An evaluation of the impact of scientific explanation model on pre-service teachers' understanding of basic concepts in electricity

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Abstract. Electricity as a topic is regarded as challenging worldwide because students from different countries around the world are reported to have the same pattern of learning difficulties in understanding electricity due to misconceptions associated with it. The current study explored the impact of the scientific explanation model commonly known as CER, as an instructional strategy, on bridging the conceptual gap about some basic concepts of the DC circuit. A two-tier test was developed and then used as an instrument for data collection. The results revealed that the CER model as an instructional strategy has the potential of diagnosing and minimizing misconceptions students have. However, some misconceptions were still available after instruction. The results of this study is consistent with literature that previously concluded that the teaching of electric circuits for qualitative understanding is challenging to students from secondary to tertiary levels

Keywords: Preservice teachers, charge, misconceptions, language of science, scientific explanation

1. Introduction and background

Electricity as a topic is regarded as challenging worldwide because students from different countries around the world are reported to have the same pattern of learning difficulties in understanding electricity due to misconceptions associated with it [1]. For example, "when resistors are connected in series, the one with higher resistance has lower current" [2], which is a misconception. This misconception is sometimes caused by the incorrect mathematical interpretations of Ohm's law. The other misconception "*current is consumed by circuit elements"* was reported in most studies [3], is sometimes caused by the incorrect understanding of current convention. These are just few examples of misconceptions, there are many and are obstacles to learning. The literature on misconceptions suggested further research to determine if instructors are able to prescriptively address students' misconceptions in such a way that learning is improved significantly and also if teachers are gathering insights into students' preconceptions and thought processes. The understanding of students' preconceptions and thought processes is believed to be helpful in planning for future interventions. As an attempt to bridge the conceptual gap in students' understanding of basic electric circuits, literature advised university lectures to pay more attention into students' misconceptions [4] by developing instructional strategies or materials that will enhance students' understanding. In bridging the gap, a two-tier test was developed guided by selected designed principles adopted from knowledge building theory [5]. The current study explored the impact of the scientific explanation model, which has elements; claim, evidence and reasoning abbreviated (CER) [6] as an instructional strategy, on bridging the conceptual gap about some basic concepts of the Direct Current (DC) circuit. The study was guided by the following research questions:

(a) Does the CER model as instructional strategy helped in minimising the target misconceptions students have?
(b) Which targeted misconception(s) resisted instruction?

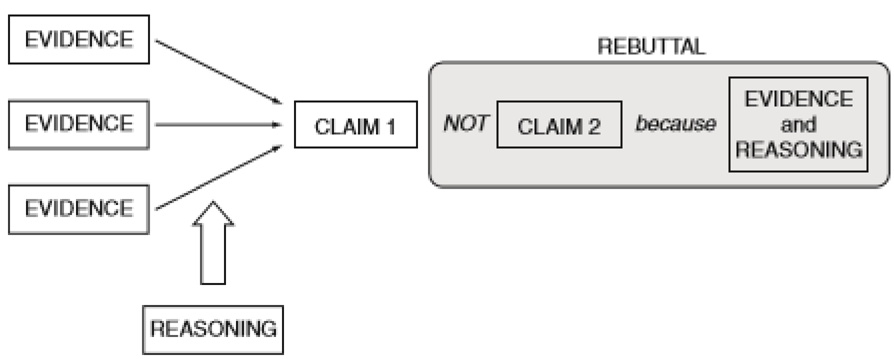
2. Motivation for the study

The usage of words in physics is different from how the same words are used in our everyday language [7] According to [8]: *Often a student can listen to, or read a statement in science and make sense of it by using the everyday interpretation of the word*. For example, the meaning of power in everyday language is different from the meaning in physics. Based on the fact that students have challenges regarding the languages of physics it is necessary to evaluate the actual students' understanding of the physics concepts. In other words, the identifications of students' conceptions or misconceptions should be done prior to instruction. Misconceptions are classified as robust if they are present before instruction, common to a significant percentage of students in a particular class, reproducible in form and structure across different classes at different institutions in different contexts, and resistant to instruction [9]. In the context of this study, the operational definition of misconception was based on the comparison of the model used by students with the model that is used by a scientific community in explaining the phenomena. A misconception is said to exist if: "the model constructed by an individual fails to match the model accepted by the mainstream science community in a given situation"[10]. Even specialists in the field can have misconceptions, for example, our famous Newton who formulated the three laws of motion once had a misconception. According to [11], one of the misconception held by Newton through his many years of research was that: *space is not an absolute void, but rather is continuously filled with ether* (a hypothetical elastic type of gas which has no mass).

2. he Scientific Explanation Framework: CER Model

From constructivist view point, teachers are expected to use "certain strategies and methods which involve students in constructing the desired meaning of scientific concepts and which help the students undergo the desired conceptual change"[12]. The Scientific explanation model CER [6] in fig 1 was adopted as the strategy to facilitate conceptual change when students construct their own understanding.

Figure 1: The Scientific Explanation Framework taken from fig 2.2 in McNeill and Krajcik (2012)



According to the CER model [6], any scientific explanation consists of a Claim, Evidence and Reasoning. A claim (abbreviated C in CER) was defined as *a conclusion to a question or problem* that is investigated, evidence (abbreviated E in CER) was defined as *scientific data that supports the claim* and reasoning (abbreviated R in CER) was defined as *a justification that links the evidence to the claim.* The last stage, rebuttal in figure 1 is an additional stage that is included only after students have mastered how to claim and to give evidence justifying with reasons to support their claim. During intervention, students were introduced to the CER model and were also advised to apply the model while answering all questions.

3. Methodology

3.1 Participants

The participants in the study were students registered for B.ED (FET) second year pre-service teachers taking physics with code PSFTOA2 as one of the major. The participants are formally registered in the faculty of education and only doing physics in the faculty of science. The minimum requirement to register for first year students is a score of 3 which is very low. The total numbers of participants were 45 but only 39 were considered when analysing the concept tests results since they wrote both pre and posttests. The course PSFTOA2 was offered during the first semester.

3.2 Instrument for data collection

Guided by literature on students' understanding of basic electric circuits [3],[13] and personal experience teaching the topic, a the test instrument consisting of four questions probing students' understanding of charges in electric circuit was formulated. Questions were designed to illuminate students' conception/misconceptions about charges in electric circuit. The instrument consisted of multiple choice questions with free response answers. The answer to the multiple choice questions constitute a claim, while the free response answers constitute evidence and reasoning. The test instrument can be classified as a two tier test [9.Table 1 that follows show question items of the developed test with their targeted conception/misconception..

Table 1: Instrument Question Items and their targeted misconception

Question item no	Statement of the Question	Conception/misconception targeted
1	When a battery/ cell no longer works, ***it is out of charge*** and ***must be recharged***.	*Conservation of charges*
2	The charge that flows through the circuit ***originate from the battery.***	*Battery as the source of charges*
3	Charges ***become used up*** as they flow through a circuit and the amount of charges that exit the light bulb is always less than that enters the bulb.	*Conservation of charges / current consumption.*
4	The electrical utility company like ESKOM, ***supplies millions of electrons*** to our home every day so that we can have current.	*Conservation of charges*

To allow simple scoring, a rubric adapted from [6] was converted to table 2. Table 2 categorized students' explanations into two four categories labelled A to D. The instrument was administered before and after instruction. During intervention, students were familiarized on how to answer questions based on CER. They were shown examples of how to support a claim with correct evidences and reasoning.

Table 2: Classifications of students' conceptual understanding

Category	Claim	Evidence & reasoning	Classification
Category A	Correct Claim	Correct evidence & reasoning	**Understanding**
Category B	Incorrect Claim	Correct evidence & reasoning	**Partially Understanding**
Category C	Correct Claim	Incorrect evidence & reasoning	**Guess**
Category D	Incorrect Claim	Incorrect evidence & reasoning	**Do not Understanding**

4 Results and Discussion per question

Question item 1: When a battery/ cell no longer works, it is out of charge, must be recharged. The term "recharge" according to Thesaurus, means to renew, refresh, boost, revive, revitalise, restore etc. In terms of physics, are we restoring charges when we recharge a battery? Do our physics students understand the term recharge in the context of recharging a battery scientifically? The answers about students' understanding are shown in table 3 that follows.

Table 3: Battery runs out of charge responses

	Understand	*Partially understand*	*Guess*	*Do not understand*
Before Instruction	2.6 %	7.7 %	28 %	62 %
After Instruction	28 %	26 %	28 %	21 %

To show an understanding of the physics concept in this question, students were expected to choose false as the correct *claim* and use the *principle of conservation of charge* to conclude that a battery can't run out of charge because they are always within a material (*evidence and reasoning*). From the results, before intervention, only 1 (2.56 %) student had a clear understanding of the principle of conservation of charge and make use of it to conclude correctly, 3 (7.69%) students had what we call a false negative explanation (partially understanding), 11 (28%) students guessed their answers(correct claim) because their explanation showed that they believe in the misconceptions *that the battery can run out of charges* and , lastly the majority of students 24 (62%) did not have an idea about the concept being tested. After intervention, there was a slight improvement in terms of choosing the correct answer and the correct explanation. A notable observation was that the percentage number of those who guessed remained unchanged and lastly the number of those who did not understand the concept at all decreases to 8 (21 %). Some of those in 21 % still retain that *their everyday usage of the word recharge* meaning *to return or restore* etc. Based on the contexts mentioned from the dictionary, one can conclude that students associate the word charge with that of some unscientific definition from dictionary. This can be seen as the origin of the association of charge with energy (38.46%). Some of those who did not use the everyday context in explaining mentioned the following two statements: (a) *The battery runs out of charge because the bulb consumes charges when lighting which is a common misconception (33.3%).*
(b) *Since the battery has positive and negative terminals and charges are positive and negative hence the charges are from the terminals of the battery, which means that they are from the battery* (38.46 %)

Question Item 2: The charge that flows through the circuit originate from the battery. All the participants passed the chemistry module where the origin of charges was introduced using the atomic models. The question was included to test if students are associating the terminals of the battery charges of the battery because a battery consists of a positive terminal and a negative terminal, and at the same time charges are electrons (positive charge) and protons (positive charge). The results of this question item are shown in Table 4 that follows.

Table 4: Charges from battery responses

	Understand	***Partially understand***	***Guess***	***Do not understand***
Before Instruction	8 %	8 %	15 %	69 %
After Instruction	36 %	38 %	13 %	13 %

Based on the fact that to define what a charge is was challenging as observed during the pre-instructional activity, and given that a battery consist of positive and negative terminals, it seems logical but unscientific to think that charges are from the battery or alternatively " *a battery is the source of charges*". Those who understand the concept were expected to answer false, and to mention that all materials have charges, furthermore the number of charges in the material can also help to identify the type of the materials. The results in table 4 show that there was an improvement from 8 to 36 % in terms of understanding. After instruction, only 13 % of students guessed and another 13% still do not understand the origin of charges and stick to their original conviction that charges originate from the battery.

Question item 3: Charges used up in circuit. The question was aimed at assessing students' knowledge of the common science principle: The principle of conservation of charges. It was in response to the common misconception that many students think charges are used up in the circuit which contradicts the principle of conservation of charges. According to the principle, charges are conserved in an isolated system. The results in table 5 revealed that, before instruction, (2.6%) understood, 5.1 % partially understood, 20.5% guessed while the majority (71.8%) did not understand the principle in context. After instruction, it can be claimed that the CER model helped many students to understand the principle but with only few (2. 8 %) that retained their original understanding. The results is consisted with literature that says some misconceptions resist instruction.

Table 5: Question 3 responses

	Understand	*Partially understand*	*Guess*	*Do not understand*
Before Instruction	2.6 %	5.1 %	20.5 %	71.8 %
After Instruction	66.7 %	7.7 %	2.8 %	2.8 %

Some of the notable explanations used by students before instruction were as follows:

- *Charges are used up and converted to light and heat in order for light bulb to shine"*
- *Resistance of the wires decreases the amount of charges*
- *When charges light the bulb the amount of energy reduces because of resistors which try to block the movement of charges which makes the existing charges less than the starting charges.*
- *When the bulb is brand new, it is more brighter than when it is old, bulb used up charges*
- *Some charges are used by the bulb to light, energy is converted to heat, which causes the bulb to light up*
- *Resistor reduces the amount of charges*

Question item 4: Utility Company supply electrons

The question was again the principle of conservation of charges, and to test if students are able to differentiate qualitative terminologies that are reported to be confusing students. The terminologies are: current, energy, potential difference, charges, power and resistance. We expected them to say the municipality only maintain or create the potential difference to enable the charge to move, and when a charge move, there will be current.

Table 6: Question item 4 responses

	Understand	*Partially understand*	*Guess*	*Do not understand*
Before Instruction	12.8 %	2.6 %	51.2 %	33.3 %
After Instruction	7.7 %	7.8 %	30.8 %	48.7 %

Some of the 5 sampled students' notable responses that revealed elements of misconceptions before and after instructions are shown in table 7.

Table 7: Students responses to question item 4

St #	*Before Instruction*	*After Instruction*
S1	*It supplies millions of electrical energy so that we can have current*	*It supplies millions of electric charges*
S2	*Electrons are not the one sent to our homes, the circuit* ***carries charges*** *which are provided by the supplier, ie box, main switch or so forth*	*Current is the* ***movement of charges not the movement of electrons***
S3	*Electrons are electricity conductors, for the current we need electrons so that we can conduct electricity. The electrons are negatively charged and enhance the movement of energy or voltage*	*We need electrons to have current*
S4	*They don't supply electrons* ***but charges which we use in our electric circuit***	*Electrons alone cannot form current, current is defined as the flow of charges not electrons*

Students' responses suggest that the student did not understand the distinction /similarity between an electron and the charge even after intervention. This was regarded as a very difficult question, because most students was unable to differentiate a charge and an electron as shown when one said: *Electrons* *are not the one sent to our homes, the circuit* ***carries charges*** *which are provided by the supplier, ie box, main switch or so forth. The results revealed that some students, refers potential difference as energy*

5. Conclusion

In answering the first research question, the results suggest that the CER model was very helpful in identifying conceptions/misconceptions students have. Some of the notable misconceptions were the following:

- *Resistor reduces the amount of charges in the circuit*
- *The battery as the source of charge*
- *When the bulb is brand new, it is more brighter than when it is old, bulb used up charges*

The misconceptions that students have prior to instruction but that resisted instruction by many students, were the ones that deals with electrons and electricity, especially the one that say the Eskom supply electrons as indicated on the following explanations:

- *Electrons are electricity conductors, for the current we need electrons so that we can conduct electricity*
- *At our homes, we have power stations nearby each township, so utility company supply the power stations with electrons so that we can have electricity*

The results of this study is consistent with [1] that previously concluded that the teaching of electric circuits for qualitative understanding is challenging to students from secondary to tertiary levels. Based on the results of this study, it can be suggested that further interventions be done to help students to discern terminologies that are used to define electricity in our daily lives.

References

[1] Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' un derstanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning, 24*, 271-2

[2] Bilal, E., & Erol, M. (2009). Investigating Students' conceptions of some electricity concepts. *Lat. Am .J. Phys.Educ. 3*(2), 193-201.

[3] Küçüközer, H. and Kocakülah, S. (2007). Secondary school students' misconceptions about simple electric circuits, *Journal of Turkish Science Education* 4, 101-115.

[4] Soong, B. (2008). Learning through computers: Uncovering students' thought processes while solving physics problems. *Australasian Journal of Educational Technology, 24*(5), 592-610.

[5] Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer, *Cambridge Handbook of Learning Sciences* (pp. 97-118). New York: Cambridge University Press.

[6] McNeill, K., & Krajcik, J. (2012). *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing.* Pears

[7] Harlow, D., & Otero, V. (2006). Talking to Learn Physics and Learning to Talk Physics. In P. H. McCullough, & J.Marx (Ed.), *Physics Education Research Conference Proceedings. 818*, pp. 53-56. merican Institute of Physics.

[8] Gilbert, J.K., Osborne, R.J. & Fensham, P.J. (1982). Children's Science and Its Consequences for *Teaching. Science Education,* 66(4), 623-633.

[9] Ekici, E. (2016). "Why Do I Slog Through the Physics?" Understanding High School Students' Difficulties in Learning Physics. *Journal of Education and Practice, 7*(7), 95-107.

[10] Clerk, D., & Rutherford, M. (2000). Language as a confounding variable in the diagnosis of misconceptions. *International Journal of Science Education, 22*(7), 703-717.

[11] Nussbaum, J. (2005). History and Philosophy of Science and the Preparation for Constructivist Teaching: The Case of Particle Theory . In J. Mintzes, J. Wandersee, & J. Novak, *Teaching Science for Understanding: A Human Constructivist View* (pp. 165-194). Academic Press

[12] Tsai, C., & Chou, C. (2002). Diagnosing students' alternative conceptions in science through a networked two-tier test system. *International Journal of Computer Assisted Learning, 18*(2), 157-165.

[13] Lee, Y. and Law, N., (2001) Explorations in promoting conceptual change in electrical concepts via ontological category shift, *Int. J. Sci. Educ.* 23, 111-149