The Use of Simulations in Correcting Electricity Misconceptions of Grade 10 South African Physical Sciences Learners

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Abstract

This study investigated the use of interactive computer simulations in addressing misconceptions held by Grade 10 South African learners on electric circuits. The sample comprised 130 learners from three under-performing schools in a socio-economically disadvantaged township. The misconceptions were identified by means of a three-tier diagnostic test. The first tier consisted of conceptual questions; the second tier asked for reasons for the choice made on the first-tier item; and the third tier addressed the confidence level of the respondents. A statistical analysis of the data collected revealed a significant difference in the performance of learners on the pre-test and post-test, with learners performing better on the post-test. This suggested that the use of simulations in the science classroom did, to a certain extent, reduce the number of misconceptions previously held by learners. The results from this study support the findings of studies conducted in other countries, and suggest that simulations may be a viable cognitive learning tool in enabling learners to investigate their pre-conceptions and thereby effect conceptual change.

Introduction

Despite widespread use of computers and network technologies in many areas of our lives, and the use of technology by scientists across many disciplines, such technology has often been under-utilised and poorly integrated into school science curricula, with a tendency for teachers to default to traditional teaching approaches (Burden & Kearney, 2016; Cochrane & Antonczak, 2014). However, with the advent of portable technologies, the use of technologies to support learning has once again captured the imagination of teachers and researchers across the world (Krajcik & Mun, 2014). In South Africa, the imperative for the integration of information and communication technology (ICT) in learning is expressed through the South African White paper on e-Learning where it is stated that "ICTs, when successfully integrated into teaching and learning, can advance higher-order thinking skills such as comprehension, reasoning, problem solving and creative thinking and enhance employability" (Department of Education, 2004, p. 14). In the midst of a global information technology revolution, South Africa needs to keep abreast of learning technologies and how these can be exploited in scaffolding learning. In an emerging economy like South Africa, there is a strong need to exploit the use of technology within the sphere of science teaching and learning in the advancement of scientific knowledge acquisition. This is deemed crucial in the provision of scientists and engineers. According to Mdlongwa (2012) South African schools have used traditional teaching methods that have remained intact. The failure of schools to use ICT as a

means of enhancing teaching and learning has led to South Africa's failing to close the 'digital divide'. The use of ICT in schools could help overcome some of the challenges of improving the efficiency and productivity of both learning and teaching in South African schools (Mdlongwa, 2012). Furthermore, Czerniewicz and Brown (2014) found that access to success in higher education is about on-going and continuing access to various forms of capital such as ICT.

Researchers have called for an extensive examination of the use of technology learning resources such as simulations in particular learning contexts in order to understand the widespread use of its integration in learning (Cheng & Tsai, 2013; Song, 2014). According to Krajcik and Mun (2014, p. 356) the functionality of simulations can enable learners to "interact virtually with phenomena too dangerous to do in real time, and solve complex problems". Recent research emphasizes the use of technology such as simulations in learning environments where learners develop knowledge and skills in inquiry-based learning (Chang, Quintana, & Krajcik, 2010; Kang, Kim, & Lee, 2011; Quintana, 2012). However, there is a relative paucity of research globally on its effectiveness in eliminating misconceptions and thereby supporting conceptual understanding in science.

Research data collected over more than three decades has shown that the majority of learners come to the science classroom with pre-instructional knowledge and beliefs about phenomena and concepts that will be taught (Duit & Treagust, 2003). Posner, Strike, Hewson and Gertzog (1982) state that children formulate their own concepts or explanations about how the world around them works. Children also construct these perceived regularities or patterns when asking family members or acquaintances about how and why things happen (Kibuka-Sebitosi, 2007; Pfundt & Duit, 2006). These concepts or ideas are commonly referred to as pre-conceptions. Pfundt and Duit (2006) argue that these pre-conceptions affect learning as they become integrated into learners' cognitive structures. Many of these experientially and socially constructed conceptions are different to the scientific concepts that are taught in the science classroom. These learner pre-conceptions which do not match the concepts accepted by the mainstream scientific community are referred to as misconceptions. Since these pre-conceptions 'work' in the context of the learners' observations, learners "cling rigidly to their current beliefs" (Pine, Messer & St. John, 2001, p. 83) and are hesitant to accept scientific concepts. As a result, learners experience difficulty in integrating any new information within their cognitive structures, resulting in an inappropriate understanding of new concepts.

A major aspect of science teaching concerns the perceived role and value of learner ideas that teachers hold. Larkin (2012) metaphorically cast misconceptions as either *obstacles* or *resources* in the teaching of science. According to Larkin "When student misconceptions are cast as obstacles, their presence implies a barrier to student learning and suggests that their absence would lead students more directly to intended learning goals" (p. 932). This perspective suggests that misconceptions need to be dismantled and replaced in order for meaningful learning to take place (Hammer, 1996). The view of misconceptions as *resources* purports that that these ideas "may be refined, revised, bridged, and built upon by both teachers and students alike" (p. 932). The position taken in this article is that learners' misconceptions can serve as a *resource* for discussion, debate, and investigation in the re-construction of ideas. The process of correcting learner misconceptions depends on not only the transmission of new knowledge but also the integration of new concepts related to learners' existing conceptual structures (Vosniadou, 2002). Computer simulation environments allow learners to observe and investigate models of abstract and complex concepts, and to modify existing scientifically

incorrect conceptions (Chang, Chen, Lin, & Sung, 2008; Chen, Pan, Sung, & Chang, 2013; de Jong & Van Joolingen, 1998).

In responding to this call, the research reported in this article investigated the effect of teachers using computer simulations in addressing misconceptions of electric circuits held by Grade 10 Physical Sciences learners at under-performing Dinaledi schools in the township of Soweto. A review of research by Smetana and Bell (2012) on the effectiveness of computer simulations for supporting science teaching and learning during the past four decades revealed that simulations can facilitate conceptual change, and therefore help eliminate misconceptions. A study by Crooks, Sharma and Wilson (2015) provides further evidence that simulations are beneficial in the teaching of Physics. They argue that simulations provide greater opportunities for learners to experience physics phenomena and perform experiments individually. This has resulted in higher levels of comprehension, retention and engagement as well as a positive impact on learner attainment in physics. However, despite this extensive research on simulations, Smetana and Bell (2012) remark that there are "a limited number of studies involving low-achieving students and English-language learners (ELL)" (p. 1362). This gap in the research is addressed in this study that was undertaken at South African schools where learners are performing poorly in science, and where English is the second language of such learners. The topic 'electric circuits' was chosen as studies have revealed common and extensive learner misconceptions related to this topic (Kucukozer & Kocakula h, 2007; Pesman & Eryilmaz, 2010). The common misconception types will be discussed later. There has also been a dearth of research on the effectiveness of simulations in addressing school learner misconceptions in electricity, with the review by Smetana and Bell (2012) showing only one study by Baser (2006) on pre-service teachers having been conducted.

In South Africa, the term 'township' usually refers to underdeveloped urban areas that historically were created for 'non-whites' during the apartheid era. Communities living in townships in most cases have a low socio-economic status. Dinaledi Schools are specialist Mathematics and Physical Sciences public schools (Department of Education, 2007). They were established in 2001 and there are currently approximately 500 schools nationally. International assessments such as Trends in International Mathematics and Science Studies (TIMSS) repeated over the years from 1990 to 2003 show that the performance of South African learners in mathematics and science, especially Black learners from impoverished communities such as townships is alarmingly poor compared to other developing countries (Martin, Mullis, & Chrostowski, 2004). More recently, the World Economic Forum report for 2015/16 painted a dismal picture, with South Africa placed at 138 out of 140 countries. Dineledi Schools were an initiative by the South African Department of Education to uplift learner participation and performance in Mathematics and Physical Sciences. These schools are provided with additional resources and support to improve teaching and learning.

It is against this background that the following research question was pursued:

> To what extent, if any, can the use of simulations correct misconceptions held by Grade 10 Physical Sciences learners at under-performing Dinaledi Schools?

Cognitive Tools Framework

This investigation is framed by a cognitive tools framework that "allows a detailed examination of a particular technological resource relative to its predicted role and value in learning science" (Songer, 2007, p. 479). Songer defines a cognitive tool as "a computer-available information

source or resource presenting focused information specifically tailored for particular learning goals on a particular topic of interest for learning by a particular target audience" (p.476). The framework guides the investigation in three areas: examine audience and knowledge; create learning activities; and examining learning performance. Each of these facets is now discussed.

Examine Audience and Knowledge
This aspect of the investigation refers to a clear definition of the target audience (age, abilities, prior knowledge, and beliefs) as well as learning goals (science content, scientific reasoning, beliefs/attitudes about science). Within the context of this study, the research focussed on misconceptions of electric circuits held by Grade 10 Physical Sciences learners, and the extent to which these misconceptions could be eliminated through the use of simulations.

A review of the literature on misconceptions in physics shows that electricity is a content area that is strewn with misconceptions. Table 1 summarises the different types of misconceptions in electricity.

Table 1: Misconception types in electricity

Misconception type	Description
M1: Sink or Unipolar Model	For current to flow, only a single wire should connect the power supply to a device (Sencar & Eryilmaz, 2004; Peşman & Eryilmaz, 2010).
M2: Attenuation Model	The current decreases as it travels around the circuit (Shipstone, 1988; McDermott & Shaffer, 1992).
M3: Sharing Current Model	The current is shared equally by all devices in a circuit (Shipstone, 1988; Sencar & Eryilmaz, 2004).
M4: Clashing Current Model	Positive and negative electricity meet at the electrical device and clash there, causing the electrical device to work (Engelhardt & Beichner, 2004; Peşman & Eryilmaz, 2010).
M5: Empirical Rule Model	The further the light bulb is from the power source (battery), the dimmer the light bulb (Borges & Gilbert, 1999)
M6: Short Circuit Model	The light bulb will glow regardless of the short circuit that is created by the presence of the conducting wire (Heller & Finley, 1992).
M7: Power Supply as a Constant Current Source Model	The battery is a constant current source rather than a source of constant potential difference (Shipstone, Jung & Dupin, 1988; Engelhardt & Beichner, 2004).

M8: Parallel Circuit Misconception	The more resistors that are added in parallel, the greater the total resistance Heller & Finley, 1992 Borges & Gilbert, 1999).
M9: Sequential Reasoning	Any change taking place in a circuit is carried forward in the direction of the current, but not backwards (McDermott & Shaffer, 1992; Chambers & Andre, 1997).
M10: Local Reasoning	The changes in circuits have only local effects rather than effects on the whole (Cohen et al., 983; Heller & Finley, 1992).
M11: Current Flow as Water Flow	Electric current flows within the conducting wire much like water flows through a pipe (Sencar & Eryilmaz, 2004; Peşman & Eryilmaz, 2010)

Create Learning Activities

Learning activities refers to the specific tasks that the target audience will perform with the digital resource. In this research, the computer was the digital resource through which learners could engage with simulations. Simulations offer idealised, dynamic and visual representations of physical phenomena and experiments which would be dangerous, costly or otherwise not feasible in a school laboratory (Osborne & Hennessy, 2003). Computer software programs, such as interactive simulations, are an innovative way to transfer scientific ideas and connect learners in educational activities (Perkins et al., 2006; Linn, Eylon, & Davis, 2004). Khan (2011, p. 216) defines interactive computer simulations as "a computer program that attempts to simulate a model of a particular system". These simulations are useful in that they allow learners to visualise aspects of science and to manipulate variables in multiple ways and, in so doing, observe changes as a result of these interactions (Khan, 2011).They also allow science teachers to demonstrate experiments that would be dangerous, costly or otherwise not feasible in a school science laboratory (Osborne & Hennessy, 2003). Simulations can therefore be used to simulate these experiments and the intended results can be observed (Khan, 2011).For example, learners are able to interactively perform complex mechanics 'experiments' where friction and gravity can be adjusted, and then observe the results immediately (Khan, 2011).

The simulations for this research study were sourced from the Physics Education Technology (PhET) project. PhET was developed by a group of researchers from the University of Colorado at Boulder in the United States of America and the simulations are grounded in research on how learners learn, their conceptual difficulties and misconceptions. The PhET project goals are "increased student engagement, improved learning and improved approaches towards learning" (Wieman, Perkins, & Adams, 2008, p. 394).The PhET simulations are highly interactive and provide animated feedback to the user. These simulations are freely available on the internet and therefore accessible to all South Africans. In addition, the PhET simulations can be downloaded onto a computer or laptop and then used without internet connectivity. Further to this, the learners who participated in this study have been exposed to PhET simulations before.

Extensive research has been conducted on the use of simulations in the science classroom, and some of the advantages are quite compelling. Firstly, they can reduce instructional costs and provide immediate and high quality feedback responses to the science learners (Finkelstein et al., 2005).Therefore, the need to purchase expensive circuit boards and other electrical devices is eliminated, as is the possibility of a failed experiment due to faulty equipment.

Secondly, simulations allow learners to play a more active role in the learning process, thus allowing them to construct their own knowledge. This constructivist approach to teaching and learning is essential for conceptual change and the weakening and elimination of misconceptions (Jaakkola, Nurmi, & Veermans, 2011).

Thirdly, when teaching the topic on electric circuits, the use of simulations permits the learners to visualise more than one circuit at a given time, thus allowing them to compare circuits (González & Reitman, 2001). Simulations of electric circuits also ensure that potential differences and current can be measured quickly and effortlessly, by simply inserting the relevant meter into the circuit (Baser, 2006).

Fourthly, simulations also create opportunities for learners to reflect and modify their concepts while providing them with numerous occasions to receive feedback (Zacharia & Olympiou, 2011). In so doing, learners are also able to formulate and test hypotheses and reconcile any discrepancy between their ideas and the observations in the simulated world (Bliss & Ogborne, 1989).

Lastly, simulations have the ability to foster peer interaction. Research conducted by Bilan (1992) found that learners would often seek out peers to share their experiences and discuss problems. The research also reported that the simulations were able to keep learners with varying abilities interested in interacting with the simulations (Bilan, 1992). This finding was supported by the work of Vogel and colleagues (2006) who found that the use of simulations assisted in improving learner motivation and attitude towards science.

Examining Learning Performance

Learning performance refers to the specific products that are generated by the student as a result of interactions with digital learning activities. Learner performance in this study entailed the understanding of concepts on electric circuits. In order to diagnose learner misconceptions, the research used an instrument that comprised of twenty three-tier multiple-choice questions on the electric circuit.

Williams (2006) justifies the design of a three-tier multiple-choice test, as he argues that such a test uses Bloom's taxonomy as a framework for promoting different levels of thinking. This was the case with the diagnostic questionnaire used in this research study. The findings of research studies conducted by Connelly (2004), Mann and Treagust (2000), and Williams (2006) provide further evidence that three-tier multiple-choice instruments make it easier to test learners' higher-order thinking, more so than conventional multiple-choice questions. The format of a three-tier test is described in the next section.

Methodology

This study adopted a quasi-experimental research design where the purpose is "to determine the cause and effect – and there is an intervention controlled by the experimenters" (McMillan & Schumacher, 2010, p. 22). This quasi experimental design uses a pre-test/post-test design. This design involves studying the same participants before and after the experimental manipulation or intervention. The reason pre-test/post-test designs are considered quasi-experimental is because the majority of researchers will manipulate the entire sample. This ensures a larger sample size in order to test the effectiveness of the manipulation (McMillan & Schumacher, 2010).

Context of the Study
This study was conducted at three under-performing Dinaledi schools in Soweto. These Dinaledi schools are classified as under-performing because their matric pass rates were below 60% for two consecutive years. The three schools are situated in fairly close proximity to each other. All three Dinaledi schools selected for this study are Quintile 3 schools. All schools in South Africa are categorised into five categories called quintiles. Quintile 1, 2 and 3 schools are located in poverty-stricken areas and are, therefore, known as 'no-fee schools'. Quintile 4 and 5 schools are located in more affluent communities, and are fee-paying schools. However, due to their Dinaledi status, the schools in this study are well resourced. Each of these schools receives additional resources such as textbooks, calculators, digital projectors, laptops, and digital software programs.

Data Collection and Analysis
In order to fully address the research question, items from two validated tests were sourced. Twelve items from an instrument developed by Pesman and Eryilmaz (2010) and eight items from a test by Millar and Hames (2002) were selected. This resulted in a test that consisted of 20 three-tier multiple-choice test items. The first five items of the test are presented in Appendix A. The first tier of each item consists of a content question having two to five choices. An example is presented below.

1.1   Will the light bulb in **Figure 1** light up?

Figure 1
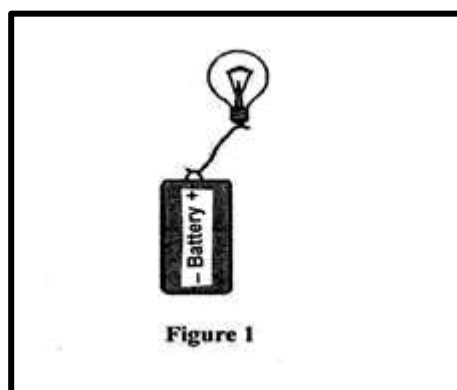
a) Yes, it will.
b) No, it will not.

The second tier of each item contains a set of four possible reasons for the answer given in the first tier. The reasons consist of the designated correct answer, together with common learner misconceptions identified from the literature. An example is presented below.

1.2.   Which one of the following is the reason for your answer to question 1.1 above?

    a) The battery and the light bulb are connected by the wire.
    b) An extra wire must be connected from the negative terminal to the battery to the screw base of the light bulb so that the positive and negative charges meet in the light bulb.
    c) An extra wire must be connected from the negative terminal of the battery to the screw base of the bulb so that the electric current passes through the bulb.

The third tier asks about the confidence level of the respondent in responding to the first two tiers.   An example is presented below.

1.3   How confident are you that your answers to 1.1 and 1.2 are correct?

    a) Very confident
    b) Fairly confident
    c) Not confident
    d) Just guessing

If a learner gives the correct responses to the first and second tier and answers 'very confident' for the last tier, then the response is regarded as a correct answer (Eryilmaz & Sürmeli, 2002). So in the above example, the learners would have had to provide an answer to 1.1 as (b) and 1.2 as (c) and 1.3 as (a) in order for the question to be considered correct. Research studies conducted by Tamir (1989) found that the use of three-tier multiple choice diagnostic instruments to be an effective way of assessing meaningful learning among learners. Tamir revealed that to some extent the three-tier multiple choice questions addressed the limitations of traditional multiple choice questions, as it requires learners not only to justify their choice of answer, by giving a reason, but also to indicate how confident they were about their choice of answer. Furthermore, Connelly (2004), Mann and Treagust (2000) and Williams (2006) found that the three-tier multiple choice instruments makes it easier to test learners' higher level thinking, more so than conventional multiple choice questions.

This diagnostic test was administered as a pre- and post-test to 130 Grade 10 learners. The aim of the pre-test was to reveal the misconceptions learners bring as prior knowledge to the science classroom. Once the misconceptions were identified, an intervention strategy was introduced whereby learners engaged with the PhET simulations. The post-test was then administered to investigate the extent to which the learners underwent conceptual change and therefore had a reduction in the number of the previously identified misconceptions. The percentage of correct responses for each item on both the pre- and the post-test were calculated. Thereafter, the results for the pre- and post-test were compared in order to evaluate whether the use of simulations in the teaching of electric circuits was an effective intervention strategy in

eliminating the identified misconceptions. A dependent t-test (also called the paired t-test or paired-samples t-test) was used to compare the means of the same sample of learners for the pre- and post-test to establish whether there was a statistically significant difference between these means. The results were tabulated and also represented graphically.

The Intervention

Once the misconceptions were identified by analysing the results of the pre-test, an appropriate simulation was selected. Each of the teachers from the three schools was issued with a CD containing the PhET simulations as well as instructions to be followed. A workshop was organised to orientate the teachers towards using the simulations and how to incorporate them into their lesson preparation. A practice run was conducted to address any difficulties they might have, and to ensure that there would be no unforeseen mishaps. An example of one of the simulations is presented in Figure 1 below.
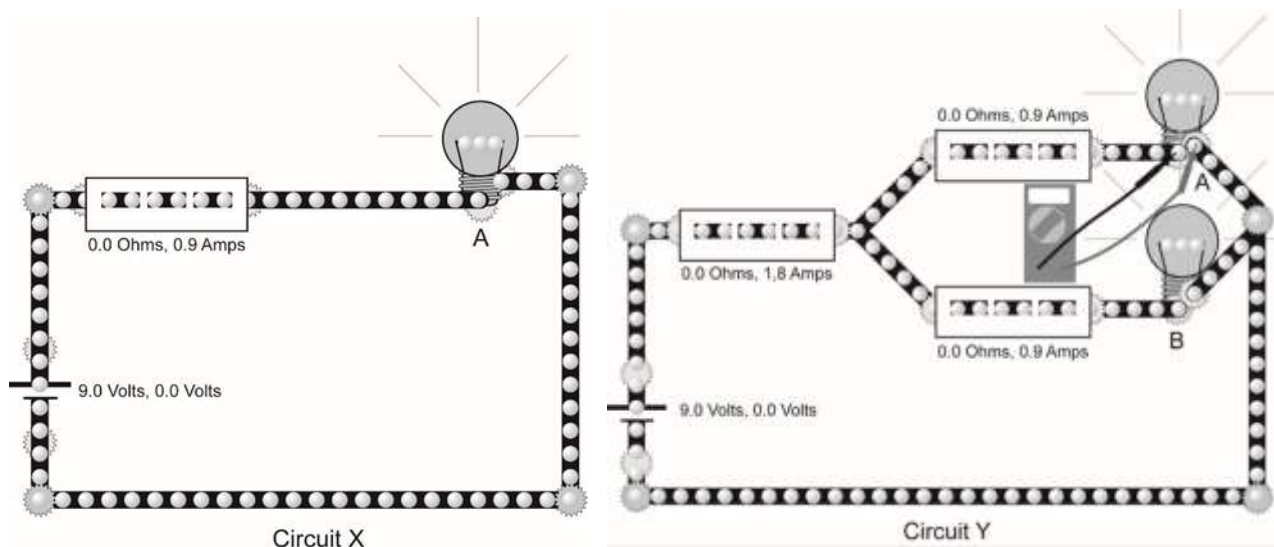
Figure 1: Screen shot of one of the simulations used

The above simulation was used by teachers in addressing a misconception identified from the pre-test. This simulation is well documented in the literature and referred to as a 'parallel circuit misconception' (Cohen, Eylon & Ganiel, 1983; McDermott & Shaffer, 1992; Chambers & Andre, 1997). Here learners conceive that as more light bulbs are added in parallel, the brightness decreases due to an increase in resistance. In addressing this misconception, the teacher supported learners in using the appropriate PhET simulation in order effect conceptual change towards a scientific understanding of the phenomenon. The teachers firstly showed the learners how to construct circuit X and circuit Y on the simulation, and how to place them alongside each other. Thereafter, the teacher allowed the learners to run the simulation in order to observe the brightness of the light bulbs as more light bulbs were added in parallel. The learners also took note of the voltmeter reading.

Results

Table 2 presents the overall descriptive statistics for the pre-test and post-test.

Table 2: Descriptive statistics for pre-test and post-test

	Pre-test	Post-test
n	130	130
mean	4.66	5.29
5% trimmed mean	4.61	5.13
standard deviation	2.49	3.15
minimum	0.00	0.00
maximum	12.00	12.00
range	12.00	12.00

The mean score for the pre-test was calculated to be 4.66, while for the post-test it was 5.29. Therefore, the mean for the post-test score is higher than the mean score for the pre-test. This would suggest that the learners did better on the post-test than on the pre-test. The 5% trimmed mean is obtained by removing the top and bottom 5% of the population, and then the mean is recalculated (Pallant, 2013). This was done to establish whether the extreme scores had a strong influence on the mean. From Table 2, it is seen there is very little difference between the original mean and the 5% trimmed mean for both the pre- and post-test. Therefore, the outliers had no significant influence on the mean.

The paired sample t-test reflected a significant difference in scores for the pre-test and post-test ($t(129) = -2.16$, $p = 0.03$ (two-tailed)), with learners performing significantly better on the post-test than on the pre-test. It can, therefore, be concluded that the use of simulations resulted in learners performing significantly better on the diagnostic test on electric circuits.

A detailed analysis of comparative performance for each three-tier item is now presented (Figure 2).
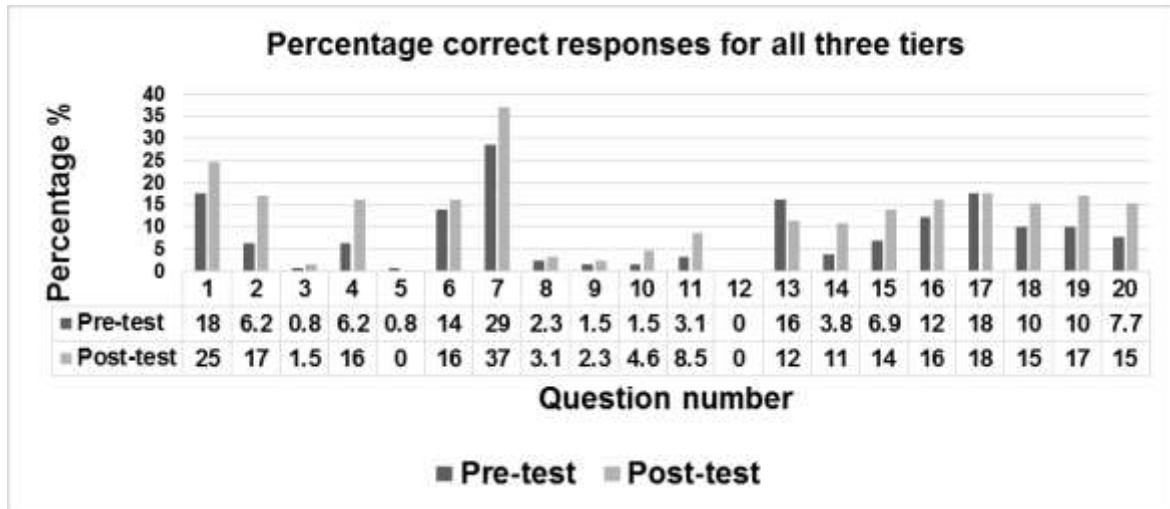
Figure 2: Percentage of learners having correct responses for the pre-test and post-test items

The results indicate that there was an increase in the percentage of correct responses from the pre-test to the post-test for items 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 14, 15, 16, 18, 19 and 20. Thus, there was an increase in learner performance in 80% of the questions. For items 5 and 13 there was a decrease in the percentage of correct responses; and for questions 12 and 17 the results of the pre-test and post-test remained unchanged. From these results, it can be concluded that the use of simulations as a vehicle to bring about conceptual change, resulted in a decrease in misconceptions, as more learners chose the correct responses.

A detailed analysis now follows on the types of misconceptions that were identified and the effectiveness of the simulation intervention in eradicating such misconceptions. From the results of the pre-test, eleven common misconceptions were identified. These identified misconceptions corresponded to the misconceptions
identified from the extensive literature on electric circuits (Table 1) already described.

Figure 3 represents the overall percentage of misconceptions for the pre- and post-test.
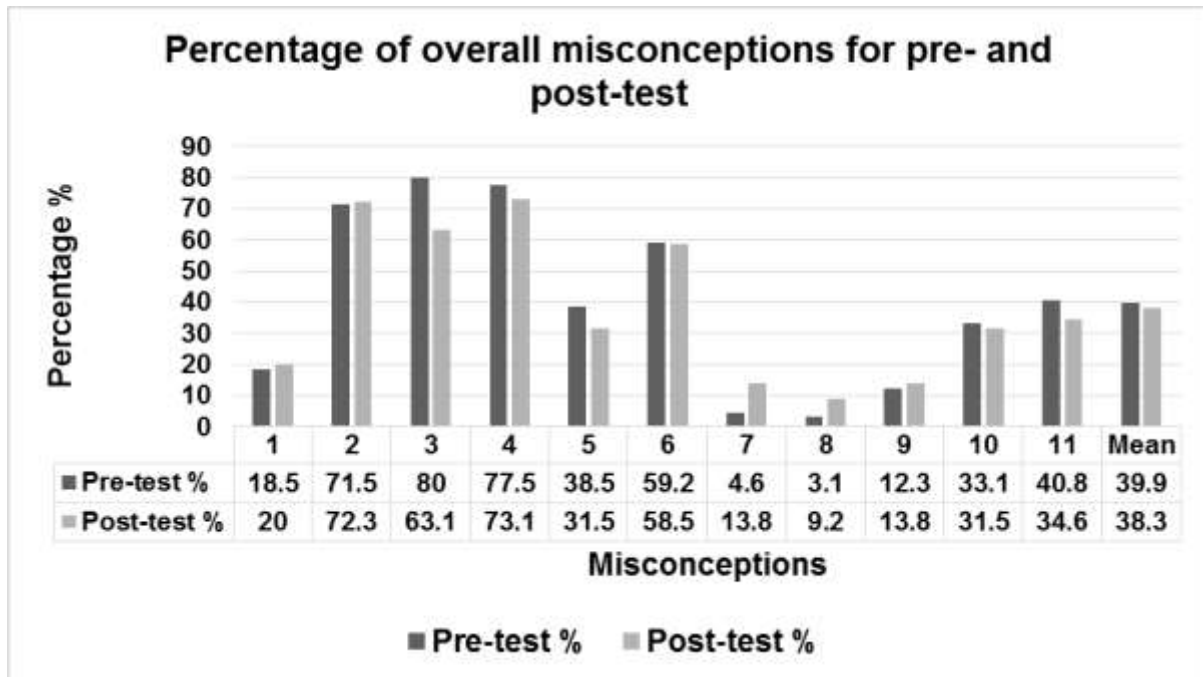
Figure 3: The percentage of misconceptions types revealed the pre- and post-test

From Figure 3 it can be deduced that from the pre- to the post-test there was a decrease in the percentage of misconceptions for misconceptions M3, M4, M5, M6, M10 and M11. It can therefore be concluded from the results that there was a decrease in the prevalence of six of the 11 misconceptions. It should also be noted that some misconceptions persist even after instruction. These results support the findings (Jaakkola & Nurmi, 2008; Ronen & Eliahu, 2000; Treagust & Duit, 2008) that misconceptions are highly resistant and therefore very difficult to eliminate, even when interventions that are specially designed to eliminate them are used.

McNemar's test is a matched-pair test used to determine whether there is a statistically significant change in nominal data in a pre-test/post-test experimental design. The McNemar's test was performed for each of the 11 misconceptions. However, only the Shared Current Model misconception (M3) produced a statistically significant result ($p < 0.05$). It can conclude that for the Sharing Current Model misconception (M3), the use of simulations as an intervention in reducing the misconceptions was effective.

Discussion

This examination on the use of simulation was guided by the cognitive tools framework. The research findings do add credibility to the framework as it enabled the researchers to clearly and coherently plan the study with respect to the target audience and the envisaged learning goals; as well as the learning activities to achieve such goals and the corresponding measurement of performance on these goals.

This study used a three-tier diagnostic test to identify misconceptions that Grade 10 learners from under-performing Dinaledi schools held in the field of simple electric circuits, and then investigated the use of simulations to address such misconceptions. The statistical analysis of

the data collected revealed that there was a significant difference in the performance of learners on the pre-test and post-test, with learners performing better on the post-test. This suggested that the use of simulations in the science classroom did, to a certain extent, reduce the number of misconceptions that were previously held by learners. The results therefore supported the findings of studies conducted by Pesman and Eryilmaz (2010), Engelhardt and Beichner (2004), Taşlidere (2013), and Kapartzianis and Kriek (2014).These studies all found the use of simulations to be effective in addressing learner misconceptions of electric circuits.

South Africa like other countries has a high stakes assessment system that influences teachers in 'teaching to the test' (Ramnarain, 2013; Ramnarain, 2016). Further to this, the pressure to cover topics in a content-laden curriculum means that there is insufficient time to support learners in eliminating science misconceptions (Ramnarain & Hobden, 2015) The pedagogical approach of using simulations in addressing misconceptions is a feasible means by which teachers under these prevailing constraints can address learner misconceptions, and support learners in eliminating them.

However, it should be noted that some misconceptions are robust and resistant to change, and that there is no single intervention that can prove successful in eliminating all learner misconceptions (Taşlidere, 2013). Possible reasons for this could be the effects of age, gender and language (Sencar & Eryilmaz, 2004; Rollnick, 2000). It is recommended that a follow-up study be conducted to test the effects of age, gender and language on learner performance. It is further recommended that the use of simulations be investigated not only for electric circuits, but also for other physics and chemistry topics in Grade 10.

The findings of this research add support for the integration of technology in the teaching and learning of science, especially at schools where performance in science is poor, and in contexts such as in South African where ICT integration is developing. Despite the widespread use of technology in many aspects of our work and personal lives, ICT has been under-utilised in the science classroom (Songer, 2007). A study by Wilson-Strydom and Thomson (2005) revealed that teachers at disadvantaged schools are just starting to explore the possibilities of integration of ICTs in their lessons, and that they need to be supported in this regard. A possible reason for this is that teachers lack the pedagogical knowledge and technological knowledge required to achieve this integration. This research has shown that if teachers are provided with the necessary support, this integration can take place to good effect. The cognitive tools framework can be applied in guiding the redesign of existing digital resources into a cognitive tool that may contribute to the achievement of science learning outcomes.

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Appendix A

Diagnostic test for misconceptions on electric circuits

1.2   Will the light bulb in **Figure 1** light up?

Figure 1
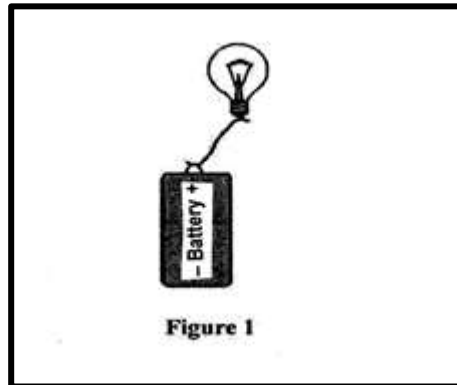
   c) Yes, it will.

      d) No, it will not.

1.2.   Which one of the following is the reason for your answer to question 1.1 above?
      d) The battery and the light bulb are connected by the wire.
      e) An extra wire must be connected from the negative terminal to the battery to the screw base of the light bulb so that the positive and negative charges meet in the light bulb.
      f) An extra wire must be connected from the negative terminal of the battery to the screw base of the bulb so that the electric current passes through the bulb.

1.3   How confident are you that your answers to 1.1 and 1.2 are correct?
      e) Very confident
      f) Fairly confident
      g) Not confident
      h) Just guessing

2.1   Consider the **Figure 2**, the circuit diagram below.

Figure 2
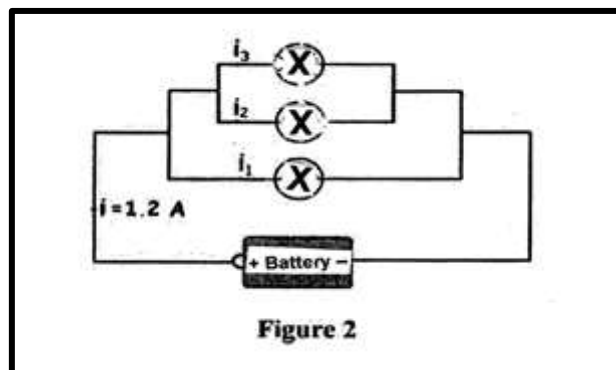
The current at the main branch is **1,2A**.What are the magnitudes of the currents i_1, i_2 and i_3?

a) $i_1 = 0{,}6A I_2 = 0{,}3A$ and $i_3 = 0{,}3A$
b) $i_1 = 0{,}4A I_2 = 0{,}4A$ and $i_3 = 0{,}4A$

2.2 Which one of the following is a possible reason for your answer to question 2.1 above?
   a)   After the current is divided evenly on the first junction, it is again divided evenly on the second junction.
   b)   Because the identical light bulbs are in parallel, currents with the same magnitude pass through the light bulbs.

2.3 How confident are you that your answers to question 2.1 and 2.2 are correct?
   a) Very confident
   b) Fairly confident
   c) Not confident
   d) Just guessing

3.   Study the two circuit diagrams, **Figure 3** and **Figure 4** below and then proceed to answer **questions 3** and **4**.
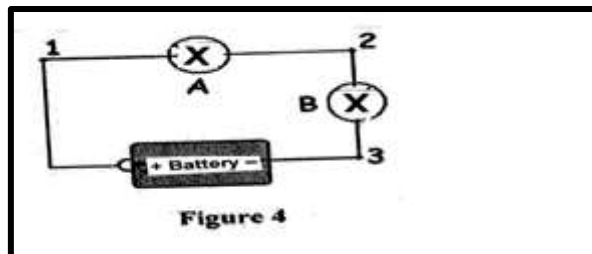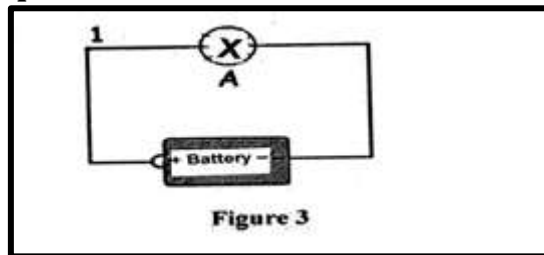
Figure 3

Figure 4

3.1 Compare the size of the current at **Point 1** in **Figure 3** with the current at **Point 1** in **Figure 4**.
   a) More current in **Figure 3**
   b) More current in **Figure 4**
   c) Equal current in both Figure 3 and Figure 4.

3.2 Which one of the following statements best explains your answer to question 3.1 above?
   a) The currents, which come from the batteries with the same magnitude, have not been consumed yet in both **Figure 3** and **Figure 4.**
   b) The potential difference supplied by the batteries, are the same in both **Figure 3** and **Figure 4**, but the total resistance in **Figure 4** is bigger.
   c) In **Figure 3** the current is consumed or used up by one light bulb, while in **Figure 4** the current is consumed (or used up) by two light bulbs.

3.3 How confident are you that your answers to question 3.1 and 3.2 are correct?
a) Very confident
b) Fairly confident
c) Not confident
d) Just guessing

4. Study **Figure 4** below and answer the questions that follow.
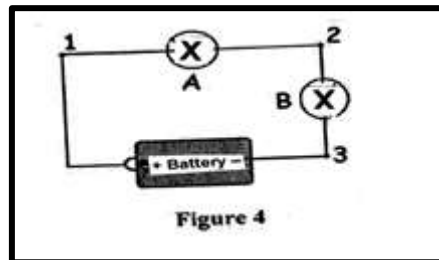
Figure 4

4.1 In **Figure 4** compare the magnitude (size) of the current at **Point 1** and **Point 2** and **Point 3**, as well as compare the brightness of the **light bulb A** and **light bulb B**.
i_1 represents the current at **Point 1**
i_2 represents the current at **Point 2**
i_3 represents the current at **Point 3**

|	Current	Brightness of light bulbs
a	$i_1 = i_2 = i_3$	Light bulb A and light bulb B have the same brightness
b	$i_3 > i_2 > i_1$	Light bulb B is brighter
c	$i_1 > i_2 > i_3$	Light bulb A is brighter
d	$i_1 > i_2 > i_3$	Light bulb A and light bulb B have the same brightness

4.2 Which one of the following statements best explains your answer to question 4.1 above?

a) The closer the light bulb is to the battery, the brighter the light bulb will glow.
b) In series circuits, the magnitude (size) of the current is the same at all points in the circuit.
c) The current is consumed by the light bulb and it causes the light bulb to become less bright.

4.3 How confident are you that your answers to question 4.1 and 4.2 are correct?

a) Very confident
b) Fairly confident
c) Not confident
d) Just guessing

5. Study the electric circuits in **Figure 5**, **Figure 6** and **Figure 7** and answer **questions 5, 6, 7** and **8**
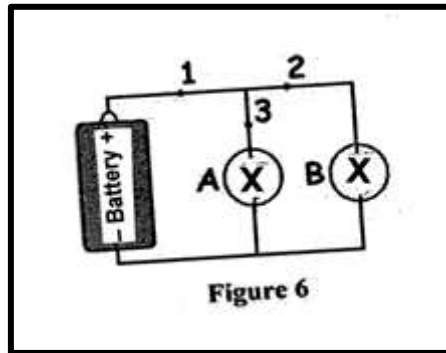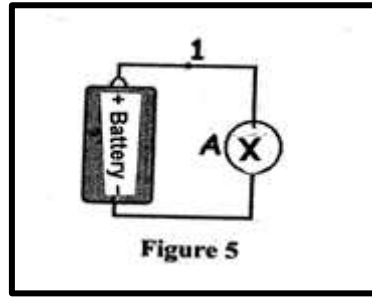
Figure 5

Figure 6

5.1   Compare the amount of current at **Point 1** in **Figure 5** with the amount of current at

Point 1 in **Figure 6.**

   a)   There is more current at **Point** 1 in **Figure 5**
   b)   There is more current at **Point** 1 in **Figure 6**
   c)   There is the same amount of current at **Point 1** in **Figure** 5 and in **Point** 1 in
        Figure 6.

5.2   Which one of the following statements best explains your answer to question 5.1?

   a)   Because there are two bulbs in **Figure 6**, the total resistance is more.
   b)   In **Figure 6**, the current coming from the battery is divided into two branches.
   c)   While the battery supplies one light bulb with current in **Figure 5**, it supplies
        two light bulbs in **Figure 6**.
   d)   The total resistance is smaller in **Figure 6.**
   e)   The currents have not been divided into branches in both **Figure 5** and **Figure
        6**.

5.3   How confident are you that your answers to question 5.1 and 5.2 are correct?

   a) Very confident
   b) Fairly confident
   c) Not confident
   d) Just guessing