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South African twelfth grade students' conceptions regarding Electrochemistry

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ABSTRACT

This current study explored twelfth-grade students' conceptions regarding electrochemistry in the Ximhungwe circuit of the Bohlabela district in the Mpumalanga province of South Africa. The sequential explanatory design was used to gather and analyse quantitative data first before gathering and analysing qualitative data for the current study. In the 2015 academic year, a sample of 10 twelfth-grade physical sciences students from four intact science public high schools was conveniently selected to participate in the current study after analysing the results of the quantitative data. Thirteen questions in which at least 30% of students showed misconceptions were selected for the interview. The result of the interviews indicated that students in the experimental group (EG) had more accurate concepts related to the function of the salt bridge in galvanic cells and the concept of electrical neutrality of anodes and cathodes compared to the control group (CG). Both the EG and the CG had the same viewpoints related to oxidation numbers, electrode potential, Emf calculations, and the identity of electrodes in galvanic cells and electrolytic cells when the placement of the electrodes was altered. However, students in both groups had limited knowledge about electrolytic cells, although the CG had more limited comprehension. It was recommended that educators teach concepts as much as they teach algorithms.

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1. INTRODUCTION

Electrochemistry has been one of the most problematic sub-disciplines of the Physical Sciences paper 2 (chemistry) examination for grade 12 (final year) South African physical sciences' students. This is due to the continuous annual low performance of students in this learning area in the final Matric examination. Electrochemistry contributes 17.4% (Department of Basic Education (DBE) [1] towards the chemistry paper yet the mean pass rate of the electrochemistry part keeps on declining when likened to the mean pass rate in chemistry. This has been ascribed to conceptual problems encountered by students as a result of the way core knowledge is attained in the classroom as well as problem-solving challenges the learners experience. Commonly, educators talk, and learners become mere listeners, which prevents elaborate discussion of the subject matter in the classrooms.

Numerous conceptual difficulties and misconceptions regarding electrochemistry concepts such as electrode potential and galvanic and electrolytic cells have been reported in the science and chemistry education literature [2-5]. Similarly, despite the wide application of electrochemistry in industry and other fields, science teachers [6-7] and students alike [8-13] have difficulties with electrochemistry concepts. Correspondingly, alternative conceptions about electrochemistry have also been stated by several studies [14-16] which have indicated that electrochemistry can be described as one of the most challenging, problematic as well as demanding sub-disciplines of chemistry [17] since it has so many ambiguous and abstract terms with stated discrepancies and unreasonable representation [14, 15, 18].

One of the fundamental explanations behind this circumstance is because this topic requires higher-order thinking skills in the ambit of the three representation levels of microscopy, macroscopy, and symbolism [5, 19]. Electrochemistry is additionally thought to be abstract to students [2, 3, 20]. The movement of the electrons is invisible and consequently, some students might not be able to visualise this movement. Accordingly, some researchers have indicated that learners need to understand the movement of ions and electrons during the electrolysis process, and only then can they transform the process into chemical formulae and equations [2, 3, 21].

To meticulously explore further on alternative conceptions in electrochemistry, Sanger and Greenbowe [22, 23] replicated and extended two studies on electrochemistry formerly investigated by [24, 25]. The sub-disciplines of electrochemistry that were examined (the concentration, electrolytic, and galvanic cells) produced 28 alternative conceptions. As an extension of the research on electrochemistry done by Garnett and Treagust [24, 25], Sanger and Greenbowe [26] adapted the interview protocol developed by Garnett and Treagust to interview each of the sixteen students. At the end of the research, Sanger and Greenbowe asserted that the alternative conceptions they identified in their study were very much like those found by Garnett and Treagust [26]. They indicated however that in the United States students are generally assessed on algorithmic problems in electrochemistry and therefore for most of the students their dearth in conceptual knowledge was a non-issue as it did not affect their grades. As a result of this, students usually pay less attention to conceptions in electrochemistry as opposed to those related to algorithmic knowledge in electrochemistry. Nevertheless, in South Africa, learners are usually evaluated on both algorithmic problems and conceptual knowledge in electrochemistry.

Numerous studies have been conducted on students' comprehension of electrochemistry by proposing several procedures to facilitate conceptual change. Niaz [27] undertook a study, which involved an in-class activity related to the conceptual change model proposed by [28]. The focus of the study was to generate cognitive conflict by designing specific experiments that generated cognitive dissonance among the students used in the study. At the end of the study, Niaz asserted that active participation of students in the instructional process assists in generating cognitive conflict among students to enable them to develop a better comprehension of concepts and that rote learning does not contribute to students' conceptions of electrochemistry.

In the review of related literature, it was found that student misconceptions in electrochemistry are numerous and varied relating mainly to galvanic and electrolytic cells. From the foregoing, the purpose of the current study was to identify common misconceptions in electrochemistry, specifically electrolytic and galvanic cells among South African twelfth-grade physical science students and to ascertain the reasons why they continue to exhibit these misconceptions in their final grade 12 examinations.

2. RESEARCH METHOD

2.1. Research design

As discussed previously, this research is part of a major study that applied the mixed-method design, which involves both quantitative and qualitative procedures. Specifically, the sequential explanatory design was used to gather and analyse quantitative data first before gathering and analysing qualitative data [29]. This current research reports on the qualitative data used to further explore South African twelfth-grade students' conceptions about electrochemistry.

2.2. Participants

The present research used interviews from 10 volunteer-students to get detailed facts about students' comprehension of electrochemistry conceptions. Five students each were selected from the experimental group (EG) and the control group (CG). The EG was taught using 21st-century collaboration whereas the CG was taught using the lecture method.

2.3. Instrument

The researcher used Electrochemistry Concept Test (ECT) to gather data in the present research in the form of a semi-structured interview. The test was created by the researcher to assess the students' comprehension of electrochemistry concepts. A semi-structured interview protocol was employed to examine students' perceptions qualitatively as it offered respondents some directives on what needs to be discussed.

The questions in which more than 30% of students showed alternative conception from the results of the descriptive statistics on the quantitative data were used. In all 13 questions comprising concepts regarding electrolytic and galvanic cells, and electrode potential were selected, 3 from the pilot study questions, and 10 from the main diagnostic questions.

2.4. Procedure

The use of the interview was to ensure that any gaps or information that might have been omitted in the data collected quantitatively are catered for. Besides, the interview was used as a follow-up to certain respondents to the ECT questionnaires to further investigate their responses. There was no specific sequence followed for the questions, however, the researcher did ask mainly about galvanic cells, electrolytic cells, and electrode potential.

The researcher used between 30 and 45 minutes to interview the students based on the keenness and nervousness of the students. The interviews were conducted after school to fulfil the research ethic rules laid down by the Department of Basic Education, South Africa. The researcher taped all the interview sessions; however, the students were assured of the confidentiality of their views in the interview (i.e. the only person who would listen to the records would be the researcher).

2.5. Analysis of data

A thematic analysis approach was used to analyse the data. After the interview sessions and the transcription process, the researcher employed the six phases of thematic analysis which involves "familiarisation with the data, coding by searching for interesting patterns, searching for themes based on codes, reviewing themes, defining and naming the themes, and writing up" [30, p. 79] to analyse the data. The thematic analysis was completed with the assistance of the table of alternative conceptions.

3. RESULTS AND DISCUSSION

Based on the interview transcripts, the researcher outlined eight coding classifications to analyse the data generated. GC represents Galvanic Cells and EC represents Electrolytic Cells. Table 1 presents the classification used for the analysis.

Table 1. Eight coding classifications to analyse the data generated

Coding	
GC-Movement	Students' answers associated with electron movement in galvanic cells.
GC-Salt bridge	Students' answers associated with the aim of the salt bridge in galvanic cells.
GC-Placement	Students' answers associated with the identification of how the electrodes in galvanic cells alter when physical placement is modified.
GC-Reaction	Students' answers associated with the reactions at anodes and cathodes in galvanic cells.
EC-Placement	Students' answers associated with an identification of the electrodes when the placement of the electrode changes.
EC-Identity/same	Students' answers associated with the identification (being anode or cathode) of electrodes when the same electrodes are utilised in electrolytic cells.
EC-Reactions	Students' answers associated with the reactions at anodes and cathodes in electrolytic cells.
EC-Reactions/inert	Students' answers associated with the reactions at anodes and when an inert electrode was utilised.

Besides, each coding classification was categorised as an appropriate conception (AC), inadequate conception (IC), and misconception (M), or no conception (NC). Each of the coding terms have been exhaustively explained in Table 1.

Table 2 indicates the coding classifications outlined by the researcher and the allocation of students into experimental and control groups across the coding classifications. The results indicated that more students have appropriate conceptions on galvanic cells than electrolytic cells.

For instance, from Table 2, it is observed that 22 student responses from the EG, representing 55% of the responses had an appropriate conception about Electrochemistry based on the eight categories. Similarly, 10 student responses from the CG representing 25% of the responses had an appropriate conception of Electrochemistry based on the eight categories. However, only 6 student responses (15%) were misconceptions exhibited by the EG as against 14 student responses (35%) by the CG. Consequently, the CG had more misconceptions (35%) than appropriate conceptions (25%) in Electrochemistry conceptions, whereas the EG had more appropriate conceptions (55%) than misconceptions (15%) in Electrochemistry conceptions. These results further suggest that the collaboration as a conceptual change teaching strategy (CCTS) helped students to eradicate more misconceptions than the traditional teaching method (TTM) as the latter showed more misconceptions than the former.

Table 2. Distribution of students interviewed across the coding categories

	Variable							
	EG (N=5)				CG (N=5)			
Coding	AC	IC	M	NC	AC	IC	M	NC
GC-Movement	2	0	3	0	0	0	5	0
GC-Salt bridge	4	0	1	0	0	2	3	0
GC-Placement	5	0	0	0	5	0	0	0
GC-Reaction	4	0	1	0	1	0	4	0
EC-Placement	3	0	0	2	3	0	0	2
EC-Identity/same	1	0	0	4	0	1	2	2
EC-Reactions	0	0	0	5	0	0	0	5
EC-Reactions/inert	2	0	1	2	1	0	0	4
Total	22	0	6	13	10	1	14	13

AC: Appropriate conceptions, IC: Inadequate Conceptions, M: Misconceptions, NC: No Conceptions

3.1. Concepts about galvanic cells

Items 1, 3, 8, 9, 10, and 11 were the questions used in the interview on galvanic cells to interrogate students' opinions related to electron movement. Two students in the EG stated that "*it was not electrons but the ions that moved in the solution."* However, the remaining eight students, 3 from the experimental group and 5 from the control group mentioned that "*to finish the circuit, it was the electrons that moved in cell solution(s)."* Five (CG) of the 8 students thought "*electrons move freely in solutions to complete the circuit."* They were emphatic on the `completion of the circuit`. It is believed that the last two statements are alternative conceptions that arose from their pre-knowledge of current electricity. It is therefore not surprising that one student from the five remarked: *"Sir, I learned in electric circuits that electron movement causes current to flow. And once the key is closed and there is a continuous movement of electrons, the current will also continue to flow."* However, the remaining three students (EG) stated that "*electrons were put into solution after getting assistance from ions by migrating from one ion to another* (two students) or *by "adhering to ions"* (one student). This student had the opinion that the electrons stayed with the ions as *"electrons could not advance with ions; hence, no electron flow took place in the solution."*

In conjunction with the function of the salt bridge, all 10 students interviewed had the appropriate conception related to the function of the salt bridge. They mentioned that the *"salt bridge maintains charge balance or electrical neutrality in galvanic cells"*. When the figure in Item 11 was shown to them, they were further asked to explain what they meant by electrical neutrality. Four students from the EG indicated that *"To maintain neutrality, the negatively charged ions in the salt bridge will migrate into the anodic half-cell. A similar (but reversed) situation is found in the cathodic cell, where positive ions are being consumed, and therefore electroneutrality is maintained by the migration of positive ions from the salt bridge into this half-cell."* The other six, one from the EG and five from the control group, could not give a scientific explanation to the question. It is believed that their conception related to the electron movement hampered their conception of the function related to the salt bridge. Four students from these six (one from the EG and three from the control group) opined that *"electrons moved via the salt bridge."* They believed, that *"the salt bridge helped the flow of electrons as positive ions in the bridge attracted electrons from one half-cell to the other half cell"*. One of the remaining two students indicated that *"the salt bridge provided electrons to finish the circuit"*. The other one thought that *"electrons come inside the electrolyte at the cathode, move through the electrolyte, and come out at the anode."*

Students were then subjected to questions related to the placement of electrodes. All 10 students stated that "*cathodic and anodic functions did not alter when the placement of the electrodes was changed*." Students in both groups appeared to modify their perspectives on the identification of electrodes based on their physical placement. This could be because the emphasis of the students was on algorithmic issues and hence, they effortlessly recognised the electrodes by calculation. When a student was questioned concerning the distinctiveness of the electrode, they instantly employed reduction potential tables and reactions. It seems students have learned that oxidation takes place at the anode and reduction occurs at the cathode. One of the students from the EG indicated that *"irrespective of the physical placement, oxidation will always occur at the anode and reduction at the cathode in a galvanic cell."*

Students were also asked to outline the correct statement about the electrochemical cell in item 8 in the structured interview questions. Four students in the EG and one student in the CG mentioned that *"Cation movement is labelled 4."* However, four students in the CG stated that *"Electron flow is labelled 2."* The remaining student in the EG stated that *"the anode is labelled 1."* When they were further probed, it was revealed that those who indicated that "*Cation movement is labelled 4*" understood electrical neutrality in galvanic cells. They explained that oxidation occurred at the copper electrode and therefore they stated that *"Cations move towards the cathode so that the cell remains electrically neutral."* The remaining student in the EG, who stated that *"the anode is labelled 1"*, explained that "*electrons are attracted to the cathode because it is positively charged.*" The student explained further that because the electrons are produced at the anode they will automatically move towards the cathode, which is positively charged. Two of the four students in the CG who stated that *"Electron flow is labelled 2"* indicated that the electrons move from one-half cell to the other. When asked further to explain, they said, *"electrons enter the electrolyte at the anode where electrons are produced, move through the electrolyte, and enter the cathode"*, which is positively charged. This answer during the interview session introduced a new alternative conception which was not mentioned in the literature review.

3.2. Concepts about Electrolytic cells

Items 2, 12, and 13 were the questions used in the interview on electrolytic cells to indicate students' opinions related to electron movement. The outcomes of students' interviews related to electrolytic cells indicated that students did not understand the conceptions related to electrolysis as compared to the conceptions related to galvanic cells. Questions about electrolysis remained unanswered in most cases. Students appeared to know more about the identity of electrodes compared to other conceptions related to electrolysis. Three students in the CG and three in the EG had the appropriate conceptions that "*the identity of electrodes is dependent on the link with the power source (such as the battery).*" The remaining two students, on the other hand, in the CG and two students in the EG did not have any clue as to how the electrodes were recognised as anode and cathode. Similar to galvanic cells, students mentioned that *"the identification of the electrode did not alter when the placement of the electrodes was modified given that the link with the power source remained unchanged."* However, the inferences from the research also indicated that students in both groups had limited knowledge about electrolytic cells. This may be due to the limited scope covered on this topic by the Curriculum and Assessment Policy Statement (CAPS) for South African high schools [16]. "A National CAPS is a single, comprehensive, and concise policy document, which has replaced the Subject and Learning Area Statements, Learning Programme Guidelines and Subject Assessment Guidelines for all the subjects listed in the National Curriculum Statement Grades R–12" [31, p. 105].

When the 10 students were told to reply if a reaction took place when the same electrodes were employed, it was only one student from the EG who gave the appropriate conception. Two students from the CG had a misconception and thought that "*no reaction would take place since the same electrodes were utilised."* Furthermore, one student from the CG had very inadequate knowledge related to the use of the same electrodes. The following students thought that electrodes should always be the same. One of them mentioned that *"if unidentical electrodes were utilised, this system would become a galvanic cell, while the other mentioned that since both electrodes were in the same cell, they should be similar."* Other students (two students from the CG and four students from the EG) mentioned that *"they had no clue."* Students also had inadequate knowledge related to *Emf* in electrolysis. Three students from both the CG (two) and EG (one) did not have any clue about any *Emf* that the electrolytic cell was capable of producing. Only one student from the EG had the right idea that the *Emf* was negative. The student explained that "*Fundamentally a reaction will not occur if the cell potential is negative until a voltage greater than the cell potential is applied. Nevertheless, it will run in the opposite of a galvanic cell, oxidising the cathode and reducing (depositing onto) the anode as in electroplating*." Three students had misconceptions about the *Emf* of the electrolytic cell. Two of them (one from the CG and another from the EG) stated that "*the Emf was positive as the electrolytic cell was linked to the battery."* The third student from the CG mentioned that "*the Emf was not positive and it could not be negative either* and so *the Emf* was *zero."*

4. CONCLUSION

Given the interview outcomes, it was observed that the students essentially emphasised on algorithmic issues instead of conceptions. They employed the same logic in solving conceptual issues that they utilised to solve algorithmic issues. Few students who chose the incorrect answers at first for the quantitative aspect later discovered the right responses when the interview was conducted as they emphasised on theories and employed logic as needed. Students had more concepts related to galvanic cells comparable to electrolytic cells. The logic could be that the teachers focused more on the algorithmic problems related to electrolytic cells in the class. This is surprising as both conceptual and algorithmic questions are asked during the final year examinations for Grade 12 physical science students in South Africa. Additionally, only algorithmic issues related to electrolysis were resolved, and hence students only emphasised on the algorithmic aspects related to electrolysis. It could also be that they failed to differentiate between the two kinds of cells. Most of the interviewees also showed limited conceptions or no conceptions at all about electrochemistry. Surprisingly, a novel alternate conception that was not stated in literature but found among the participants of this study ("electrons come into the electrolyte at the anode where electrons are produced, move through the electrolyte and enter the cathode, which is positively charged") was identified.

The result of the interviews also indicated that students in the EG had more accurate concepts related to the function of the salt bridge in galvanic cells and about the concept that anodes and cathodes were electrically charged. Both groups had the same viewpoints related to oxidation numbers, electrode potential, Emf calculations, and the identity of electrodes in galvanic cells and electrolytic cells when the placement of the electrodes was altered.

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