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A Constructivist Approach to the Teaching and Learning of Electricity

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Abstract
The science education research literature suggests that students have difficulties understanding key ideas about phenomena associated with electric circuits. This paper discusses some of the main findings by science education researchers have in relation to problems Middle Year students have in learning about electric circuits. This paper also explores the implications of the research findings for the teaching and learning of electric circuits and discusses various constructivist teaching and learning approaches that could be applied to address students' problems.
Introduction

This paper deals with a topic that is very familiar to teachers and students alike. Electricity is very much a part of our daily lives, a fact that is brought home to us in times when power blackouts occur. Despite the omnipresence of electricity in our daily lives few Middle Years teachers assert a confidence in having a scientific understanding of what happens within the electrical devices that are used on a regular basis. From this perspective the conceptual area of electricity presents a challenge for new and experienced teachers (Heywood & Parker, 1997).

The study of electricity in schools is usually in two main areas that are described as static electricity and current electricity. Static electricity deals with the separation of electric charges that occur in phenomena such as lightning and shocks one may receive from touching a doorknob, or another person, after walking on carpet. Static electricity is not as relevant to our daily lives as current electricity. Current electricity relates to the motion of electric charges and deals with many aspects of our lives such as the operation of electrical devices in the home (for example, lighting, toasters, refrigerators and lawn mowers). Current electricity plays an important part in communication through the telephone, television and computer, and manufacturing goods (most industries rely on electric motors). The focus of this paper will be on current electricity.

Due to our daily experiences with electricity, scientific terms such as electricity, power, current and energy are part of our everyday language. However, the meaning given to such terms by people are often quite different to those accepted by the scientific community. This may lead to confusion in the minds of students as electrical terms are introduced and discussed in the classroom.

High on the list of terms with several everyday meanings is the term electricity itself. For example, a dictionary definition of electricity gives two different scientific views of the term:

1. a fundamental form of kinetic or potential energy created by the free or controlled movement of charged particles such as electrons, positrons, and ions.
2. electric current, especially when used as a source of power.

*World English Dictionary 1999*

The first definition equates electricity with a form or energy while the second definition equates it with current. Is electricity current, power or energy? One might expect that a students’ textbook uses a consistent definition for the term electricity. However, the following quotes from the same textbook on the topic of Electric Circuits suggests otherwise.

- The moving electricity is called an electric current (p. 259).
- If too much electricity flows, the wire becomes hot and melts, making an open circuit (p. 262).
- The electricity used in our homes, streets, schools and factories is made in huge generators...once the electricity has been generated it has to be taken to where it is to be used (p. 267).
- Electricity is a good source of heat (p. 273)

*Heffernan & Learmonth (1980) The World of Science Book One*

From a scientific perspective electricity is not any of these terms, current, power or energy. The term electricity only refers to a field of science or class of phenomena in the same way the words physics or optics are used.

The misuse of the term electricity is not the only difficulty students have in understanding this topic. The following section highlights the major areas of difficulties education researchers have found in students’ understanding of electrical phenomena.

Students’ Difficulties in Understanding Electric Circuits

There has been considerable research into children’s understanding of electricity (for example, Gott 1984; Koumaras, Karatogloy & Psillos 1995; Osborne & Freyberg 1985; Shipstone 1985). There have also been studies that have explored preservice and practising teachers’ understandings of electricity (for example, Pardham & Bano 2001; Mohapatra). An online bibliography of literature on students an teachers conceptions and science education, which include conceptions of electric circuits, can be found at Duit (2004) http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html.

The underlying idea that students bring with them at the beginning of formal instruction, and which many retain, is one in which there is a source, such as a battery, and a consumer such a bulb or a motor. From this perspective Shipstone (1985) suggests that students believe that:
Electricity, current, power, volts, energy, 'juice', or whatever, is stored in the source and flows to the load where it is consumed. The battery is usually seen as the active agent or 'giver' in this process, with the load being the 'receiver', but it is also common to find the load regarded as the active agent, as a 'taker', drawing what it 'needs' from the battery.


This type of thinking has been termed a **source-consumer model** or **unipolar model**. Examples of circuits which indicate a **source-consumer model** are given in **Figure 1** below. These circuits represent attempts made by students to light a bulb when given a battery, bulb and wires.

![Figure 1](image-url)

**Figure 1** Examples of attempts by students to light a bulb (taken from Shipstone, 1985, p. 35 in Driver et al, 1985).

Maichle (1981) found that 85% of 13-15 year-olds who had completed an introductory electricity course, agreed with the statements:

In every new battery is stored a certain amount of electric current...[and]...the current contained in a battery will be consumed by electric appliances in the course of time.

40% of 36 pre-service physics teachers also decided these statements were correct. In this example, the students have referred to current being used up. However, they might not necessarily use this term, using electricity, volts, power or 'juice' instead. The examples (a)-(c) in **Figure 1** have only one wire. Following instruction most students recognise the requirement for two wires to obtain a complete circuit. However, they may still retain the **unipolar model** through thinking that the second wire doesn’t play an active part of the circuit; it might only be considered a safety wire.

Apart from the unipolar, or source-consumer, model researchers have found other models used by students in their understanding of electric circuits. These are shown diagrammatically in **Figure 2** below. Once again, whilst current has been used in describing the model it may not be the specific term used by students. The models are described as:

- **Clashing currents model**: current flows from both terminals. Students explain the production of light in the bulb as a result of a 'clash' between two currents.
- **Attenuation model**: current leaves the battery from one terminal and is 'used up' in the bulb leaving less current to return to the battery.
- **Sharing model**: while multiple bulbs in a series circuit are considered to be equally bright the current is considered to be 'used up'.
- **Scientific model**: current remains the same in all parts of the circuit. Multiple bulbs in series will be equally bright.
Shipstone (1985) found in his study of students aged 12-18 that the relative popularity of various models changes with the age of the student. The popularity of the models is shown in Figure 3 below. Note that in this graph the unipolar model is not shown as it is generally less than 5% among the students of this age range.

Apart from finding the models described above researchers have also found that students believe that batteries supply a constant current to a closed circuit rather than supplying a constant voltage. This particular thinking has been termed a constant current source model. If changes are made to a particular circuit, such as adding another bulb in series, students with this thinking will not recognise that such a change will result in a decrease in the current flowing in the circuit.

Another model found in students' thinking about electric circuits has been termed a sequential model. Students with this thinking adopt a local reasoning about circuits ignoring the effects of a change on one part of the circuit will cause a change in the whole circuit. If students are presented with a circuit and asked to predict what would happen if a component were added or removed students using a sequential model reason that current up to the point where the change occurs is unaffected; it is only affected at the change point and after it.

Finally, students associate voltage as a consequence of current rather than being the cause of current. Students expect voltage to increase as current increases; they don’t believe that a voltage can exist without a current, as found in an open-circuit.
A listing of students' alternative conceptions of electric circuits can be found in Appendix 1. It contains examples of other student difficulties with electric circuits found by researchers. The next section outlines some of the implications this research has for the teaching and learning of electric circuits.

Implications for Teaching and Learning about Electric Circuits

Given the significant amount of research literature that highlights the difficulties students have about understanding electric circuits it is important to adopt teaching and learning strategies that directly address these difficulties. By applying a constructivist approach to the teaching and learning of electric circuits the students must first be aware of their often, deep-seated, alternative conceptions. Therefore, strategies need to be undertaken that initially elicit the pre-instructional understandings of the students and then assist them in changing their understandings to a more scientific one if it is found that the students don’t have a scientific view. A set of useful understandings about electric circuits suitable for Middle Years students can be found in Appendix 2. This set of understandings can form the basis of a set of teaching and learning activities pertaining to electric circuits.

The following discussion points highlight particular approaches for the teacher to adopt in his/her teaching of electric circuits based on the research into students understandings of electric circuits:

- The terms one uses to describe and explain electrical phenomena need to be the same for students and the teacher. As discussed in the introduction the term electricity is misused by teachers, students and textbooks. The implication for the teaching of electric circuits is to have a consistent use of the term electricity as the topic name and refrain from using it when explaining what happens in an electric circuit. Alternatively, because the term is used so often in everyday language, the teacher might use the term as an everyday term of a specific quantity. For example, electricity is an everyday term for energy so that when electricity is used in the classroom the teacher and students understand it as synonymous with energy. The teacher also needs to discuss with students possible multiple uses of the term electricity in the students’ textbook, explicitly pointing out to them what meaning has been attached to descriptions of electric circuit that use electricity. The consistent use of the scientific meaning to other terms such as power, charge, voltage need to also be developed over the period of teaching the topic. Activity 1 given below describes strategies to elicit students’ everyday terms related to electricity.

- A key idea that needs to be established early on in teaching electric circuits is the requirement for a complete conducting loop containing the battery, bulb and wires for the bulb to light. In other words, a bulb will only light in a closed circuit. Therefore, students with a unipolar model for an electric circuit need to undertake an activity whereby their model does not work. Such an activity is described in Activity 3 given in the next section.

- Once the requirement of a closed circuit for the bulb to light is established it is important to assist students to discriminate between the concepts of electric current and electrical energy (Shipstone, 1985). Without a consideration of energy students readily fall into thinking that electric current that gets used up, which is characterised by the attenuation and sharing models for an electric circuit. Shipstone (1985) suggests that the concept of electrical energy should be introduced before the idea of electric current is encountered. Students building circuits with bulbs and/or motors need to be encouraged to describe their observations in terms of the supply of electrical energy from the battery to light bulbs, run motors, etc.

- The alternative conception that electric current is used up can be addressed through the use of multiple ammeters placed in the circuit. A Predict Observe Explain (POE) strategy, described in Activity 5 below gives experimental support to the scientific model. Osborne and Freyberg (1985) found that the use of multiple ammeters in a circuit and the use of the analogy of the heart and blood circulation to be effective in moving students to the scientific model.

- The introduction of electrical current should follow the introduction of electrons as particles contained within the wire, battery and bulb that carry the energy from the battery to the bulb. Emphasis is placed on the view that electrons are contained in the wire and don’t emanate from the battery when a closed circuit is formed.
To offset students thinking that voltage is a property of current rather than a precondition to current, researchers suggests the introduction of voltage first as a property of an isolated battery. It is the voltage of the battery that provides the precondition for current to flow in a closed circuit and that the voltage is still present when no current is flowing in an open circuit. Students need experience in using voltmeters to measure battery voltage alongside current measurements with the use of ammeters. These researchers advise against students measuring the voltage distribution in a circuit on the grounds that it can lead students to the idea that voltage is consumed.

The concept of electrical resistance needs to be introduced early in the teaching of electric circuits. Students need to understand changes to a circuit such as adding bulbs increase the resistance of the circuit.

It is important to treat series and parallel circuits separately and at different times before treating them together. The key ideas related to series circuits need to be established before moving onto parallel circuits.

The use of analogical models helps students understand the phenomena associated with electric circuits. More importantly, analogical models help students to take a system view of an electric circuit that involves several interconnected concepts such as energy, voltage, resistance and current. Analogies rely on connecting shared features, or attributes, of an analogue with attributes of the target phenomena. For example, the commonly used water circuit analogy draws an analogy of a water reticulation system with an electric circuit. In the water circuit analogy the water pump in the analogue represent the battery in the target. Just as it is important to map shared attributes it is equally important to point out to the students those attributes that are not shared, called negative attributes. For example, a hole in the pipes of the water system will mean that water leaks out. There is no common feature in the electric circuit that would match this attribute. Finally, researchers stress the point that students need to have a good understanding of the analogue to gain full benefit of the analogy. In addition, it is important to apply multiple analogies in explaining electric circuits as each provides explanation of particular aspects of the phenomena. Activity 8 and the next section outline a series of useful analogies that may be employed in the classroom.

Mulhall (2006) warns against the premature introduction and sole use of mathematical models to explain electrical behaviour in electric circuits. She suggests that

"formulae, such as those used to calculate currents for given voltages and combinations of resistances are already an abstract representation of the circuit and, as such, are inappropriate for beginning students, and potentially alienating even for those who are older, where they are not underpinned by a sound qualitative understanding. Yet many textbooks, even for the lower years of secondary school, present mathematical relations, supported by experimental verification, as the sole explanation for the behaviour of electric circuits. (p. 2)"

Most science teachers agree that the electric field model is the model we want students to eventually adopt. However, there is disagreement as to the appropriate time when to adopt this model, with some researchers suggesting that it should be adopted from the earliest stages of learning.

**Electric field model**

In this model the battery separates charges so that the negative terminal has an excess number of electrons while the positive terminal has a deficiency of electrons. When connected into a closed circuit the battery sets up an electric field, which travels at the speed of light throughout the circuit. Electric fields are like gravitational fields. Imagine if you were able to turn gravity on and off – turning off gravity would mean that objects would become suspended, and at the moment gravity is turned on all suspended objects would move at the same time. In a similar manner the electrons in the wire are affected by the electric field, and when turned on will move in a direction away from the negative terminal.

Just like objects that are higher up from the ground have more gravitational potential energy electrons closer to the negative terminal have more electrical potential energy. As the electrons move they collide with atoms in the wire and bulb filament thus transforming their electrical potential energy into kinetic energy of the atoms, creating light and heat. This is like a ball falling through the branches and
leaves of a tree. The ball converts gravitational potential energy to moving the leaves and branches as it falls to the ground. It is important to note that when electrons move through a resistance that their speed does not change, their kinetic energy is maintained – the energy that is transferred to the atoms is the electric potential energy of the electrons.

The next section provides a series of activities that are designed to elicit and/or address students’ difficulties in understanding aspects of electric circuit phenomena and are informed by the research literature into students’ understanding of electric circuits.

**Some Ideas for Teaching and Learning about Electric Circuits**

**Activity 1: Exploring everyday terms about electricity**

This activity is designed to elicit from the students the terms they use in everyday speech related to electrical behaviour.

Undertake a brainstorm of words related to the term *electricity*. Each student is to provide a word that comes to mind when they hear the term *electricity*. The words are listed on the board and a record is kept by the students. From the list discuss with the students what they understand the meaning of some of the terms. For example, power, volts, current. From this initial list you might get the students to construct a concept map – from the map it will be evident what connections the students understand between the terms.

As a follow-up to the brainstorm activity refer back to this list throughout the topic to discuss with the students the scientific meanings given to the terms. Alternatively, get the students to construct a glossary of terms that has three columns; the first column contains the initial list, the second column contains their initial understanding of the term and the final column contains the scientific definition (in the students own language) to be added when addressed in class.

Discuss with the students the meaning of the term *electricity*. As mentioned in the introduction it is important to establish from the beginning a consistent use of the term, whether that be the correct meaning (as a topic name), or an everyday name for an electrical quantity, such as *electrical energy*.

**Activity 2: Students questions about electricity**

It can be quite revealing for the teacher to ask his/her students what would you like to know about the phenomena of electricity. Students’ questions can inform the activities students undertake and what specific contexts related to electricity might be followed.

Using a ‘Think Pair Share’ strategy, students are to initially write down one or two questions they might have about electricity. In pairs/fours the questions may be refined or more maybe added. For example,

- How does electricity make sound?
- How does electricity make mobile phones?
- How many voltages do we use in a day?
- How much electricity does the world use in a month?
- How can electricity be so fast?
- Are there different types of electricity?
- How much electricity can kill you?
- What is the difference between energy and electricity?

Following the reporting of each foursome, a set of class questions maybe generated and recorded by the students. During the topic attention is drawn back to these questions as to whether they have been answered.

**Note:** there is a website that contains students questions (and answers) http://amasci.com/elect/elefaq.html

**Activity 3: Bulb challenge.**

This activity is designed to expose and address students’ unipolar model. Students with such a model will soon find their model does not work. Students are provided with a worksheet bulb challenge (refer to **Appendix 3**). Importance needs to be placed on students making their own judgement as to which
arrangements work. Some classroom discussion of students' predictions and explanations is needed before students test out their predictions.

Students find that a complete loop containing the wire, bulb and the battery is required before the bulb lights up (see Figure 4). There are four arrangements in which this will occur.

The key concept that underpins this activity, which should come out of the discussion of the results, is "the bulb will glow when a complete loop that contains wires, bulb and batteries is formed". This loop is called an electric circuit, or more specifically a closed electric circuit to distinguish it from an open electric circuit.

Figure 4 Conducting path in a complete circuit

It may not be easily seen by the students that a conducting path passes from the base of the bulb through the filament and then through the side of the bulb. This can be demonstrated to the students in Activity 4.

**Activity 4: Inside the bulb**

Demonstrate to the students the conducting path through the bulb. Provide the students with a cut down version of an actual bulb. Use a household light globe.

**Activity 5: Investigating electric circuits**

Students need to build up a series of observations and experiences actually constructing electric circuits. They need to understand and use the symbolic form of electric circuits. For example,

![Figure 5: Electric circuit arrangement and circuit diagram](image)

Students in groups of 2/3 are given a tub containing batteries, wires, bulbs and switches. Each group is accountable for its tub and maintaining its contents. To ensure this occurs number each tub so that each group gets the same tub each lesson they use it. In addition each tub has contains a table of contents that needs to be checked by the students, and the teacher, towards the end of each lesson.

Students complete a number of investigations that involve the construction of various electric circuits and students record their findings to electric circuit investigations:

Some investigatable questions include:

- How important is the location of the switch in an electric circuit?
- What is the effect on the brightness of the bulbs of adding extra bulbs into the circuit?
- What is the effect on the brightness of the bulbs of adding extra batteries into the circuit?
- What is the effect on the brightness of the bulb with a circuit that contains three batteries where the batteries are arranged differently? For example, + - + -; + - + -; + - + -.

For each question, students are required to provide a circuit diagram of the circuits they constructed, their observations, and an answer to the question. Bring the students together regularly to discuss the students findings. The findings they make, which becomes the consensus view of the class, should include:
• It does not matter where the switch is located in the electric circuit.
• Adding extra bulbs into a series circuit results in the bulbs glowing less brightly, and equally brightly.
• Adding extra batteries may result in no brightness in the bulb (+- + = no brightness; ++- or - -++=double brightness).

This series of investigations may bring into conflict students’ non-scientific models. For example, students with a unipolar model will predict that the bulb will light up if the switch is placed between the bulb and the negative terminal of the battery. Students with an attenuation model will incorrectly predict the two bulbs in the series circuit as unequal in brightness. This set of observations about electric circuits forms a base in which to explain the scientific model of electric circuits.

Activity 6: Predict Observe Explain (POE) strategy for electric current
In this strategy students are first presented with a circuit that contains a battery, bulb, and ammeter placed near the positive terminal of the battery. They are to predict the reading on the ammeter if it were placed near the negative terminal of the battery. At this prediction stage students are asked the reasons behind their predictions. The teacher places the ammeter at the other point (alternatively, another ammeter is placed into the circuit) of the circuit. The observation of similar ammeter readings gives support to the scientific model. A discussion may ensue as to what gets used up if the current remains constant. As a follow-up activity, students might predict the relative brightness of 2, or 3, bulbs placed in the series circuit. The observation that the bulbs are equally bright can be explained by the supply of the same amount of energy with a constant current, experimentally checked with the placement of an ammeter at different points in the circuit.

Activity 7: Eliciting students’ predictions to changes in electric circuits
Mohapatra (2006) used a simple diagnostic test (Appendix 4) that exposed people’s alternative conceptions of electric circuits. In a classroom setting a selection of questions from these tests may be given to the students. As a whole class discussion one can share the students’ predictions and explanations.

Such questions can also be used again at the end of the topic as a summative assessment task. A valuable resource to elicit students’ understandings of electric circuits can be found in Appendix 1 and Appendix 2. Teachers can generate questions from the lists of understandings and alternative conceptions to use in classroom questioning and tests.

Activity 8: How do electric circuits work? Applying some teaching analogies.
We are now in a position to discuss the theory that explains the findings from the electric circuit investigations. One needs to introduce the role of the electron as an energy carrier. The energy is obtained from the battery which gives a push to the electrons. The electrons, through collisions with atoms in the filament, transfer their energy to the atoms which vibrate giving of light and heat energy.

The initial emphasis should be on the concept of energy and electrons as energy carriers. Such an approach aligns with a firmly held belief of students that something is contained in the battery that travels to the bulb to be used up. Whilst energy doesn’t get ‘used up’ but rather transformed, it can be better understood by the students than focusing on electric current in the first instance. In addition, the focus on electrons and flow of electrons as electron current is preferred to jumping too quickly to conventional current.

The analogies that are taught to the students need to explain the following key observations:
• A complete loop that contains a battery, bulb and wire is required.
• The bulb emits light immediately the switch is closed, and turns off immediately the switch is opened.
• Two bulbs in a series circuit are equally bright, and less bright than if there was one bulb in the circuit.

We can use a number of analogies to present the key concepts. The teacher needs to discuss with the students those links between the analogue and the target that show the key idea (positive attributes) as well as pointing out links that do not link (negative attributes), as well as the neutral links (neutral attributes). A description of various analogies is given in the next section.
Activity 9: Virtual electrical circuit investigations.

Commercial software, such as Crocodile Clips, allows students to build and test virtual electric circuits. Free simulation software can also be found at Physics Education Technology (PhET) Simulations (http://phet.colorado.edu/web-pages/simulations-base.html, or just google PhET simulations). This software, apart from being free and downloadable from the web, can be used in a variety of ways. Teachers run simulations as part of the classroom teaching in addition to setting investigatory tasks such as those described in Activity 5 and Activity 10. Figure 6 below is an example of a virtual circuit that can be constructed by the software. Notice that the simulation models the movement of electrons, so that when the switch is closed the balls representing the electrons move around the circuit.

I have found it useful in circumstances where the classroom only has a few computers, or where batteries and bulbs are in short supply, to have some of the class undertaking virtual investigations, other students undertaking investigations with real batteries and bulbs, and other students completing written work.

Figure 6: Virtual electric circuit using the PhET simulation software

Activity 10: Problem solving circuits

The following problems could be solved by students building actual circuits, or by constructing virtual circuits. In providing a solution to the problem, students draw a circuit diagram.

You are to construct circuits using batteries, bulbs and switches that do the following. In the spaces below draw the circuits.

A There are three globes in a circuit that are all equally bright.
B There are three globes in a circuit that are all equally dull.
C There are three globes, one globe is very bright and the other two are dull.
D There are three globes that are turned on and off by the one switch.
E There are three globes, each of which is turned on and off by its own switch.
F One switch controls one globe, a second switch controls the other two globes, and the third switch controls all three globes.
G Two globes are on, but a switch turns one light off when it is pressed ‘on’.
H Households sometimes have two switches, each of which can turn a light on and off. Reproduce this arrangement using a battery, wires, bulb and two switches.
Some Analogies for Teaching and Learning about Electric Circuits

The following analogical models might be useful in explaining aspects of electric circuits. Table 1 outlines the linking elements between the target and the analogue. A description of each analogy is given below.

Table 1 Electric circuit target elements and linking analogue elements

<table>
<thead>
<tr>
<th>Target</th>
<th>Analogue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electric Circuit</strong></td>
<td><strong>Water Circulation</strong></td>
</tr>
<tr>
<td>Electrons (charges)</td>
<td>Water particles</td>
</tr>
<tr>
<td>Battery</td>
<td>Pump</td>
</tr>
<tr>
<td>Energy</td>
<td>Gravitational potential energy</td>
</tr>
<tr>
<td>Conducting wires</td>
<td>Pipes</td>
</tr>
<tr>
<td>Bulb, Resistance or Load</td>
<td>Vertical pipes</td>
</tr>
<tr>
<td>Current</td>
<td>Flow rate</td>
</tr>
<tr>
<td>Ammeter</td>
<td>Flow rate meter</td>
</tr>
<tr>
<td><strong>Delivery Truck</strong></td>
<td><strong>Toy Rail Cars</strong></td>
</tr>
<tr>
<td>Delivery trucks</td>
<td>Rail cars</td>
</tr>
<tr>
<td>Warehouse with parcels</td>
<td>Pusher at station</td>
</tr>
<tr>
<td>Parcels</td>
<td>Push at station; effort to scale the hills</td>
</tr>
<tr>
<td>One-way streets</td>
<td>Rail track</td>
</tr>
<tr>
<td>Shops</td>
<td>Hills</td>
</tr>
<tr>
<td>Delivery trucks frequency/rate</td>
<td>Rail car frequency/rate</td>
</tr>
<tr>
<td>Observer taking note of traffic flow</td>
<td>Observer taking note of rate of rail car flow</td>
</tr>
<tr>
<td>Observer taking note of rate of rail car flow</td>
<td>Speedometer</td>
</tr>
<tr>
<td><strong>Bicycle Chain</strong></td>
<td><strong>Student Role Play</strong></td>
</tr>
<tr>
<td>Chain links</td>
<td>Students</td>
</tr>
<tr>
<td>Cyclist</td>
<td>Student holding tokens</td>
</tr>
<tr>
<td>Kinetic energy of rider &amp; wheel</td>
<td>Tokens</td>
</tr>
<tr>
<td>Laid out path in classroom</td>
<td></td>
</tr>
<tr>
<td>Student (when receiving a token will undertake some action; eg jump)</td>
<td></td>
</tr>
<tr>
<td>Student frequency/rate</td>
<td></td>
</tr>
<tr>
<td>Student frequency/rate</td>
<td></td>
</tr>
</tbody>
</table>

*Water circulation analogy*

The analogue is a water reticulation system where water is enclosed within a set of vertical and horizontal pipes. A water pump raises water (giving it gravitational potential energy) to a high horizontal pipe. The water loses potential energy in falling down vertical pipes. Refer to Table 1 for the links between the target and the analogue. Figure 7 gives a pictorial representation of the links.

*Figure 7: Water circulation analogue and electric circuit target*
Whilst this model is often used in classrooms researchers have found that students don’t find the analogy useful as they don’t fully understand water reticulation systems. However, this analogy has some good positive attributes. For example,

- When pump starts water moves at all points in the system; all bulbs light instantaneously and ammeters give a reading as soon as the closed circuit is formed (battery is connected).
- Water flows in one direction determined by the pump; current flows in the one direction determined by the polarity of the battery.
- Water flows naturally into branched pipe systems; in parallel circuit current flows into each branch.

A possible negative attribute is that water reticulation systems can leak causing flow rates to diminish, or water will flow out of the pipe if it is cut. Current does not diminish in the circuit, nor does it ‘leak out’ if a wire is cut.

**Delivery Truck Analogy**

In this analogy truck fill up with a set number of parcels from a warehouse and deliver them to shops located at various points along a one-way street network. Some positive attributes of this model include:

- Trucks travel in one direction; current flows in one direction.
- The warehouse provides a set number of parcels to each truck and will run out eventually; the battery provides a specific amount of energy per charge (determined by the voltage of the battery) and the battery will run flat eventually.
- Trucks deliver the same number of parcels to identical shops in their loop; identical bulbs all light with same brightness in a series circuit.

A possible negative attribute is that parcels do not reach shops instantaneously not at the same time, whereas all bulbs light instantaneously and at the same time.

**Student Role Play Analogy**

In this analogy a path is made in the classroom through the positioning of tables and chairs. Student charges line up along the path, leaving few gaps and facing in one direction along the path. Along the path there is a student battery who holds tokens and a student bulb. On the call from the teacher students move, as they pass the student battery they collect a set number of tokens, and on reaching the student bulb pass the tokens over. The student bulb needs to undertake some action, such as a jump, for each token received. Some positive attributes of this model include:

- Tokens are delivered to the student bulb from the student battery by the student charges/electrons; energy from the battery is delivered by the electrons to the bulb where it gets transformed.
- Student charges remain on the path; current does not diminish around the closed circuit.

This analogy has a number of negative attribute when considering multiple bulbs in a series circuit and parallel circuits. In the analogy how does the student charge know how many tokens to pass over, and in a parallel circuit, how does the student charge know which path to take? To account for the electric circuit observations this role play analogy needs to have specific rules that apply – these can be negotiated between the teacher and the students. For example, the students act out the role play for one bulb and a battery. Then the teacher asks the students how the role-play can be modified for a circuit that contains two bulbs – if students can see equally bright bulbs then they can introduce a rule for the role-play to follow. For example, if the student battery supplies T tokens and there are B bulbs, then each bulb will receive \( \frac{T}{B} \) tokens.

**Bicycle Chain Analogy**

In this analogy a rider applies a push in the pedals. This push transfers movement energy (kinetic energy) via the chain links, to the wheel (refer to Figure 8 below).
Figure 8: Bicycle chain analogy representing a one, and two-globe electrical circuits

Some positive attributes of this analogy include:
- Energy is transferred from the pedal to the wheel via the chain; energy in the battery is delivered by the current to the bulb where is gets transformed.
- A push of the pedal moves each chain link immediately; current is the same all round the circuit and flows immediately the closed circuit is formed.

A negative attribute for this analogy is that it cannot explain parallel circuit phenomena, or if the chain breaks the wheel still spins for a while; bulb stops glowing immediately the circuit is broken.

**Toy Rail Car Analogy**

In this analogy rail cars are linked to completely cover a track which contains hills. At the station a person pushes one of the cars, and as cars move through the station each car is pushed. The pushing of one car moves all cars in the rail loop and allows the cars to scale the hills. The push on each car is always the same so if the loop were to increase in the number of hills the cars would move more slowly.

This analogy has a number of positive attributes that include:
- The push on one car moves all cars at once; the current flow immediately the circuit is closed.
- Energy in the push is used up by the cars as they scale each hill; energy from the battery is transformed at the bulbs.
- A greater number of hills with the same push results in a lower flow rate of cars; a greater number of bulbs results in a lower current.

As a negative attribute it is difficult to imagine how this analogy could account for a parallel circuit.

**References**


Heffernan & Learmonth (1980). *The World of Science: Book One*


World English Dictionary 1999
Appendix 1

Students' Alternative Conceptions of Electric Circuits

- The terms 'electricity', 'current', 'power' and 'energy' mean the same thing.
- In a circuit that contains wires, a battery and a globe, the battery store electricity/power/current which flows to the globe where it is consumed.
- The globe in an electric circuit takes what it needs from the battery.
- Energy is used up by a working bulb.
- The thing that gets used up in an electric circuit is current.
- For a circuit that contains a battery and a bulb, the bulb lights up because:
  - the current from each end of the battery clashes in the bulb to provide the light (clashing-currents model)
  - some of the current from one end of the battery is lost as it passes through the bulb (consumption model)
  - current from one end of the battery is all used up in the bulb, making the second wire unnecessary (source-sink model).
- Batteries store a certain amount of electricity or charge.
- The electricity companies supply electrons for your household current.
- We pay electricity companies for power.
- 'Static' and 'current' electricity are two types of electrical energy.
- 'Electricity' is used up in electric circuits.
- Charge is used up in electric circuits.
- Energy is used up in electric circuits.
- More devices in a series circuit mean more current because devices 'draw' current.
- Electric power is the same as electric energy.
- Electricity means the same thing as current, or voltage, or energy.
- Batteries store, and supply, electrons or 'electricity' to the electric circuit.
- A wire from a battery to a bulb is all that is needed for the bulb to light up.
- The electric energy in a circuit flows in a circle.
- Electric current is a flow of energy.
- The stuff that flows through wires is called 'electric current'.
- Electrons travel at, or near, the speed of light in the wires of an electric circuit.
- Voltage flows through a circuit.
- Voltage is energy.
- High voltage by itself is dangerous.
- Electrons move by themselves.
- Current is the same as voltage.
- A conductor has no resistance.
- The bigger the battery, the more voltage.
- Batteries create energy out of nothing.
- Alternating Current (AC) charges move all the way around a circuit and all the way back.
- AC voltage and current remains constant as in Direct Current (DC) circuits.
Appendix 2

Key Concepts of Simple Electric Circuits

The following list of concepts and understandings are considered appropriate to effectively teach electric circuits to Middle Years students.

- An electric circuit is a complete (unbroken) pathway.
- Electrons are very, very tiny particles.
- An electric current consists of a flow of electrons.
- Electrons are part of all atoms that make up all substances.
- The electrons are in the wires all the time.
- Conductors have free electrons, which can move.
- The battery provides the push to move the electrons.
- The battery voltage is a measure of the push.
- A chemical reaction in the battery creates an electric field, which produces the push.
- All the electrons move instantaneously.
- The size of the current in a circuit depends on the resistance.
- A series circuit has all the components in a line. There is only one pathway.
- The current is the same all around a series circuit.
- In a series circuit adding more globes increases the resistance and decreases the current. The globes are dimmer and equally dim.
- A parallel circuit has branches. There is more than one pathway.
- Identical globes in parallel are as bright as one globe alone. The current in each branch is the same.
- The current in the battery leads is the sum of the currents in the separate branches.
- In a globe, moving electrons collide with fixed atoms in the filament causing them to vibrate.
- The vibrating atoms emit light and heat.

Summers, Kruger & Mant (1997, p. 15)
Appendix 3

Bulb Challenge

You will need:
- Battery.
- Globe.
- One piece of wire.

Predictions

Predict which of the arrangements (A-L) below will make the globe light up.
Write Y for yes or N for no for each picture. Complete the sheet on your own.

The reason(s) for my selections is/are
Class Predictions:
Fill in the following table based on the class predictions.

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some of the reasons given by the class as to why some arrangements will/will not work:

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

Testing:
Now test each of the arrangements using a globe, battery and one piece of wire. Place a Y (yes, the globe glows) or N (no, the globe does not glow) in the table below.

Results:

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions:
Answer the following questions:


__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

2. What similarities do you find in the arrangements that made the globe glow?

__________________________________________________________________________
__________________________________________________________________________

3. Write down a rule that can be followed that will make the globe glow.

__________________________________________________________________________
TEST ON SIMPLE DC CIRCUITS

Instructions
In the following circuits it is assumed that
a. the cells are ideal cells i.e the internal resistances are zero.
b. the connecting wires have zero resistance.
c. all the cells are identical
d. all the bulbs, are identical.

Set-I

Study the following four circuit diagrams and answer the questions

Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1d

Part (A)
Choose the correct option (✓)

1 a Bulb A is brighter than bulb B : YES/NO
1 b Bulb B is brighter than Bulb C : YES/NO
1 c Bulb D is brighter than Bulb E : YES/NO
1 d Bulb F is brighter than Bulb G : YES/NO
1 e Bulb G is brighter than Bulb H : YES/NO

Part (B)
Grade the bulbs A,B,C ................. H in order of decreasing brightness.

Part (C)
Explain your answers for questions given in part-A.
Study the following circuit diagrams and answer the given questions.

**Part (A)**
Choose the correct option (✓)

2 a. Brightness of bulb A and B will be same in all the diagrams. : YES/NO
2 b. Brightness of bulb B₁ & B₂ are not equal : YES/NO
2 c. Brightness of bulb B₂ & B₄ are not equal : YES/NO
2 d. Bulb B₄ is brighter than bulb B₃ : YES/NO
2 e. Bulb B₄ is brighter than bulb B in set-I : YES/NO

**Part (B)**
Grade the bulbs B₁, B₂, B₃, B₄ in order of decreasing brightness.

**Part (C)**
Explain your answers, given for the questions in part-A
TEST ON SIMPLE DC CIRCUITS

Instructions
In the following circuits it is assumed that
a. the cells are ideal cells i.e the internal resistances are zero.
b. the connecting wires have zero resistance.
c. all the cells are identical
d. all the bulbs, are identical.

Study the following circuit diagram and answer the questions.

Part A
Choose the correct option (✓)
1 a. Bulb A is brighter than bulb C
1 b. Bulb B is brighter than bulb C
1 c. Bulb D & E glow with equal brightness
1 d. Bulb D is brighter than bulb F
1 e. If bulb C is removed brightness of bulb A will increase

Part (B)
Grade the bulbs A, B, C, D, E, F in order of decreasing brightness.