

Using a Bicycle Analogy to Alleviate Students' Alternative Conceptions and Conceptual Difficulties in Electric Circuits

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Doi:10.5901/mjss.2014.v5n15p297

Abstract

Generally, students both at school level and at university level have experience some conceptions and conceptual difficulties in electric circuits. This article reports the findings of the study that investigated the effect of a bicycle analogy in alleviating alternative conceptions and other conceptual difficulties about electric circuits. The research sample consisted of hundred (100) first year science education students from the Faculty of Education at a South African university. A pre-test/post-test comparison group design was followed. A test consisting of eleven items from the ECCE was used to collect data. Data analysis was done by calculating the average normalized gain $\langle g \rangle$ scores for the group between the pre and post-test. A $\langle g \rangle$ score of 0,4 was obtained, signifying that the instructional intervention, involving the use of the bicycle analogy, had been effective in significantly alleviating the alternative conceptions and other conceptual difficulties held by the participants about electric circuits.

Keywords: alternative conceptions, analogy, normalized gains, instructional intervention, conceptual difficulties

1. Introduction

Since the introduction of Curriculum 2005 (C2005) in a phased-in process in South African schools in 1998, the country's education system has seen fundamental reform. This entailed movement from a curriculum founded on a highly specified content base towards an outcomes-based education (OBE) curriculum in which the development of skills and attitudes was given equal prominence to discipline content (Hobden, 2005).

Electricity is one of the major themes of South Africa's National Curriculum Statement (NCS) at school level in South Africa (S.A). However, electricity as a theme is not limited to Further Education and Training Band (F.E.T) in schools, but also form part of the first year university physics curriculum at most universities. The importance of this topic does not end with the high school curriculum but also finds itself as part of the first year university physics curriculum at most universities. In terms of the merits of learning about electricity, learners need to understand it because it constitutes an aspect of energy – energy being a unifying concept in the overall science curriculum. However, as a unifying concept, learners often come across concepts of electricity from different angles – and this is what makes it fertile ground for alternative conceptions, in which students develop views and imageries that are conceptually different from scientific ones (Nada; Iman & Waisim, 2009). This view was earlier expressed by Calliot and Xuan (1993) who contended that because electricity is very common in everyday situations, it is almost natural that students should have many alternative conceptions about it.

From the point of view of instructional approaches, some teachers choose not to use analogies at all – thereby forsaking the advantages of analogies in teaching certain science concepts. However the use of analogies in the teaching of science does not always produce the intended effects, especially when students take the analogy too far and are unable to separate it from the content being learned. Some students only remember the analogy and not the content under study, while others focus on extraneous aspects of the analogy and draw spurious conclusions about the target concept (Gokhan, Refik, Yasemin, Bahattin, 2012). The bicycle analogy is familiar to the student; development of systematic understanding is possible.

2. Literature Review

Students' underachievement in science has been the subject of major concern in many countries for many years. Some of the salient factors contributing to this problem and, frequently mentioned in the extant literature are: (a) students' alternative conceptions and (b) poor instructional practices (Osborne, 1981). The question arises as to the most appropriate instructional strategies that could be used to accomplish conceptual change.

The ability to reason by analogy is central to human cognition and learning. Two notable features of analogy are first, promotion of higher order reasoning skill which allows successful performance on novel problems, the ability to transfer knowledge to new situations, and learning by taking in a variety of information from different contexts (Richland, Morrison & Holyoak, 2006). Secondly reasoning by analogy is thought to involve specific processes such as the ability to exert inhibitory control, keeping multiple relations in mind, and accumulating relevant domain knowledge (Richland *et al.*, 2006). Analogy is thus a complex skill that is essential for higher-order learning and thinking.

In general, alternative conceptions and other conceptual difficulties experienced by learners are not adequately addressed by standard teaching in science classrooms and science textbooks. Simply presenting students with the logical arguments of scientific concepts during teaching does not encourage conceptual learning to the extent that such reasoning actually makes little sense in the context of students' own beliefs (Baser & Geban, 2007). According to Carey (1985) students reading a science text or listening to a science teacher must gain a proper understanding by relating what they are reading (hearing) to what they know, and this requires mentally active constructivist work. This notion is the cognitive rationale for making science lessons relevant to students' concerns (Baser & Geban, 2007).

Teaching strategies in science are important in terms of facilitating meaningful learning and preventing alternative conceptions and other learning difficulties. Numerous studies (e.g. Harrisson & Treagust 1994; Gilbert, 1989; Richland *et al.*, 2006) have shown that careful use of analogies is effective in refining students' alternative conceptions in science. Analogies are generally effective in teaching and akin to, constructivist learning theories in two aspects, namely: promoting an environment in which students are active learners, and the notion that new concepts are based on old concepts. Typically, analogies involve the presentation of a new abstract concept alongside a concrete, familiar one to help learners to conceptualize it (Lawson, 1993). Furthermore, analogies can also be used to facilitate the development of conceptual models of newly presented scientific mechanisms or structures by comparing them to something that is familiar to the learners (Iding, 1997). It is because of this that the use of analogy instruction helps learners understand theoretical concepts, or change their alternative conceptions. For example, Stavy (1991) used analogies to overcome learners' misconceptions about conservation of weight. Analogical reasoning, as a tool for helping learners overcome misconceptions, is described by different researchers as, for example, bridging analogies or chains of analogies (Clement, 1987). Analogical reasoning has been refined for use in the classroom and is encapsulated well in the bridging of analogical strategies. The educator's correct use of bridging analogies can help learners to span the conceptual gap between anchor (a mastered) concept and target (new or misconceived) concepts (Clement, 1987; Bartlett, 2004).

The analogical reasoning strategies can involve a series of analogous demonstrations presented sequentially for comparison. An example from Newton's third law is: 'a book is lying on a table; gravity pulls the book towards the centre of the earth (action force)' (Brown & Clement, 1989). Many learners cannot identify the reaction force when given the action force (weight) of a book lying on a table. The educator may use the analogy of a hand pressing down on a vertical spring where the hand is analogous to the book and the spring is analogous to the table. The concept of reaction force may be clarified by this analogy. The idea is that most learners will understand the book on the table (target concept) after the educator has taught the more comprehensible hand on the spring example (anchor concept). Regardless of the concept to be taught, this approach is heavily predicated on the need for concrete examples and demonstrations, as these help learners to develop visual models of the abstract concepts being studied (Brown, *et al.* 1989).

In the same vein, according to Martin (2003), learning is most effective when the concepts under consideration can be aligned with one's present understanding or knowledge. In this sense analogies are useful because they allow students to learn intuitively. Analogies may be used in two ways. First, they may be used as a bridge between familiar and new situations. The success of this strategy depends on both the students' understanding of the familiar situations and on the persuasiveness of the argument that draws out similarities between the two situations. The second use of analogies is in representing abstract ideas in terms of concrete or physical structures. The success of the second strategy depends largely on whether the concrete structures that are used fall within most students' life experiences, as well as on the persuasiveness of the argument that maps them to the abstract idea under study (Martin, 2003).

The use of analogies as a cognitive tool can be found in almost all societies and cultures and at almost any time in human history. Analogical thinking is a way of understanding new or novel situations by building models based on one's existing knowledge of familiar scenarios (Martin, 2003). The new situation may, at least superficially, be quite unlike the

familiar domain, but relationships among elements of the new scenario may closely resemble relationships shared by elements of the familiar domain. The familiar domain is referred to as the source analogue, the new domain as the target analogue.

However, it is very important to emphasize that analogies can be useful but if they are not well-chosen could give incorrect information to students, or even create further alternative conceptions and confusion. It is therefore essential to advise teachers to always remember that when they describe what electricity is like, they should use useful and appropriate analogies for the learners to form an appropriate understanding of the construct.

From this snapshot of the literature it is apparent that students' inability to apply memorised facts and procedures is a worldwide problem. In this regard, some educators see the constructivist approach as part of the solution particularly for addressing alternative conceptions.

3. Research Hypothesis

A bicycle analogy in teaching electric circuits significantly alleviates conceptual difficulties and alternative conceptions held by university science education students.

4. Research Methods

4.1 Research Design

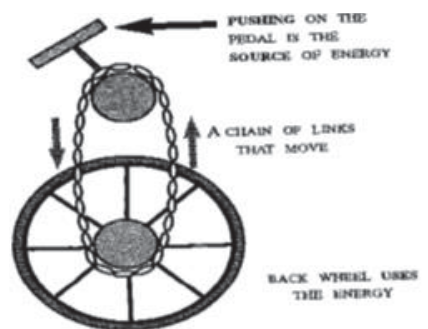
A pre-experimental one-group pretest-post test research design was followed to compare the conceptual gains made by the participant group as a result of a treatment or intervention to investigate the extent to which the bicycle analogy could help alleviate or overcome alternative conceptions and conceptual difficulties about electric circuits. Average normalised gain $\langle g \rangle$ scores were calculated in order to ascertain how much the group benefitted from the intervention.

4.2 Instructional Intervention

Overall, the instructional intervention was based on developing students' understanding from "contextual" to "conceptual" (Lemmer & Lemmer, 2005). Thus, in this study, students were given a bicycle analogy as their contextual problem and point of reference; they were made to answer questions related to the bicycle analogy. During the post-activity discussion, the researcher introduced the concepts: electrical resistance, battery, current intensity, electric charges, electric field, electromotive force (emf) and the Law of Energy Conservation. With the acceptance of the analogy, students were able to understand the interpretation of electric circuit experiments. After the students had understood the contextualised concepts and principles from the bicycle analogy, they were able to explain emf, the function of the battery and the law of energy conservation.

Figure 1: Is a bicycle analogy

Chain links are like electric charges



- Explain how energy is transferred when a bicycle is pedaled

- What is the function of the chain?
- What will happen if the chain breaks?
- How does this model resemble an electric circuit?

To ensure conceptual understanding of electric resistance, battery, current intensity, electric charges, electric field, an emf, a conceptual problem (experiments) was used to conceptualise these concepts. This analogy is related to a move from contextual to conceptual development of ideas.

In this study, the students were given a bicycle analogy and the first researcher discussed with them how energy is transferred when a bicycle is pedaled. When the bicycle is pedaled or when the pedal is pushed with a constant force, against constant obstacles (i.e. electrical resistance), the flow rate of the wheels (current intensity) will be the same at each point. The pedals (i.e. source of energy = battery) maintain the movement by tiring the muscles (energy exhaustion of the battery). The chain which serves as a link (it is like electric charges) moves slowly but the energy (the pushing on the pedal) is instantly available. The energy is only transferred from the source (pedal) to the user (wheels) when the links move. The links never get lost or are used up and this is how Law of Energy Conservation was introduced, and the concept of electric field was also brought in. It was explained that a battery / cell is a device which separates positive (+ve) and negative (-ve) charges – and the charge separation in the cell sets up an electric field between the opposite charges. Further discussion was conducted to make it clear that when a disaster happens, such as the chain breaking, the wheel of the bicycle would still rotate for a short while, thereby still supplying energy to the system. In applying this example to the notion of electrical circuit they could understand that the bulb may appear to continue shining for a short while (filament dying out) after its source of electricity has been cut off. Somehow, this contradicted their normal experiences with electrical switches, whereby the light instantly goes off as soon as the switch is turned off.

Table 1 presents the corresponding meanings between the bicycle and simple electric circuits.

Table 1: Correspondence between the Bicycle analogy and a simple Electric Circuit

Bicycle Analogy	Electric Circuit
Pedals	Source of energy (battery)
Wheels	Bulbs
Muscular fatigue of person	Wearing out of the battery
Chain	Electric charges

Thus, like in the case of bicycle pedals, it was explained that a battery is a device which converts chemical energy into electrical energy on a continuous basis, and which tries to maintain a constant potential difference across its terminals.

In very broad terms, a battery comprises of a chemical reaction that is in some way constrained to create an electrical current. Any chemical reaction is caused by electrons moving between atoms. Clearly, when the chemical reagents in the battery have been used up then there will be no more electrons to move from one reagent to another, and thus the battery is dead (worn out). Once an explanation for the battery's wearing out was understood, the crucial point of acceptance was students recognizing that the bicycle speed was the same everywhere.

With the acceptance of the above analogy, students were able to understand and accept the interpretation of the electric circuit experiment (the current is the same everywhere, although the battery wears out).

4.3 Data Collection

4.3.1 Research Instrument

The Electric Circuits Concept Evaluation (ECCE) test was developed by Prof David Sokoloff to assess students' understanding of simple circuit concepts (Sokoloff, 1992). The questions in the instrument assess students' understanding of current and potential difference in simple circuits connected in series and parallel. During the development of the test, Sokoloff (1992) administered it during the spring term of 1992, both as a pre and post-test to students in one lecture section of the physics course (PHYS 203) at the University of Oregon where it was found that students did not master simple circuits by a traditional instructional approach. Using the ECCE test McDermott and Shaffer (1992), as cited by Sokoloff (1992), found that the pre- and post-testing showed dramatic gains in students' understanding of "current and voltage" in simple series and parallel direct current circuits. Eleven questions were taken from this test to probe targeted alternative conceptions regarding electric circuits for this study.

4.3.2 Research Sample

The test developed and utilised for this study was administered to hundred (100) first year university science education students. The students were enrolled for the Bachelor of Education (B.Ed) programme, and were registered for the module Electricity and Magnetism. The test probed the learners' alternative conceptions and conceptual difficulties about electric circuits. The students were given sixty minutes (1hour) to complete the test. The researcher invigilated the writing of the test to ensure that security is maintained and the test is conducted in a fair and appropriate manner.

4.3.3 Data Analysis and Interpretation

This study made use of *average normalized gain scores* in addressing the research hypothesis of this study. According to Hake (2002a: 3), the *average normalized gain scores* afford a consistent analysis of pre- and post-test data over a diverse learner population. Overall, the average normalized gain score is regarded as a much better indicator of the extent to which a treatment is effective – more so than is either the actual learning gain or the post-test results alone (Hake, 2002b: 2; Meltzer, 2002). In determining the effectiveness of the treatment or instructional interventions, high average normalised gain scores are those with $(g) \geq 0,7$; medium average normalised gain scores are those with $0,7 > (g) \geq 0,3$ and low average normalised gain scores are those with $(g) < 0,3$ (Hake, 1998). Relating this to the types of instructional approaches used, Hake (1998) and Meltzer (2002) explain that if the treatment yields $\langle g \rangle > 0,3$ then the course could be considered to fall in the "interactive zone" – whereupon it is understood that interactive engagement methods promote conceptual understanding through engagement of students in heads-on and hands-on activities which yield feedback through discussions with peers and /or teachers, all as judged by their literature description.

5. Results and Discussion of Results

5.1 Biographical Profile of the Respondents

The research sample comprised 39 male and 61 students, giving a total of 100 participants. The official language of instruction at the university where the study was conducted is English.

5.2 Normalised gain scores for the students

To quantify the success of the intervention that set out to alleviate students' conceptual difficulties and alternative conceptions, the average normalised gains were calculated using Hake's (1998) formula.

$$\begin{aligned} \text{Actual percentage gain} &= \text{post-test} - \text{pre-test} \\ &= 61,6 - 32,4 = 29,2\% \end{aligned}$$

$$\begin{aligned} \text{Maximum possible gain} &= \text{Total possible} - \text{actual gain} \\ &= 100 - 29,2 = 70,8\% \end{aligned}$$

$$\text{Average normalised gain} = 29,2\% \div 70,8\% = 0,4$$

This calculation summarised in Table 2.

Table 2: Average normalised gain scores for for this study (n=100)

Pre-test Mean Scores	Post-test Mean Scores	Actual % gain	Average normalised Gain score	% Gain
32,4	61,6	29,2	0,4	40

Indeed, the performance of students increased dramatically between the pre-test and the post-test. The average normalised gain score of 0,4 for the group fall in the "interactive zone" (Hake, 2002). The effectiveness of the strategy used in the intervention was, thus, comparable with contemporary interactive strategies and agrees with the hypothesis.

6. Conclusion

The results of this study have revealed the effectiveness of the intervention in helping students perform well on the topic 'electric circuits which was also found by Gokhan et al, (2012) Indeed, the bicycle analogy used in the study seems to have successfully guided the students to construct scientifically acceptable notions of electricity and electric circuits. The

high gains achieved by students illustrated the success of the intervention in effecting conceptual change towards the correct scientific conceptions. To this end, this study has succeeded in achieving its objectives, thereby making a significant contribution to both theory and practice.

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