a battery, a piece of nichrome wire and an ammeter. First, they had to calculate the resistance of the wire and then they had to explain how the potential drop, the current and the resistance would be affected if the 6 V battery were to be replaced by a 12 V battery.

Worksheet 2 was based on the setup used in the practical: a piece of nichrome wire, a rheostat, battery and ammeter in series, with a voltmeter across the nichrome wire. Students were asked how the total resistance, the current, the voltmeter reading and the resistance of the nichrome wire would change when the rheostat was shifted to increase its resistance.

Four weeks later, 3 pairs of students were interviewed and videotaped. The pairs were selected on the grounds of their performance in worksheets 1 and 2. One group had a high, one an average, and one a low score. They were confronted with a similar situation as in worksheet 1, where they had to predict how the potential difference, current and resistance would change if another cell were added in series. Then they had to do the experiment and finally compare their findings to their prediction and explain the difference.

In the semester test, written one week after the interviews, one of the questions was similar to the question in worksheet 1. The circuit consisted of a nichrome wire, cell, ammeter and voltmeter. First the students had to calculate the resistance, then they had to explain how the voltage, current and resistance would be affected by adding another cell in series.

Results

The practical started smoothly with students building circuits, taking measurements and drawing graphs of potential drop versus current. Towards the end, some of the students became puzzled and unsure about what they were 'supposed to conclude'. A number of students asked the lecturer whether the conclusion was that the 'current is inversely proportional to the resistance'. One group actually wrote the conclusion

……the greater the resistance, the smaller the current…..

in their reports. The students were apparently thinking about the resistance of the rheostat: when increasing the rheostat's resistance they observed the current dropping. It seems that the act of manipulating the rheostat was a distraction, the focus shifted from the nichrome wire to the rheostat. Instead of relating the current in the nichrome wire to the voltage drop across it, they related the current to the rheostat. They used the current and voltage measurements to plot a graph without thinking about stated purpose of the experiment and the meaning of the graph: The graph showed the current proportional to the voltage, indicating a constant resistance for the nichrome wire. Apparantly, these students could not distinguish between the procedure and purpose of the experiment. The confusion was discussed during the practical with those students who asked the lecturer about the matter. Also, the practical was discussed in detail during the next class, and much emphasis was placed on the fact that physically the nichrome wire was still just like before, having the same resistance as before shifting the rheostat.

It is also possible that this inappropriate conclusion was not related to the experiment itself, but a result of inspecting the formula V=IR. If the students had some memory of 'something being constant', they could conclude that resistance was inversely proportional to current by assuming that V was a constant in the formula. Should this be the case, it would mean that these students had very little conceptual understanding of the concrete reality of the circuit, and that their reasoning was purely algebraic (Gaigher, Rogan & Braun, 2007).

For worksheet 1, eight out of twelve student pairs said that the voltage, current and resistance would double if a second cell were added to the circuit. Six pairs actually recalculated the resistance value, contradicting themselves by using the original value for current. Figure 1 show an example of students' work where such a contradiction occurred. Two of the eight pairs did not actually recalculate the resistance but argued that the resistance would double as it was 'proportional to the voltage', also assuming an unchanged current. Once again, it is not clear whether these students argued conceptually or whether they simply assumed a cause-effect relationship in the formula V = IR, remembering that 'something stayed constant'.

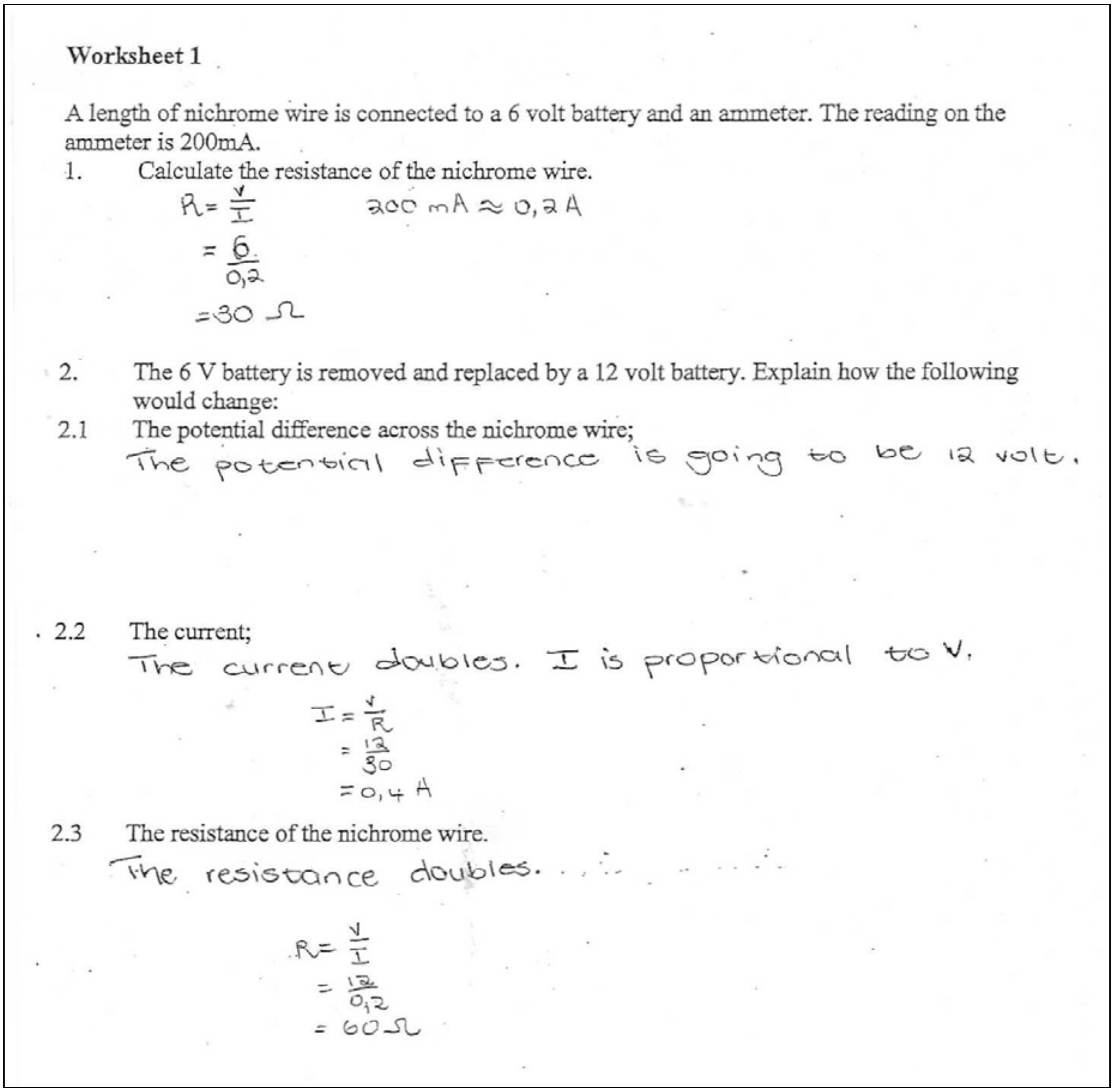
Worksheet 2 showed that the students learnt from their experience in the practical, and the discussion thereof. Eleven out of twelve student pairs correctly answered that the resistance is constant despite some of them making wrong predictions about the current and voltage across the nichrome wire. The following examples of answers illustrate that they have gained some understanding that shifting the rheostat does not affect the nichrome wire physically:

> The resistance is constant because the nichrome wire is unchanged….
> Stays the same, the nichrome wire was not changed, eg it was not made longer….
> Stays the same because the length, thickness and temperature stays the same…..

Nothing has happened to the wire. It’s length and width remained the same throughout, as well as the material that it is made of….
That is a constant resistor with constant resistance if the temperature is constant…..

The only pair who had it wrong seemed to refer to the resistance of the rheostat, showing no improvement since the practical:

The longer the wire the more the resistance…..



Worksheet 1

A length of nichrome wire is connected to a 6 volt battery and an ammeter. The reading on the ammeter is 200mA.

1. Calculate the resistance of the nichrome wire.

$R = \frac{V}{I}$ 200 mA ≈ 0,2 A

$= \frac{6}{0{,}2}$

$= 30\ \Omega$

2. The 6 V battery is removed and replaced by a 12 volt battery. Explain how the following would change:

2.1 The potential difference across the nichrome wire;

The potential difference is going to be 12 volt.

2.2 The current;

The current doubles. I is proportional to V.

$I = \frac{V}{R}$

$= \frac{12}{30}$

$= 0{,}4$ A

2.3 The resistance of the nichrome wire.

The resistance doubles.

$R = \frac{V}{I}$

$= \frac{12}{0{,}2}$

$= 60\ \Omega$

Figure 1. Example of students’ work showing a contradiction in arguing about changes in current and resistance.

This discrepancy between the success in the worksheet 1 and worksheet 2 was unexpected. In both circuits, a nichrome wire was used which had a constant resistance regardless of changes in the circuits.

	Increase	**Unchanged**	**Decrease**
Total Resistance	12*	0	0
Current	0	3	9*
Voltage across nichrome wire	5	0	7*
Resistance of nichrome wire	1	11*	0

Table 1. The effect of increasing the rheostat's resistance: summary of answers for worksheet 2 for 12 student pairs. Correct answers are indicated by asterisk.

In the Predict, Observe and Explain (POE) interviews, a piece of nichrome wire and a bulb were given to perform the experiment. Although the data from the interview cannot be generalised because only 6 of the 24 students were interviewed, there is an indication that no transfer has taken place between what they learned in the practical and during instruction and when they were asked to recall and apply the same knowledge by predicting, doing the experiment and then explaining what they did.

Table 2 compares the answers of the interviewed students on the question of how an extra cell would influence the resistance of a nichrome wire. The three data sources used were worksheet 1, the interview and semester test. The comparison shows some progress: in worksheet 1, all three pairs said that the resistance would double; during the interviews, only one group thought it would double and in the test, 4 individuals said that it would not change.

Pair	**Student**	**Worksheet 1**	**POE Prediction**	**Test**
1	R	double	increase	increase
	M			decrease
2	B	double	decrease	unchanged
	T			unchanged
3	D	double	unsure	unchanged
	N			unchanged

Table 2. Comparison between worksheet 1, POE predictions and test answers on how an extra cell would influence the resistance.

In the semester test, only 9 out of 24 students correctly answered that adding another cell in the circuit would leave the resistance unchanged (See Table 3).

	Double or increase	Unchanged	Decrease	Change	Not attempted
Voltage	19*	1	0	0	4
Current	11*	9	1	0	3
Resistance	5	9*	4	2	4

Table 3. Summary of students' answers on the test question. Asterisk indicates correct answers.

Discussion

Both the practical and worksheet 1 indicate that the students tended not to regard the circuit as a system, where the manipulation of one quantity influences the entire system. They were inclined to focus on two quantities at a time in a simple cause and effect relationship, without considering other effects in the system.

In the practical, the purpose was to explore the relationship between the potential drop and current for the nichrome wire. The nichrome wire was part of a system which was manipulated by shifting the rheostat. However, some students related the observed change in current to the physical manipulation of the rheostat, and regarded this relationship as the conclusion instead of regarding it as procedural knowledge in the investigation. In the end, the graph and the stated purpose of the experiment were often overlooked.

In worksheet 1, a similar way of thinking was observed. The physical change imposed on the circuit was assumed to influence only the quantity in question, without considering the behaviour of the system. When asked the effect of an extra battery on the current, most students had it correct: the current doubles, but when asked about the effect on the resistance, once again they believed that it would double. Some students actually recalculated the resistance, using the original current, ignoring the change in current calculated in the previous question. Regarding the question on the change in current, the correct answer, namely the doubled current, could also be the result of simply considering two quantities at a time: assuming the same resistance value as before, without thinking about whether or not resistance change. It seems that in both the case of current and resistance, the students only focused on two quantities at a time, ignoring the behaviour of the system.

Students' answers in worksheet 1 also showed a tendency to think of resistance as a mathematical variable rather than a physical property of the wire. This reflects an algebraic approach (Gaigher, Rogan & Braun, 2007), not expected amongst students in a course on conceptual physics. Many students do not view resistance of the given nichrome wire as an inherent physical property of the resistor, but as a mathematical variable. The items are related algebraically, without considering the items as part of a system, and without appreciation of unchanged physical state of the wire.

Regarding learning and transfer, it appears that the students remembered the practical and the issue about the rheostat when they completed worksheet 2. They were able to present this knowledge in an identical situation. Their explanations focused on the concrete situation, pointing out that the resistor was physically unchanged. However, most of them were unable to transfer the knowledge to a different context encountered in worksheet 1, despite this being a less complicated circuit. This lack of transfer reflects a mismatch between declarative and procedural knowledge (Paden, n.d.). It is also possible that the lack of transfer was aggravated by the numerical values in worksheet 1, while in worksheet 2, they were forced to use conceptual arguing.

It is not clear to which extent these students' difficulties with understanding Ohms' law can be attributed to the textbook's approach. Studies with larger groups would be required to explore such a connection.

Conclusion

This study revealed that this group of pre-service teachers did not master the concept and implications of constant resistance despite explicit instruction, a practical, and peer interaction while working through worksheets. Our research found that some students demonstrated an inability to consider a circuit as a system. Furthermore, when the context was changed understanding was often lost. This could indicate operation on low cognitive levels which has serious implications for our future classrooms, not only regarding Ohm's law, but also for the teaching of science in general.

Recommendations

Lecturers need to be sensitized to the many pitfalls regarding the understanding of Ohm's law. If student teachers enter the future classrooms with incomplete understanding of Ohm's law, the problem will be passed on to their learners and could be perpetuated into tertiary education.

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