USING MICROSCIENCE KITS TO ADDRESS A STUDENT-TEACHER MISCONCEPTION IN ELECTRIC CIRCUITS: AT THE INTERFACE BETWEEN CHEMISTRY AND ELECTRICITY

J Bradley, S Khulu, P. Moodie and M Mphahlele
Division of Science Education
School of Education, University of the Witwatersrand, Johannesburg
Corresponding author email: Peter.Moodie@wits.ac.za

ABSTRACT

A test of education students' understanding of electric circuits, written before their lectures on the topic began, led to practical work with micro-scale circuit apparatus that was designed to further probe and challenge the students' misconceptions. Response data from one of the lab pracs revealed one very common misconception, that the current through a component was the cause of the potential difference across it. A practical activity based upon the Volta pile was designed to show that current is not the cause of voltage, and that voltage is to be traced to the chemical reaction inside the cells. While some aspects of the activity were successful in a workshop at 10th ISMC, others were not. Our reflections on the outcome lead us to the conclusion that it is necessary to engage with the chemical events inside the cell, in order to understand how it works. Systems-thinking may be the way forward. *[African Journal of Chemical Education—AJCE 9(3), November 2019]*

INTRODUCTION

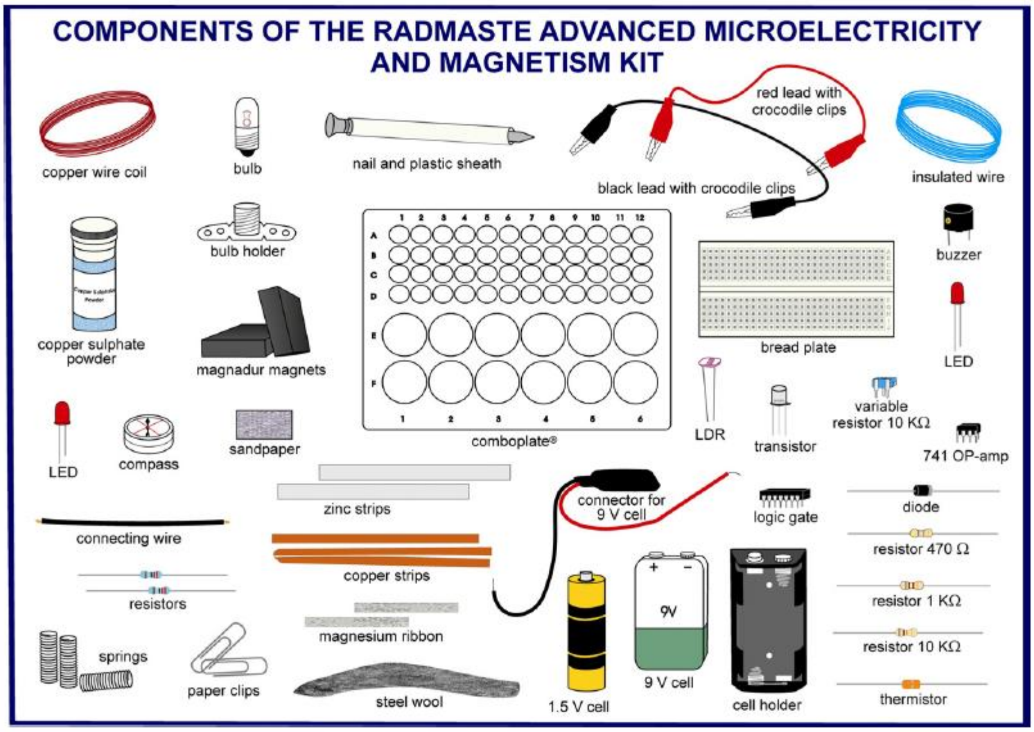
A test of the concepts of current electricity held by Physical Sciences III students in a BEd physics course during 2018, uncovered several problems in their understanding of electricity [1] (Bradley, Khulu, Moodie and Mphahlele (2019)). The misconceptions had been previously reported in the extensive physics education literature on the topic, which includes reports from studies with student teachers in South Africa and other countries (e.g. Gaigher (2014)[2]; Gaigher and Moodley (2019)[3] ; Küçüközer & Demircir (2008)[4]).

As our accompanying paper [1] reports, we decided to focus our attention on one widespread misconception – namely that current in a DC circuit causes the potential difference across it (and its components). To chemistry lecturers this misconception borders on the incredible: to such lecturers it is beyond question. The chemical reaction inside the cell drives the current in the circuit and the cell potential (V) allows the lecturer to state the energy (J) per coulomb of charge transferred. It is true that the energy transfer can happen only if there is a current, but the cell potential nevertheless quantifies this energy. Lecturers can even reassure themselves about the energy transaction involved when the same reaction takes place in a beaker; they can use thermodynamic tables with enthalpies and free energies of formation to calculate overall enthalpy and free energy changes. There is no mystery for those preparing future teachers of Physical Sciences as to what is meant by phrases like 'the cell as a source of energy'.

For our Physical Sciences students however, it seems their understanding of the roles of the cell is very confused. Furthermore, as reported [1] they specifically hold onto their misconception about current as a source of potential difference, even in the face of contrary evidence from a practical activity. This may be partly a result of not seeing any alternative that is more plausible, intelligible and fruitful [5]. We therefore decided that we needed to develop such an alternative and chose to trial our preliminary approach at a workshop at the 10th ISMC.

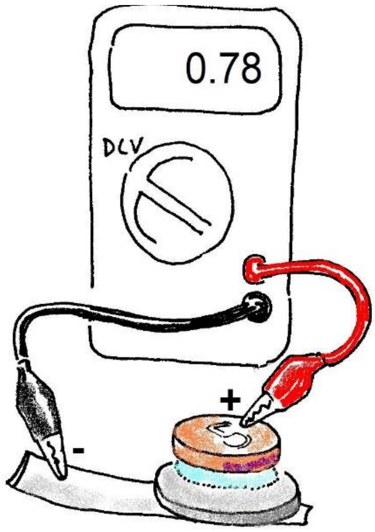
TOWARDS A NEW PRACTICAL ACTIVITY THAT ADDRESSES THE MISCONCEPTION ABOUT THE ORIGIN OF THE POTENTIAL DIFFERENCE

Our first attempt at designing practical activities for this purpose led to the workshop held at the 10th ISMC. The participants in the workshop were all experienced educators, principally at tertiary level, but with extensive and varied experience of working with school science teachers and/or student-teachers in a number of different countries. The workshop used components from the microelectricity kit shown below, together with other components needed to construct a voltaic pile. Details can be found in the workshop handout, a part of which forms an appendix to this paper.



We had combined the microscale electricity kit with extra components such as copper coins, zinc-plated washers and paper soaked in salt water; with these the participants made Volta piles as shown in Appendix 1. A key step was to make a single cell and measure the p.d. across it. See Figure 2.

1*Figure 2 A figure from the worksheet.*



The worksheet text attempts an explanation for the observation that the two dissimilar metals set up a potential difference; the explanation used the notion of electronegativity difference between the metals because this concept is a part of the senior school Physical Sciences syllabus and it appears for each element in the periodic table that is supplied to the exam candidates.

The intention of the workshop was to receive the participants' expert views on whether the lab tasks focused the students' attention on the battery and its reactants as the source of the energy and the reason for a potential difference across a resistance in a circuit, even if that resistance was very high, such as in the case of an air gap.

We got the expected advice from the workshop that electronegativity difference is not an adequate basis for explaining the potential differences of the cells used in the workshop. But in the event, the workshop participants gave us enough information to make us reconsider other points in the worksheet.

Previous experience with practicing teachers had told us that they are surprised to see that such a simple combination of two metals and salt water can produce a reading on the voltmeter. Before that observation, they tend to see the copper, salty water and zinc as simply conductors and do not think of them as chemicals that can react, at least not when the topic is in physics!

Constructing the Volta pile was, for the practicing teachers mentioned above, an interesting novelty and raised the question about the chemical reactions going on and how these components are similar to the components in a commercial battery. It appeared to be an interesting novelty also for the ISMC workshop participants.

The further activities in the worksheet invited the ISMC participants to compare the effect of making the cell with combinations of other metals such as copper and magnesium or zinc and magnesium.

The worksheet attempted to explore the reasons for electron transfer in the cells, but we decided that this had complexities that were unsuitable for the activity intended for our B.Ed. III students. It was enough if they believed a chemical reaction had happened inside the cell.

REFLECTIONS

It seems to us reasonable to say that making one's own Volta pile and using it to make an LED light up, is definitely going to bring the importance of the cell in DC circuits to the attention of students. It is more evident and plausible that a chemical reaction is behind its role. But still, until one sees how it works, it does not take students much beyond the kind of statement we find in the grade 8 national (CAPS) curriculum document [6]

> "cells/batteries are chemical systems that are sources of energy – cells store chemical substances (potential energy) – when the circuit is completed, the chemicals react together to produce an electric current – an electric current is the flow of charges (kinetic energy) along a conductor"

In the case of the self-constructed Volta pile, it is not obvious what the reaction is and what is the role of each chemical component – the zinc, the copper and the salty water. Students are familiar with the idea of chemical reaction but do not see how in this pile (or indeed in cells generally) the reaction "produces an electric current". How does it work? How can we get meaning out of those curriculum statements?

The challenge is then, not to explain why electron transfer may occur between reactant particles, but how do we get this to happen through an electric circuit. Electronegativity differences are then not only of doubtful explanatory value, but they are addressing a question that is not the priority. The priority is 'how does it work?". This question, it is interesting to note, was reportedly voiced strongly by 14-15-year-old Greek pupils when exposed to a new teaching approach which presented voltage as a primary concept in teaching about DC circuits [7].

This argument means that there is no alternative: we have to look inside the cell and find the answer there. For PS III students this is not necessarily difficult. After all they have reached the 3rd year of BEd studies, following their matriculation. They should therefore be comfortable with the key idea, namely that the electron donor is kept separate from the electron acceptor and electron transfer can only then take place via the external circuit. The oxidation half-reaction is linked with the reduction half-reaction via the electronic conductor that is the circuit. However, whilst this is essential, it is not sufficient. Electron transfer implies development of charge imbalance, and unless this imbalance is rectified, further transfers are inhibited. This is the role of the salty water in the Volta pile (in the familiar description of electrochemical cells (voltaic!) this is the role of the salt bridge).

We therefore think that having constructed a Volta pile and observed its ability to light up an LED, our students need to explore how the cell works as follows:

1. Do chemical tests on a Volta cell to find out what has been produced after it has been operating (for a considerable time). Our expectation is that the salty aqueous solution will show zinc ions and hydroxide ions are present. Another observation would be that there are no traces of the familiar blue colour of the hydrated copper ions. These tests indicate that the two half-reactions are:

   $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ and $2H_2O\ (l) + 2e^- \rightarrow H_2(g) + 2\ OH^-(aq)$

   This cell could also be established in a microwell plate if the scale of the Volta cell used in the pile is too small for satisfactory chemical testing.

2. To deduce the role of the salty water the simplest approach would be to construct a Volta cell using pure water instead of salty water, and very clean electrodes. We think there will be no

current in the external circuit (maybe a very short-lived one?). The ion movements constitute a current inside the cell. Yet there is no evidence from the chemical tests of the sodium chloride being a reactant. Hence we can argue its role is to assist the charge imbalance handicap to continuing reaction. We could replace the salt (NaCl) with other 'neutral' salts (and we could try sugary water to emphasise that it's the ions we need).

3. Our students should be able to construct for themselves then a complete picture of 'how it works'. They will see why continuity of the electric circuit is to be understood as a circuit in which the charge carriers are partly electronic and partly ionic. They will already appreciate that when a chemical reaction occurs energy is usually lost from the system and transferred to the surroundings. This is also the case in this special system and the transfer of electrons through the external circuit becomes the mechanism of this energy transfer. However, this function will not suggest to them that electrons are consumed. The electrons not only originate from one terminal but must enter the other terminal in equal numbers, otherwise there is no chemical reaction at all.

IMPLICATIONS

We started upon this project with the aim of improving the worth and purposes of practical activities in the BEd Physical Sciences III content course.

So far we have confirmed the strong case for trying to achieve this. What has become clear as we have advanced our thinking and experiences is that this aim is one that requires systems thinking. To clarify our meaning in saying this, it is important to refer to earlier use of the term 'system' in connection with electric circuits: thus Härtel [8] long ago (1982) argued for a new approach to teaching this topic by treating the electric circuit as a system. This however, did not include the events inside the cell! Our vision of systems-thinking, requires the kinds of insights that traditionally originate in physics education together with those that traditionally originate in chemistry education. The cell as a component of a DC circuit should not be marginalized in physics teaching because it leaves big gaps in the understanding of the circuit. Likewise, the treatment of electrochemical cells in isolation from their practical applications in DC circuits (that is an exclusive emphasis on the equilibrium thermodynamics with little or no reference to kinetics), as is frequently the case in chemistry teaching, should not continue.

Furthermore, fuel cells deserve attention in this regard, as they directly illustrate the link between exothermic redox reactions and potential difference and current in DC circuits. A specific example of a microscale activity that illustrates the principle of the fuel cell can be found in the paper *Microscale Chemistry and SDGs* (Ogino 2019) [9].

CONCLUSIONS

In order to implement the ideas set out above, we therefore envisage the development of a physical sciences unit in our student-teacher curriculum, devoted to electrochemical systems and their application. The reason for expressing our intention in this way, is that our existing Physical Sciences III curriculum comprises two quite separate sequential courses – one in chemistry and one in physics. Thus the mention of a physical sciences unit, means a topic that cut across the established separate courses. It remains to be seen if this will be supported by the powers that be.

We are not ready to set out the philosophy, content and intended outcomes of such a physical sciences unit in this paper, but our findings thus far lead us to believe that BEd lectures on physics and chemistry must be complemented by practical activity that requires students to apply lectured concepts to real systems. We believe that students may recognize their need for conceptual change if the physical sciences unit draws on related concepts from both disciplines; they may see that one phenomenon, such as the potential difference of a cell, must have mutually compatible explanations in both physics and chemistry. Our underlying philosophy is that science learning consists in making connections between concepts and extending one's network of concepts so that a particular problem can trigger several relevant and useful concepts that are associated in that network.

Our experience of using the micro-electricity kits to probe students' ideas about circuits, together with much previous experience with microchemistry kits, suggests that microscale practical work, with suitable preparation and questioning, will enable all the students to personally engage with the concepts and be challenged in their thinking about them.

REFERENCES

1. Bradley, J.D., Khulu, S., Moodie, P., and Mphahlele, M., (2019) Exploring pre-service teachers' misconceptions in electric circuits using microscience kits. *AJCE* 9 to be published.
2. Gaigher, E. (2014) Questions about Answers: Probing Teachers' Awareness and Planned Remediation of Learners' Misconceptions about Electric Circuits, *African Journal of Research in Mathematics, Science and Technology Education*, 18:2, 176-187, DOI: 10.1080/10288457.2014.925268.
3. Moodley, K., & Gaigher, E. (2019). Teaching electric circuits: Teachers' perceptions and learners' misconceptions about electric circuits. *Research in Science Educ.,* 49(1), 73-89. DOI 10.1007/s11165-017-9615-5.
4. Küçüközer, H., and Demirci, N., (2008). Pre-service and in-service physics teachers' ideas about simple electric circuits. *Eurasia J. Maths, Sci.,& Tech. Educ*., 4(3), 303-311.
5. Posner, GJ., Strike, KA., Hewson, PW., and Gertzog, WA., (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Educ.,* 66(2), 211-227.
6. Department of Basic Education Curriculum and Assessment Policy Statement (2011): Natural Sciences, Senior Phase Grades 7-9. Pretoria: Government printing Works.
7. Psillos, D., Tiberghien, A., and Koumaras, P. (1988). Voltage presented as a primary concept in an introductory teaching sequence on DC circuits. *Int.,J. Sci.Educ.,*10 (1), 29-43.
8. Härtel, H. (1982). The electric circuit as a system: a new approach. *Int., J.,Sci, Educ.*, 4(1), 45-55.
9. Ogino, K. (2019) Microscale Chemistry and SDGs. *AJCE,* 9, to be published.

Appendix

A section of the trial worksheet prepared for the 10th ISMC.

A workshop to generate advice about an undergraduate lab practical

The problem we are addressing

Our research has shown that our Bachelor of Education (Physical Sciences) students have a number of misconceptions about basic d.c. electric circuits; these are similar to some of those reported in the physics education literature. We have chosen to focus on one misconception that seems to be held by 82% of a sample doing a third-year course in physics. This is the idea that the current in a circuit is the cause of the p.d. across the components. It is often revealed in the student viewpoint that if a component that normally carries current is removed, then there is no p.d. across the points. We will discuss this in more detail in the presentation paper tomorrow.

This practical is intended to focus the students' attention on the battery and its reactants as the source of the energy and the reason for a potential difference across two points in a connected circuit.

The broader background is that students have come to accept a separation of physics from chemistry as normal; their lectures are given like that and they will treat physics and chemistry in the same way when they are teaching *their* students, passing on the idea that there is little or no connection between the two forms of endeavour. We would like to draw the chemistry closer to physics in at least this lab practical, and then look for further opportunities as the B.Ed. curriculum development continues.

Some of the demonstrators (the demmies) in the lab have a physics background and some have chemistry. So they will have another version of this task with answers and added information.

The questions for the workshop are then:

What do you think of the activities: engaging, trivial or under-exploited?

Do the activities focus students' attention on the reason for the energy difference that drives the current?

Could they be improved?

Which of the questions really hit the spot? Which distract students from thinking about what happens in a battery?

B.Ed. Physical Sciences III B Trial Prac 3

Historical background

In 1800, an Italian academic constructed a device which looked like the one you see in the picture. Alessandro Volta piled zinc and copper discs on each other, separated by discs of cloth soaked in salt water. Between the two electrical points you see on the apparatus, he was able to get a tiny spark. Most importantly, he was able to make a current of electricity flow steadily for some time. Nowadays we call his device a battery and say that there is a **potential difference** (p.d.) between the contacts.

A potential difference is also known as a voltage.

Figure 1 *A replica of Volta's "pile".*

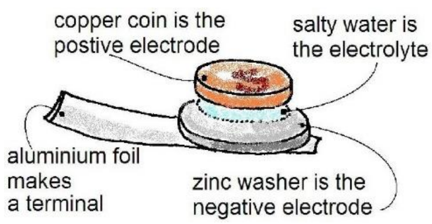
A pause for thought: How did Volta know that there
was a current flowing? Ammeters did not exist, neither did the knowledge of how a current could deflect a

Activity 1 Make your own Volta pile

you need the materials you see in [Figure 5][].

6 copper-coated coins; 6 zinc-coated washers; 6 paper towel discs; croc leads; electricity well-plate; propette; bowl of salt solution; 2 springs; LED; 3 dowel sticks or straws; conductive strip of aluminium.

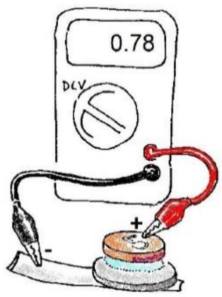
Figure 2 *This is your first cell.*



Take one zinc washer, one copper coin and a paper towel disc; use the propette to put a few drops of salt solution onto the paper towel and make your first cell. Put the zinc washer onto the conductive aluminium.

Use the voltmeter probes to measure the p.d. between the zinc and the copper.

Figure 3 *Measure the p.d. between the zinc and the copper.*



Swop the positions of the red and black probes and measure the p.d. again.

Q 1 Are the readings the same when you exchange the red for the black lead? Describe what you see.

Make 9 more cells like the first one. Lay out a row of zinc washers, put paper towel pieces on each of them, and wet the paper towel with salt solution. Put the copper coins on top of the wet paper towel.

Now push the three dowels into the well-plate, and put a
strip of aluminium on the well-plate as you see in [Figure 4][]. Now stack the cells on each other. Insert the aluminium into the spring as you see in the Figure.

 ISSN 2227-5835

Add another strip of aluminium to the top and hold it down with an extra coin. Connect it to the other spring.

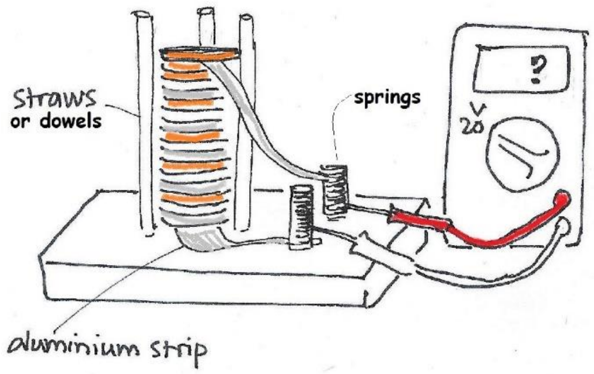
Q 2 Measure the p.d. from your Volta pile. This measurement is called the open-circuit p.d. [It will be about 4 V initially but rises to about 6.5 V]

Connect the LED in the springs, as you see in **Figure 5**[]: the LED should light up.

Q Measure the p.d. again when the LED is lit. [it will be about 1.8 V]

Q Now take out the LED and watch the voltmeter reading for about a minute. Describe the change in the voltmeter reading. [The voltmeter reading increases slowly from 1.8 V, back to about 6.5 V]

Figure 4 *This is what you are making .*



Q Is there still a p.d. across the springs when there is no LED passing a current? [This tries to address the misconception that if the circuit is open there is no voltage across the gap.]

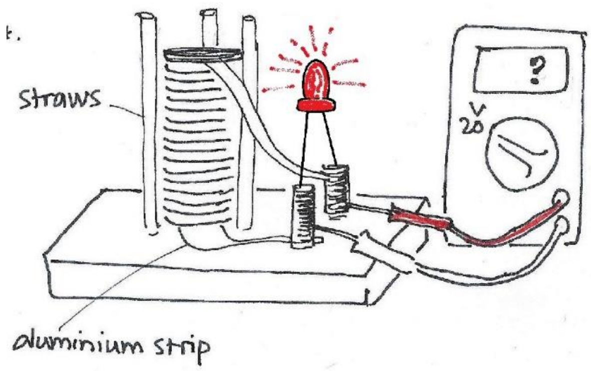
Questions about what's happening in the

Q When the LED glows, it is because electrons are passing through it. Where have all these electrons come from? Write as much as you know about this.

Q What is the cause for the electrons moving in the same direction? [student answers may include that the positive terminal is pulling them; the zinc has too many electrons; copper has too many electrons; this is a first approximation answer]

Q The electrons clearly transfer some energy in the LED, but *then* what happens to them? [Student may say they return to the copper, to the zinc, or that the electrons have

Figure 5 *Measure the p.d. again when the LED is glowing.*



Q Suggest a reason why the voltmeter reading drops when you connect to the LED. [students have usually done internal resistance at school. In Q they will be asked for reasons for internal resistance]

A red LED will glow when the p.d. across it is about 1.8 volts, and the current is about 0.02 ampere.

Q 10 If the current through the LED is 0.02 ampere, how many electrons are passing though the LED in each second? [0.02 coulomb/sec and 1 coulomb is the charge of 6.25 x 10^{18} electrons so 0.02 coulomb/sec represents 0.02 x 6.25 x 10^{18} electrons/sec.]

second? [student's reading is e.g. 1.8 V; perhaps physics student will begin p.d. = work done/unit charge or □□□V= W/q = joules of energy per coulomb of charge. W = □□□V x q;. In each sec, work done is the p.d. x coulombs = 1.8 x 0.02 = 0.036 joules in each sec. Point out that this is the same as the power, formula P = IV. The point of doing it this way is to emphasise the energy transfer caused by the p.d.]

Q 12 How many watts of power is the LED producing? [P = IV = 1.8 x 0.02 = 0.036 W]

Q 13 What will make this process stop, assuming the circuit stays connected? [This question forces the students to think about the chemical changes in the battery. The reactants will reach equilibrium when the zinc has reacted with the salt water. Ask them to examine one of the zinc washers for the condition of its surface. Some roughness or discolouration will show after about 15 minutes. Have a washer from a previous group

At this stage the students have experience of the reaction but not yet an understanding of what drives it.

Volta knew that his battery would not work unless the two metals were different in some way. But what was the difference? So we pause to revise some of your Grade 12 chemistry.

The remainder of the worksheet has been omitted deliberately because it pursued an unfruitful path and that section would distract readers from the focus of the paper