The effect of physics computer simulations on teachers' misconceptions of DC circuits

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The behaviour of direct current (DC) circuits in the electricity section of undergraduate and school curricula is a source of a multitude of common misconceptions. Our study is a pilot project to determine the effect of physics computer simulations on teachers' misconceptions of DC circuits in a local non-urban environment. The simulations are highly visual, as well as physically accurate. Three intensive workshops were presented to Further Education and Training (FET) physical science teachers in a region of the Tshwane North District. The goals of the workshops were to improve teachers' understanding of electric circuits, to improve the skills associated with connecting lights bulbs, resistors and wires in various combinations and let teachers think and argue about the behaviour of the circuits. Data was collected from pre- and post tests, worksheets, informal interviews as well as evaluation forms. Some of the misconceptions could be resolved and will be discussed.

Introduction

Secondary school teachers and university students' explanations about electricity often differ from accepted explanations of the physics community. Extensive research has already been done on misconceptions of DC circuits (Arons, 1997; Engelhart & Beichner, 2004; Mc Dermott & Shaffer, 1992). Examples of the most common misconceptions are that current is consumed and that the battery is a source of constant current (Fredette & Lochhead, 1987; Licht & Thijs, 1990 and Osborn, 1981). The need for conceptual understanding of science concepts and specifically electricity is of the utmost importance due to the fact that the emphasis in the National Curriculum Statement (NCS) for Physical Sciences is more on learner understanding of science concepts as well as the active use of scientific knowledge and inquiry processes (DOE, 2003).

Students make greater conceptual gains when using the computer to prepare for laboratories than those who use textbooks and solve additional problems on the topic, and are more capable to integrate knowledge (Linn & Hsi, 2000; Linn et al., 2004; Triona & Klahr, 2003 and Zacharia & Anderson, 2003). "Properly designed simulations used in the right contexts can be more effective educational tools than real laboratory equipment, both in developing student facility with real equipment and at fostering student conceptual understanding" (Finkelstein *et al.*, 2005).

We used a couple of simulations from the University of Colorado (USA), where members of the Physics Education Technology (PhET) project developed a suite of 60 physics simulations. The development of these simulations is grounded in research on how students learn, student conceptual difficulties and misconceptions. It is highly interactive and provides animated feedback to the user. Wieman et al. (2008): indicated that they make use of "student interviews and classroom testing to explore issues of usability, interpretation and learning" (p 394).

Aim of our study

Our study is a pilot project to determine the effect that physics computer simulations might have on two common misconceptions of DC circuits namely that current is consumed and that the battery is a source of constant current. The research was done in a local non-urban environment.

Sample

Three, two hour workshops were presented to FET physical science teachers in one region of the Tshwane North School District. All workshops were attended voluntarily. Nine teachers, seven male and two female, from eight schools attended the workshops. The average teaching experience of eight teachers was 10,5 years while one male teacher had 2,5 years experience. The workshops were presented in the computer laboratory of one of the schools.

Method

We focussed on the Circuit Construction Kit (CCK) from the PhET project. We were specifically interested to see if teachers would be able to use the CCK together with appropriate worksheets without any verbal instruction and determine if it would clear the two common misconceptions about DC circuits. This simulation kit allows the user to construct electric circuits with any number of batteries, bulbs, resistors and wires in any combination. Potential differences and electric currents can be measured by simulated voltmeters and ammeters (see example in figure 1). The CCK was selected for the following reasons: (1) the possibility to address misconceptions held of electric circuits, (2) the visual representation of electron flow, (3) the use of modelled light bulbs, and (4) the possibility to vary the resistance and/or potential difference.

The other goals of the workshops were for the teachers to improve their understanding of electric circuits (the concepts of potential difference, current and resistance), to develop the skills associated with connecting lights bulbs, resistors and wires in various combinations (for example series and parallel), to collect current, potential difference and resistance data and argue about the behaviour of the circuits. This could be done in discussions with their peers. In the end they preferred to explain their thinking by writing on the worksheets.

Data collected

The teachers were given the same pre- and post test to establish the nature of their thinking about electric circuits. The pre-test was given before the intervention while the post-test was given after the last workshop. The test comprised of questions from the Determining and Interpreting Resistive Electric circuits Concepts Test (DIRECT) (Engelhardt & Beichner, 2004). Teachers had to complete laboratory challenge write-ups compiled by the PhET group, but altered for our workshop context. Informal interviews were conducted by both researchers with the same teachers but at different times. Notes were compared. They also had to fill in evaluation forms after each workshop.

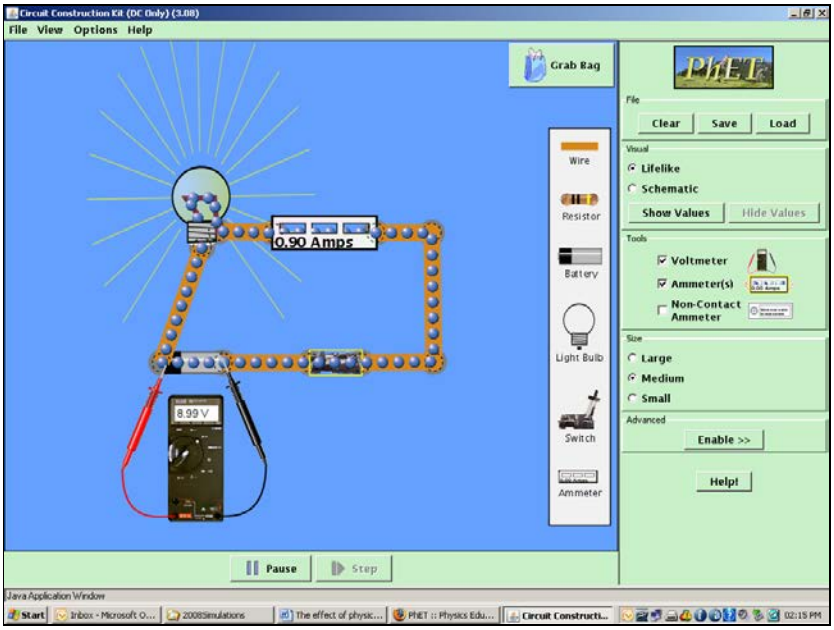

Figure 1: CCK in *Lifelike* visual mode

Results and discussion

Pre-and post tests

Only five of the nine teachers attended all three consecutive workshops and wrote the pre and post tests. The fact that there was a slight drop from the pre- to post test average (48% to 46%) was alarming. We therefore decided to analyse the results of two specific teachers who participated in all aspects of the workshops. The mark of one teacher (referred to as T1) remained the same (pre- and post 64%), while that of the other teacher (referred to as T6) dropped from 50% to 43%. Two examples from the tests follow which illustrate the thinking of the two teachers.

The first question addressed the issue of current consumed directly by asking “are the charges used up in the production of light in a light bulb?” T1 answered correctly in both the pre- and posttests but T6 persisted with incorrect answers. He did not change his idea that charge is used up and both times selected "charges moving through the filament produce 'friction' which heats up the filament and produces light" as reason for his answer. One of the other choices was that "charges are converted to another form such as heat and light". From this it seems that his confusion is originating from mixed ideas about current and energy and/or that he associated 'friction' with the consumption of charge.

An example of one of the questions probing the second misconception namely that a battery is a source of constant current, is shown in figure 2. Although T1 achieved better overall than T6 he failed this question twice by firstly answering E and then A. He probably associated an open switch with no current and therefore no potential difference. T6’s answer indicated that he initially considered this as similar to a closed circuit when he answered 6V in the pre test. He corrected himself in the post test by answering D.

What is the potential difference between points A and B?

(A) 0 V
(B) 3 V
(C) 6 V
(D) 12 V
(E) None of the above

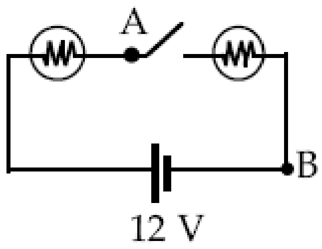

Figure 2: Example of a test question

Worksheets: electric circuits

In the second part of the simulation experiment the teachers had to construct a circuit with a battery and a light bulb in the *Lifelike* visual mode by using the CCK simulation (figure 1). The teachers had to draw the circuit diagram and answer questions. Each of the questions required the teachers to explain their observations. This was done in order to justify their arguments about the circuits' behaviours.

The first question was "How does the potential difference of the battery compare to the light bulb potential difference? Explain what you think is happening." The teachers responded as follows:

T1: They are the same. They are both 8,99V instead of 9V due to internal resistance. The electric potential energy between their end-points is the same.
T6: The potential difference of the battery is 100V and that of bulb is 0V because no current is passing through the bulb.

T1 assumed a closed circuit and gave the correct answer. T6 on the other hand, assumed an open circuit and therefore his answer is acceptable too.

In the following section, they had to include a switch to the circuit, close the switch and comment on how the potential difference (PD) of the battery compared to the light bulb potential difference and how the potential difference of the battery compared to the switch potential difference. Again they had to explain what they thought was happening.

T1: The PD of the bulb is the same as the PD of the battery. The PD of the closed switch is zero. There is no difference in electric potential energy between two ends of the closed switch.
T6: The potential difference of the battery and the light bulb show a drop, these indicate the internal resistance. Potential difference of the switch is now 0V.

Both T1 and T6 indicated that the PD across the switch is zero. In addition, T6 observed that the PD across the bulb and battery is the same even if it is smaller. Although T1 pointed out that there is no difference in electric potential energy between the ends of the closed switch, neither he nor T6 explained why this is the case. We expected teachers to be able to point out the reasons for the difference in the behaviour of batteries, resistors and switches in a closed versus open circuit.

The third part of the experiment dealt with light bulbs in series. All the questions on the worksheets were answered correctly. These questions specifically addressed the idea that current is consumed. For example if two bulbs A and B are in series, which one would be the brightest and therefore have more current through the bulb (figure 3). According to research, students would indicate bulb A (Fredette & Lochhead, 1987; Licht & Thijs, 1990 and Osborn, 1981). The answers to these questions clearly indicated that this misconception was addressed by the simulation per se.

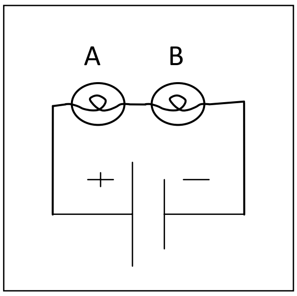

Figure 3: Two light bulbs A and B in series

The fourth part of the experiment was on light bulbs in parallel. Three figures were given, the first with one, the second two and the third three light bulbs in parallel each time connected to one battery of 12V. The teachers had to build the circuit by using the CCK simulation. They had to record the potential difference of the battery and the current into the battery of the circuit in a table. They then had to use descriptive language to record the brightness of the bulbs. The questions posed were specifically designed to address the second misconception namely that the battery is a source of constant current. The first question in this part of the experiment was to "summarise the relationships you observed and explain what you think is happening."

T1: Brightness is the same. Current reading increases. Parallel connection of bulbs results in less resistance, and hence *more current*.
T6: The more bulbs are in parallel the less potential difference across them and the *more the current* as the brightness justify.

Both T1 and T6 indicated correctly that the current into the battery increases with increasing number of resistors in parallel. One could argue that the misconception was addressed. T6 however, indicated incorrectly that the PD decreased. An additional concern is that although T6 saw in the simulation the brightness stayed the same, he indicated in the table that the brightness decreased with more bulbs added in parallel. One possible explanation could be offered that his perceptions/knowledge overruled what he saw, or that he might be so used to experiments not working that he did not take note of what he observed. The teachers then had to determine quantitatively if changing the battery potential difference caused them to modify any of their conclusions. They had to explain what they measured and drew conclusions.

T1: The conclusion is the same. Increased voltage increases the brightness of the bulbs. The current is also affected but increases with more bulbs in parallel.
T6: The more the potential difference the more the current.

Informal interviews
Teachers were asked to reflect on how they perceived their change in teaching styles (previous and current), conceptual understanding, and experience and use of computer programmes by answering questions posed to them during informal interviews. Both teachers intended to change their teaching style. When comparing the answers on conceptual understanding teacher T1 was confident that he "understand the different concepts" of electric circuits while T6 avoided the question by indicating that the computer simulations "saves time and brings reality to the classroom". When asked on how they previously taught electric circuits, T1 indicated "more on theory than practical" while T6 answered "through using practical resources such as electric station board and practical batteries, bulbs and other relevant accessories". Again T1 focused on the concepts by indicating "be able to clearly explain the relationship of series connections, voltage, resistance and current" while T6 shifted his responsibility to the simulation software by stating "I will encourage learners to use and rely on computer simulations for their better understanding of physics concepts". Both teachers seem to have enjoyed working with the simulations. When they had to express what they thought about the software, T1 said "it is very interesting and I enjoyed playing around" while T6 mentioned that it "taught me that complex topics could be easily presented to learners". They would like the software to be implemented at their schools.

Conclusion

An average of less than 50% for the kind of tests presented to this group of FET teachers is unacceptably low. The DIRECT test is used internationally to give an indication of the understanding of concepts in electricity. It is anticipated that FET teachers with on average more than 10 years teaching experience, should be in command of the elementary concepts regarding electrical circuits containing basic circuit elements like batteries, resistors and switches and that they would respond without difficulty and achieve higher scores.

The limited computer simulation intervention did not improve test results, which means that a great deal more over a much longer period of time needs to be done to improve the conceptual understanding of these teachers. After analysis of the questions in the worksheets, we consider both misconceptions to be resolved by using the simulations only and can therefore conclude that using simulations only could assist in solving misconceptions. However; more guidance from the instructors, with class discussions or with physically performing an experiment should be considered.

Another achievement was to introduce teachers to an alternative way of teaching and learning physics concepts. One of the teachers thought that "building circuits and measuring V and I become much easier when using PhET". Another expressed with excitement that "the use of PhET brings about reality in the classroom. It also saves time and is better than using apparatus".

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