GALVANIC ELECTROCHEMICAL CELLS: A STUDY OF THE UNDERSTANDING AND KNOWLEDGE RESPONSES GENERATED BY STUDENTS TESTED AS INDIVIDUALS, IN PAIRS AND IN GROUPS

A dissertation
submitted to University of Cape Town
in fulfilment of the requirements
for degree of

MASTER OF EDUCATION

in the

FACULTY OF HUMANITIES

by

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December 2001
Cape Town

ACKNOWLEDGEMENTS

The writer wishes to acknowledge his gratitude to all who rendered practical assistance and who showed an interest in the completion of the study.

In particular the writer wishes to thank :

- Professor Kevin Rochford for his unreserved availability, guidance and constructive criticism.
- The National Research Foundation
- The generous financial assistance of the University Grants Committee of the University of Cape Town.
- The headmasters who allowed me to administer the questionnaires in their schools
- The students who took part in the project and the teachers who helped to administer the project
- My wife Aisha, my sons Umr, Abdurragmaan and Muhammad Qasim and my daughter Nahwaal for their constant support and understanding

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This dissertation is dedicated to my parents Abdul Majied Gallant and Hajr Gallant

DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted for the degree of Master of Education of the University of Cape Town. It has not been submitted before for any degree of examination in any other university.

26/12/2001 Signed by candidate

Moegamad Riedwaan Gallant

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
$2F^-$	Fluoride
$CuSO_4$	Copper sulphate
Cu	Copper
ed	editor
emf	electromotive force
et al	and others
HSD	highly significant difference
KCl	Potassium chloride
Li	Lithium
RSA	Republic of South Africa
SD	significant difference
SD	standard deviation
Std.	Standard
Zn	Zinc
$ZnSO_4$	Zinc sulphate

ABSTRACT

This investigation is an application and extension of the work of Swain (1999) who recorded the productivity of the responses generated by student groups of different sizes during science lessons.

The present study selected the topic *Galvanic Electrochemical Cells*. It sought to gather achievement data from 584 high school students studying physical science by recording their technical knowledge responses generated under several different socially-determined conditions.

The investigation proceeded in three phases: -

In phase 1, physical science students in Western Cape high schools were taught the textbook chapter *Galvanic Electrochemical Cells* by their usual chemistry teachers in normal classroom lessons, without any special programme of external assistance. At the same time, the researcher was formulating, designing, compiling, trialing and defining a summative set of twelve achievement test questions covering the topics *oxidation, reduction, electrode current flow, forms of energy, salt bridge, oxidation and reduction half reactions* and *industrial applications of electrochemical cells.*

The wording and content of the final full electrochemistry test was progressively improved through three pilot trials involving consecutive groups of 63, 34 and 79

students; after which it became a self-evaluation worksheet scoring 30 marks. This worksheet test was then utilized for both formative and summative purposes, in two further phases.

In phase 2, the final version of the full self-evaluative electrochemistry test, was administered formatively to a sample of 437 physical science students in ten randomly chosen Western Cape high schools, after they had all completed the textbook chapter *Galvanic Electrochemical Cells*. However, the administration of the formative test in each classroom occurred under the following socially determined conditions: -

(a) Typically, about one quarter of the class of students completed the achievement test in writing under silent, solitary conditions as randomly chosen *individuals* (mode 1).

(b) Typically, about one quarter of the randomly assigned students completed the written test while discussing their answers in *pairs* (mode 2).

(c) Typically, about half the students, randomly selected, completed the written test as larger *clusters,* searching for group consensus on their answers (mode 3).

It was found that, under the three different socially determined modes of testing, the mean achievement scores on the full electrochemistry test were as follows:

(a) for the 99 *individuals:* $M_1 = 18.75$; (b) for the 86 (43 times 2) *student pairs:* $M_2 = 20.40$; (c) for the *clusters* of 252 students: $M_3 = 21.30$. The difference in achievement scores between testing modes 1 and 3 was significant ($F = 6.557$; $p < 0.01$).

A qualitative analysis of the data disclosed that the majority of students experienced a diversity of descriptive problems with the *identification of the anode and cathode;* with *oxidation-reduction equations;* and with *understanding the function of the salt bridge.*

In phase 3, the use of three socially determined grouping modes was retained in the research design, but the investigation engaged with a fresh sample of 147 physical science students randomly selected from five new high schools in the Western Cape.

In phase 3 the study was expanded by using the full electrochemistry test as both a formative pre-test and a summative post-test for classes. The research strategy utilized modes 1, 2 and 3 as sub-groups again, but with all students being *re-taught* the topic *Galvanic Electrochemical Cell*s by one common teacher in an attempt to **improve** the students' achievement scores through additional instructional intervention.

The programme of supplementary teaching proved to be successful for all three modes of pre- and post- testing. The mean scores of the *individuals* increased significantly by 31.9 %; the *pairs* by 33.2 %; and the *clusters* by 26.5 %. However, there was no significant difference between the final post-test scores of the students tested under the grouping modes 1, 2 and 3.

The main conclusion to the study is that, given the three socially determined modes of self-evaluation for the topic *Galvanic Electrochemical Cells*, no one mode of assessment (as *individuals;* or *as pairs;* or *as clusters*) can be recommended as the superior or dominant one for instructional purposes.

However, the investigation has generated many specific recommendations for teaching concepts more clearly; particularly for teaching aspects of electrochemistry in respect to the *anode and cathode, oxidation-reduction equations, functions of the salt bridge, the flow of the electric current in Galvanic Electrochemical Cells and the application of electrochemistry in industry.*

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CHAPTER 1

INTRODUCTION

1.1 Origin and background of the problem

During the last few years there has been a substantial amount of research into students' understanding and interpretation of scientific concepts and phenomena. Research has been conducted because cognitive scientists and educational researchers found that many students gave unexpected explanations when they tried to interpret basic scientific phenomena (Ogude, 1991:1; Galili, 2001:1073; Kolsto, 2001: 877).

Chemistry is a difficult subject for many high school students and some university students (Bojczuk, 1982, cited in Ogude 1991:8). One of the reasons why students have found difficulty in chemistry is because of the information overload (Kellet and Johnson, 1980, cited in Ogude, 1991:8), and their inappropriate pre-requisite knowledge (McDermott, 1980, cited in Ogude, 1991:8). Ben-Zvi, Eylon and Silberstein (1988), cited in Ogude (1991:9), claimed that the rapid transition between microscopic and macroscopic levels by experienced chemists posed a great problem for students during their early studies in chemistry. They argued that a major contributory factor making chemistry difficult to comprehend is students' inadequate understanding of the atomic model together with the following three aspects:

(i) The abstract and non-intuitive nature of the concepts involved.

(ii) The need to co-ordinate the levels of description in using the atomic model.

(iii) Communication; that is, the language for chemistry can be very difficult for a novice. For example, similar symbols can have different meanings according to the description being used. The symbol Cu for instance, can be used to refer to both an atom of copper and a piece of copper.

The topic electrochemistry is difficult for many students (Alsopp and George, 1982; Ainley, 1986; Chambers, 1983; Hillman, Hudson and McLean, 1982) cited in Ogude (1991:10)

Garnett and Treagust (1992a: 121) found that many students experienced problems in identifying oxidation-reduction equations. Many students were reported to experience confusion when trying to identify the anode and the cathode in an electrochemical cell or diagram or experiment (Garnett and Treagust, 1992b: 1079).

Many students have been reported to lack an understanding of the underlying concepts of electrochemistry (Sanger and Greenbowe, 1997a: 377). Garnett and Treagust (1990:147) also found that many factors contributed to students' lack of understanding in electrochemistry, including students' inadequate prerequisite knowledge of the subject.

Another problem has occurred in the setting of the examination papers. Modlin and Veira (1986), cited in Ogude (1991:11), found that physical science examination papers in South Africa emphasized manipulative skills. Little attention was given to qualitative questions emphasizing student understanding of microscopic processes.

Examination questions on electrochemical cells typically required students to perform calculations; for example, calculations of E^0 values for a particular process, or balancing a given redox reaction. Figure 1.1 presents examples of question papers from different education departments in South Africa in the year 1997. This method of testing was satisfactory, provided that the appropriate knowledge had been committed to memory. However, it often proved to be inadequate, since it did not help students to interpret what they were manipulating, and it often encouraged rote learning (Ogude, 1991:11).

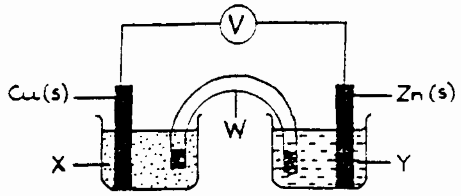
<u>Figure 1.1</u> Examples of question papers from different education departments in South Africa in the year 1997.

WESTERN CAPE EDUCATION DEPARTMENT

NOVEMBER 1997

6.1 Die volgende tekening toon 'n sink-koper elektrochemiese sel:

6.1 The following sketch shows a zinc-copper electrochemical cell:



6.1.1 Noem die energie-omsetting wat in bostaande elektrochemiese sel plaasvind.

6.1.1 State the energy conversion that occurs in the above electrochemical cell. (2)

6.1.2 Gee die chemiese formule van stowwe wat gebruik kan word om die waterige oplossings te berei, voorgestel deur:

6.1.2 Give the chemical formula of substances that can be used to prepare the aqueous solutions represented by:

6.1.2.1 W   6.1.2.2 X   6.1.2.3 Y   (3 x 2)

6.1.3 Die aanvanklike lesing op die voltmeter is 1,1V. Met verloop van tyd verminder die lesing egter. Gee 'n rede hiervoor.

6.1.3 The initial reading on the voltmeters is 1.1V. However, as time passes, this reading decreases. Give a reason for this. (2)

6.1.4 Watter elektrode is die anode?

6.1.4 Which electrode is the anode? (2)

6.1.5 Vloei die elektrone van die Zn na die Cu-elektrode of van die Cu na die Zn-elektrode in die eksterne stroombaan?

6.1.5 Do the electrons in the external circuit flow from the Zn to the Cu electrode or from the Cu to the Zn electrode? (2)

6.1.6 Wat gebeur met die massa van die Cu-elektrode terwyl die reaksie verloop? (Noem slegs of dit **toeneem**, **afneem** of **dieselfde bly**).

6.1.6 What happens to the mass of the Cu electrode as the reaction proceeds? (Only state whether it **increases**, **decreases**, or **remains the same**) (2)

6.1.7 Verskaf 'n relevante half-reaksie om u antwoord in 6.1.6 te ondersteun.

6.1.7 Supply the relevant half-reactions to support your answer in 6.1.6. (2)

NORTHERN CAPE EDUCATION DEPARTMENT NOVEMBER 1997

5.1.1 Wat is 'n oksideermiddel?

5.1.2 Skryf die oksideermiddel in 5.1 neer.

5.1.3 Maak gebruik van die redokstabel om genoemde vergelyking te balanseer.

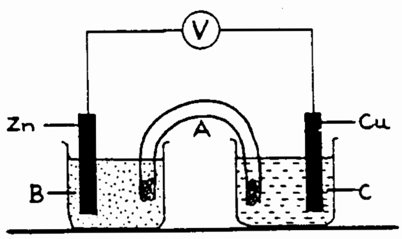
5.1.1 What is an oxidising agent? (2)

5.1.2 Write do.n the oxidising agent in 5.1. (2)

5.1.3 Make use of the redcx table to balance the equation. (8)

5.2 'n Galvaniese sel word opgestel met koper- en sink elektrodes.

A galvanic cell is set with copper and zinc electrodes.



5.2.1 Watter elektrode is die anode?

5.2.2 Gee 'n rede vir u antwoord in 5.2.1.

5.2.3 Wat word A genoem en noem 'n moontlike oplossing in A?

5.2.4 Noem die oplossings in B en C onderskeidelik.

5.2.5 Wat is die rigting van die elektronstroom in die eksterne stroombaan?

5.2.1 Which metal is the anode? (2)

5.2.2 Give a reason for your answer in 5.2.1. (2)

5.2.3 What is A called and name the possible solution in A. (4)

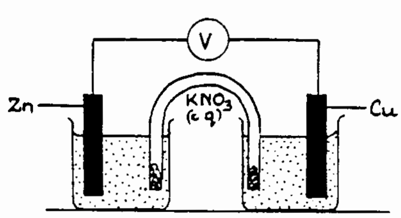
5.2.4 Name the solutions in B and C respectively. (2)

5.2.5 What is the direction of the electron flow in the external circuit? (2)

MPUMLANGA EDUCATION DEPARTMENT NOVEMBER 1997

7. Oorweeg die Zn-Cu sel as dit stroom lewer:

Consider the Zn-Cu cell when it delivers current:



7.1 Watter deeltjies beweeg in die eksterne stroombaan?

7.2 Vanaf watter elektrode beweeg hierdie deeltjies?

7.3 Watter deeltjies beweeg na die Cu-elektrode in die Cu-halfsel?

7.4 Watter elektrode is die anode?

7.5 Wat sal met die massa van die Zn-elektrode gebeur as die sel stroom lewer?

7.6 Skryf 'n vergelyking neer vir die reaksie wat by die katode plaasvind?

7.1 What particles are moving in the external circuit? (2)

7.2 From which electrode do these particles move? (2)

7.3 What particles move towards the Cu-electrode in the Cu half-cell? (2)

7.4 Which electrode is the anode? (1)

7.5 What will happen to the mass of the Zn-electrode when the cell delivers current? (2)

7.6 Write an equation for the reaction taking place at the cathode. (3)

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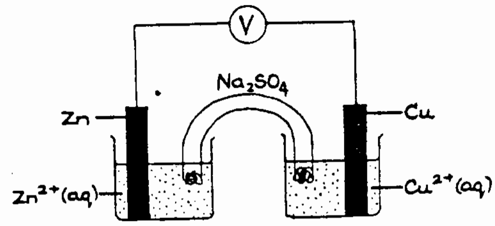
NORTHERN PROVINCE EDUCATION DEPARTMENT NOVEMBER 1997

5. Die skets toon 'n standaard sink-koper elektrochemiese sel.

Skryf 'n vergelyking neer van die reaksie wat plaasvind in die:

The diagram shows a standard zinc-copper electrochemical cell.

Write down an equation for the:



5.1.1 sinkhalfsel

5.1.2 koperhalfsel

5.2 Skryf die vergelyking vir die algehele selreaksie neer.

5.1.1 zinc half-cell (2)

5.1.2 copper half-cell (2)

5.2 Write down the equation for the overall cell-reaction. (2)

5.3 Vloei elektrone deur die voltmeter na die sinkelektrode of na die koper-elektrode.

5.4 In watter halfsel vind reduksie plaas?

5.5.1 Watter metaal is die anode?

5.5.2 Is hierdie metaal die positiewe of negatiewe elektrode?

5.6 Noem die energie-omsetting wat plaasvind terwyl hierdie sel in werking is.

5.7 Beskryf die kleurverandering wat in die oplossing van die katode halfsel plaasvind nadat die sel vir 'n ruk al stroom gelewer het.

5.8 Gee 'n rede vir die antwoord in 5.7.

5.3 Do electrons flow through the voltmeter towards the zinc electrode or towards the copper electrode? (2)

5.4 In which half-cell does reduction occur? (2)

5.5.1 Which metal is the anode? (2)

5.5.2 Is this metal the positive or negative electrode? (2)

5.6 State the energy conversion which occurs while this cell is in operation. (2)

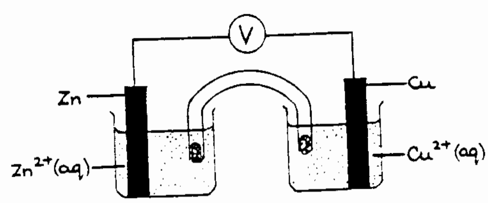
5.7 Describe the colour change which affects the solution in the cathode half-cell after the cell has delivered a current for some time. (2)

5.8 Give a reason for your answer in 5.7. (3)
[21]

NORTHWEST EDUCATION DEPARTMENT NOVEMBER 1997

6.1 'n Student het 'n standaard elektrochemiese sel gekonstrueer, deur die volgende selreaksie te gebruik:

A student constructed a standard electrochemical cell using the following cell reaction:



$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$$

Beantwoord die volgende vrae, gebaseer op hierdie sel.

6.1.1 Watter elektrode is die katode?

6.1.2 Watter elektrode se massa sal verminder?

6.1.3 Gee die funksie van die soutbrug.

6.1.4 Skryf die re'uksie halfreaksie neer.

Answer the following questions based on this cell.

6.1.1 Which electrode is the cathode? (2)

6.1.2 Which electrode will undergo a decrease in mass? (2)

6.1.3 Give the function of the salt bridge. (2)

6.1.4 Write down the reduction half reaction. (3)

1.2 Purpose of the study and focus question

The overall intention of this study is to help students reduce their misconceptions and difficulties in understanding basic electrochemistry through a programme of teaching, formative assessment, re-teaching (supplementary intervention programme) and summative assessment.

The study also aims to identify some of the intellectual problems which occur when students learn electrochemistry, as well as identifying their qualitative understanding of electrochemical processes. This is important because students often manipulate physical quantities without necessarily understanding the underlying concepts (Lippert, 1986 cited in Ogude, 1991:10).

A third purpose of the study is to examine the effect of learning group size on achievement in electrochemistry. Swain (1999:389), for example recorded the effect and results of classroom talk about the chemistry of a burning candle when he compared the learning productivity and effort of (a) 40 Egyptian teachers responding as individuals; (b) 23 pairs of Egyptian teachers; and (c) three larger groups of 15 Egyptian teachers. He found that individual work demanded the most effort but produced idiosyncratic results; pair work provided optimum conditions for participant effort and productiveness of ideas; while large group talk was more focused and more productive in terms of individual ideas, and covered a greater percentage of possible ideas, but it showed a low participation rate.

This parallel investigation with 437 participants in Cape Town is designed:

(i) to investigate and compare the number and quality of student responses in grade 12 - generated as individuals, as pairs, and as groups - in their understanding of electrochemistry with particular reference to graded evaluation materials for the topic *Galvanic Electrochemical Cells*; and

(ii) to use a supplementary teaching assistance programme to improve, where necessary, the under-achieving students' deficits in their knowledge and understanding of this topic.

The prime focus of the study is academic achievement in electrochemistry using the strategy of randomised learning in three different sizes of group formation in order to answer the following key question: **"Does a supplementary intervention programme of 30 minutes improve the students' performance to the greatest extent when its pre- and post-testing is implemented in individual mode, or in pair mode or in group mode, with their different interactive dynamics as a possible explanatory factor?"**

The results of initial pilot studies conducted suggested that the study might also include an investigation into, and a documentation of, the different forms of dynamics which occur between and among the members of small and larger groups. However different theories of group dynamics, such as competition, co-operation, and abstentions from participation and shifting responsibility did not become a focus of the study because all three modes of grouping proved, in the end, to be academically effective in the supplementary programme of assisted instruction.

1.3 Importance and value of the research

Electrochemistry is a topic which is multifaceted and can be conceptually demanding. (Ainley, 1986, cited in Ogude, 20:1991).

Electrochemistry requires an understanding of several pre-requisite concepts like electrical properties, stoichiometry, the mole concept, chemical equilibrium and ionic reactions. However, earlier investigations have indicated that students experience difficulty in understanding these physics and chemistry topics related to electrochemistry (Ogude, 1991:20).

One reason for conducting this research is to enable students to overcome some of these difficulties so that they may be able to apply their knowledge of electrochemical processes in a practical way in industrial processes of the future, if required to do so in their subsequent employment.

Electrochemistry is an important component of high school and tertiary chemistry. The working effectiveness of many industrial processes, including the technological advancement of South Africa, will continue to depend on a correct understanding of electrochemical processes such as electro-plating, the preparation of iodine, copper and chlorine, the electrolytic extraction of aluminum from melts, the working of dry cells or batteries used in flash-lights, transistor radios and other devices the production of caustic soda, the manufacture of magnesium and sodium, the metallurgical extraction of gold from ore, the refining of lead and tin (Encarta: Encyclopedia: 97; Pienaar and Walters, 1976: 335).

1.4 Research Questions

The study seeks answers to the following main research questions:

1.4.1 When randomly assigned students work on and answer a set of formative graded evaluation materials on electrochemistry either in group clusters, or in pairs, or as individuals, will their achievement scores be, on average, equal?

1.4.2 Following further instructional intervention assistance, will significant test score increases occur for the three types of instructional grouping arrangement (individuals; pairs; group clusters)?

1.5 Samples and hypotheses

The investigation tests null hypotheses in the formative pre-test phase and the summative post-test phase. Sample 1, comprising 437 students, will participate in the formative phase only. Sample 2, comprising 150 students, will participate in the full programme of intervention assistance, including both formative pre-testing and summative post-testing.

The following four null hypotheses will be tested:

1.5.1 Phase 1: Pre-testing

Phase 1(a): Sample 1 (N = 437): Formative achievement only

Ho1 When 437 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour, there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; group clusters) on the total achievement test and on its several components.

Phase 1(b): Sample 2 (N = 150): Formative achievement on the intervention programme

Ho2 When 150 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour, there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; group clusters) on the total achievement test and on its components.

Phase 2: The supplementary assistance programme of teaching intervention with sample 2.

- Summative post test achievement scores

Ho3 After the 150 participant students complete a 30 minute supplementary programme of assisted teaching in electrochemistry and they are then re-formed into their groups to study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in summative achievement scores between the three types of grouping arrangement (individuals; pairs; group clusters) on the total achievement test and on its several components.

- A comparison of the pre-test formative to post-test summative electrochemistry performance score gains made by different sized groups under the programme of supplementary intervention instruction.:-

Ho 4 After the 150 participant students have completed the 30-minute supplementary programme of assisted teaching in electrochemistry, there will be no significant differences in pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the total achievement test with respect to :-

(i) the individuals

(ii) the student pairs

(iii) the group clusters.

1.6 Procedure for analysing the data

ANOVA F ratios will be used to analyse whether the differences in achievement scores between the three types of grouping arrangement (individuals; student pairs; group clusters) are significantly different. To analyse the qualitative data the conceptual, cognitive and perceptual difficulties will be discussed.

1.7 Clarification of terms

In this study the subject discipline **Physical Science** means physics and chemistry combined as currently taught in South African high schools. Electrochemistry is located in the chemistry section of Physical Science. In the Galvanic electrochemical cell the following terms are used:

Oxidation: This is the loss of electrons by an atom, molecule or ion.

Reduction: This is the gain of electrons by an atom, molecule or ion.

Anode: This is the electrode at which oxidation takes place.

Cathode: This is the electrode at which reduction takes place.

Scientific misconception: This term is used to emphasize that a student's own particular idea arises out of individually misconceiving or misinterpreting a particular scientific concept (Ogude: 1991: 4)

Cluster: A randomly formed group of 4-6 high school electrochemistry students.

1.8 Assumptions underlying the study

This investigation initially assumes that an appreciable number of students in grade 12 have a misunderstanding of various important aspects of electrochemistry, despite normal, careful, previous teaching of this topic. This study assumes that some cognitive misunderstandings may be resistant to change, and that students tend to maintain them into tertiary levels of education.

It is also assumed that a 30-minute supplementary intervention programme of assistance teaching will afford most students with sufficient time to gain a better understanding of applicative skills and concepts in the field of electrochemistry.

The investigation assumes that, after being encouraged by both the researcher and their classroom teachers, the students will be interested in the evaluation exercise, the students will be in a positive mood and they will accept the credentials of the auxiliary teacher/ researcher who is conducting the data collection.

It will also be assumed that all the attending students will have fully completed the chapter on electrochemistry recently with their respective teachers.

1.9 Delimitation of the investigation

The study is restricted to 587 students from a sample of 15 schools in the Western Cape region of South Africa. The students consist of boys and girls who are in Grade 12, ages 16-18 years. Physical Science is one of their school subjects. The syllabus is delimited and prescribed by the Western Cape Education Department.

1.10 Chapter Summary

The origin and background of the problem, the purpose and value of the study, and the importance of the research have been described in this chapter. The null hypotheses, the intervention programme and the research questions have been formulated, the terms and the definitions have been clarified and the procedures for the collection, treatment and the analysis of the data have been introduced.

A review of related literature which forms part of the theoretical framework for this research study now follows in **chapter 2.**

CHAPTER 2

LITERATURE REVIEW

This chapter is divided into Part A - a review of the literature on the teaching and learning of electrochemistry, Part B - a review of literature on the teaching of individuals, pairs and groups and Part C -a presentation of literature on the use of pre-tests and post-tests conducted in chemical education.

PART A - LITERATURE REVIEW ON THE TEACHING OF ELECTROCHEMISTRY

2.1 An overview of students' problems and understanding on different aspects of electrochemistry

Working with 32 Australian students, Garnett and Treagust (1990:147) found that the significant factors contributing to a lack of understanding in electrochemistry were the compartmentalization of subject knowledge, inadequate prerequisite knowledge, students' faulty interpretations of language, the use of multiple definitions and models, and the rote application of concepts and algorithms.

Garnett and Treagust (1992a: 121) concluded that many of the 32 final year Australian high school chemistry students interviewed experienced problems in identifying oxidation-reduction equations. Due to several misconceptions relating to the inappropriate use of oxidation and reduction concepts, students did not understand the definitions of oxidation and reduction.

Garnett and Treagust (1992b: 1079) found that, of the 32 final year Australian high school chemistry students interviewed, some still confused the anode with the cathode. Students who thought that the anode was negatively charged believed cations would move towards it, and those who thought it was positively charged were unable to explain why electrons move away from it. They also found that students attempted to reverse features of electrolytic cells and apply the reversals to electrochemical cells.

Ogude (1991:110) found that some of the 30 final year high school students which she interviewed still confused the descriptions of the anode and the cathode in electrolytic and galvanic cells. In an electrolytic cell the cathode receives electrons from the battery and it becomes the negative electrode. At the anode electrons are released from the species undergoing oxidation at the electrode surface and the anode becomes the positive electrode. Students extend this same understanding to galvanic cells so that there is a common misconception among students that the anode means a positive electrode and the cathode means a negative electrode in both electrolytic and galvanic cells. In fact, in a galvanic cell the anode is the negative cell and the cathode is the positive cell.

Sanger and Greenbowe (1997b: 820) found that seven of the 16 freshman-level students at a Midwest American University interviewed said that the electrodes have net positive and negative charges. Those who believed that the anode is positively charged had the misconception that the anode is positively charged because it has lost electrons and the cathode is negatively charged because it has gained electrons; they interpreted anion flow toward the anode as suggesting that the anode is positively charged and cation flow toward the cathode as suggesting that the cathode is negatively charged.

Sanger and Greenbowe (1997a: 377) found that, although 16 introductory college chemistry students could solve quantitative examination problems, they often lacked an understanding of underlying concepts in electrochemistry. Student misconceptions most commonly encountered included notions that electrons flow through the salt bridge and electrolyte solutions to complete the circuit; plus and minus signs assigned to the electrodes represent net electronic charges; and water is unreactive in the electrolysis of aqueous solutions. New misconceptions which they also identified included notions that half-cell potentials are absolute and can be used to predict the spontaneity of individual half-cells, and electrochemical cell potentials are independent of ion concentrations. Most students demonstrating misconceptions were still able to calculate cell potentials correctly, which was consistent with the research suggesting that students capable of solving quantitative examination problems often lack an understanding of the underlying concepts. They concluded that probable origins of these student misconceptions were attributed to students being unaware of the relative nature of electrochemical potentials, and chemistry textbooks making misleading and incorrect statements.

Garnett and Treagust (1992), cited in Sanger and Bowe (1997b: 820), claimed that there are two origins of student misconceptions concerning the flow of current in electrolyte solutions and the salt bridge. Firstly, students interpret the terminology used in the textbook or by the instructor in a manner consistent with everyday usage, but inconsistent with scientific usage. Secondly, students apply information too generally, over-generalizing a scientific statement to situations where it is appropriate.

Ogude and Bradley (1994), cited in Sanger and Greenbowe (1997b: 820), claimed that student misconceptions concerning current flow in electrolyte solutions and the salt bridge can be attributed to two factors:

(i) reference by textbooks or by the instructor to continuity of current; and established belief in the electronic nature of current electricity; (for example phrases like "continuity of current" imply that current is uniform throughout the cell); and

(ii) careless discussion of the electrode process; (for example, textbooks with obvious mistakes or misleading statements can result in student misconceptions).

Ogude and Bradley (1998:116) discussed students' misunderstanding of the purpose of the salt bridge due to a lack of information in textbooks, as well as to inadequate information in textbooks which may be liable to misinterpretation. They stated that the high school textbooks which they reviewed commonly indicated the function of the salt bridge as 'to complete the circuit'. They also claimed that none of the high school textbooks or first year university chemistry textbooks currently in use in South Africa contained detailed information on the microscopic processes that take place in a salt bridge. They further argued that this statement was often misinterpreted by students to mean that electrons move through the salt bridge and that the salt bridge could be replaced by an electrical conductor. This was also substantiated by Sanger and Greenbowe (1997a: 387). During an interview they asked a student whether a piece of copper wire could replace the salt bridge. The student claimed that the circuit would still be complete because electrons in the solution could flow through the wire.

Ogude (1991:124) quotes the following printed examples in students' text books regarding the misleading or inadequate supply of information about the salt bridge:-

> "... the U-tube links the two solutions without the zinc and copper (II) ions coming into contact or being mixed. Pienaar and Walters (1979:645)".

> "... the U-tube contains an electrolyte so that current can flow from one half-cell to the other but the two half-cells cannot mix. Moore, Davies and Collins (1978:591)."

Bodner (1986), cited in Ogude (1991:125), indicated that inadequate information supplied to students can result in misconceptions. The statement "completes the circuit" can be misinterpreted, and the students may understand it to mean that electrons move through the salt bridge. Thus it reinforces the misconception of electronic conduction in the electrolyte. On the other hand, students may also think that if electrons complete the circuit then:

(a) electrons are found in solution, and are required to maintain neutrality, hence ion charge balance is not required;

(b) a salt bridge is a passage for electrons and can therefore be replaced by an electronic conductor such as graphite.

From these statements it can be concluded that, although the reasoning is consistent with the student's knowledge, and although the reasoning appears logical to him or her, the propositions are inappropriate and may lead to misunderstandings of concepts.

Sanger and Greenbowe (1997b: 820) worked with 16 student volunteers (nine men and seven women) from three freshman-level courses at a midwestern American university. They found that the students generally knew that current cannot flow without a closed circuit, and many students believed that only electron flow can complete the circuit. The result was that many students drew the wrong conclusion that electrons flow from the anode to the cathode along the wire, and are then released into the electrolyte at the cathode travelling through the electrolyte solutions and the salt bridge to reach the anode.

Of those students who wrongly believed that electrons flow through the salt bridge, two students stated that the anions in the electrolyte solutions and in the salt bridge help transfer the electrons from the cathode to the anode, three students stated that cations in the salt bridge and the electrolyte accept electrons and transfer them from the cathode to the anode, and three stated that electrons can flow through aqueous solutions without assistance from the ions.

Sanger and Greenbowe (1997b: 820) found that three of the students who correctly stated that ions flow through solutions and the salt bridge to complete the circuit also suggested that it is the flow of anions in solution that completes the circuit. Because cation flow does not constitute a current, their misconception was that only negatively charged ions constitute a flow of current in the electrolyte and the salt bridge.

2.2 Reasons for students' errors and misconceptions in electrochemistry

Pre-requisite knowledge is not always properly understood by students. Some students have recorded difficulties in their understanding of the mole concept (Macdonald, 1984; Gabel and Sherwood, 1984; Luckay, 1989, cited in Ogude, 1991:22). Some of the problems which they discovered were: students confusing moles with molecules; students finding problems with ratio and proportion which are central for the understanding of the mole concept; and students associating the quantity of 1 mole with a mass of 1gram. Ogude (1991:22) argued that a correct understanding of the mole concept is essential for understanding of electrochemical processes.

An understanding of chemical equilibrium and ionic equations is crucial to the correct interpretation of electrochemical processes (Ogude 1991:23). However, students have experienced appreciable understanding difficulties in chemical equilibrium (Hackling and Garnett, 1985; Bradley, Gerrans and Long, 1990; Vilakazi, 1990, cited in Ogude, 1991:23) and ionic equations (Johnson, Garforth and Lazonby, 1976, cited in Ogude, 1991:23).

Leece and Mathews (1976), cited in Ogude (1991:23), conducted a survey with A-level students in Britain. They found that equilibria and acid-base reactions, and equilibrium and free energy, were among the most difficult topics for students to understand. These topics were concerned with aspects of equilibrium, ionic reactions and free energy whose understanding is central to the correct interpretation of electrochemical processes (Ogude 1991:23).

Bradley, Brand and Langley (1985), cited in Ogude (1991:25), showed in a study done in South Africa that teachers held misconceptions which could be passed on to their students. A similar study was done by Hashweh (1988), cited in Ogude (1991:25), which proved that, in many cases, high school teachers held misconceptions similar to those of their pupils and therefore were unable to assist them in overcoming their misunderstandings.

The use of the language of science in general can also contribute to misunderstandings for students (Bradley, Brand and Gerrans, 1989, cited in Ogude,1991:25). The specific or particular meanings which scientists attribute to terms are sometimes different from the everyday meanings of these terms. For example in electrochemistry the conceptual meaning of "**reduction**" – namely a gain of electrons - is different from its everyday use which suggests loss rather than a gain (Ogude, 1991:26).

2.3 A simple explanation of the basic function of a Galvanic electrochemical cell.

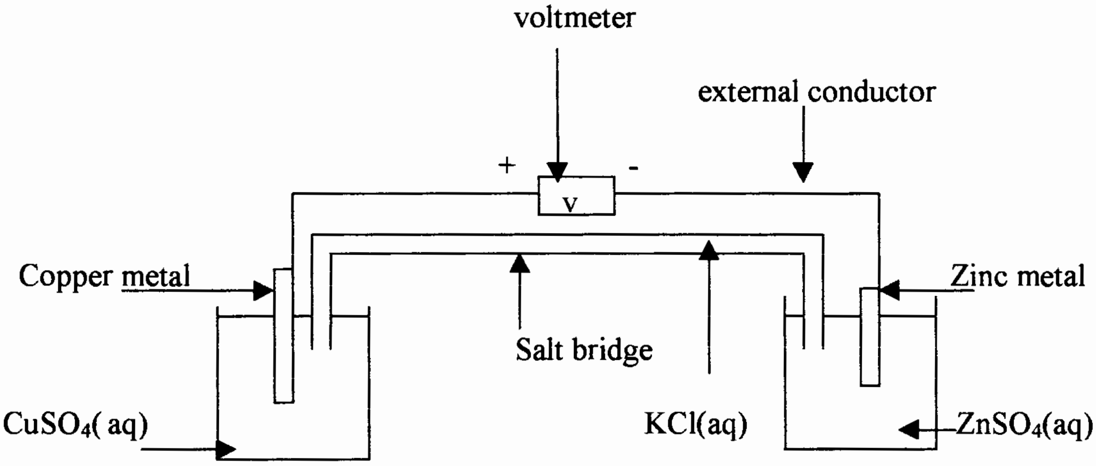
Electrochemistry can be described as that branch of chemistry which concentrates on the relationship between electricity and chemical reactions. It also explains how chemical changes can produce electricity and how electrical energy can produce chemical change (Ogude, 1991:5). The kind of cell which converts chemical energy into electrical energy is known as a *Galvanic cell* (Pienaar, 1977:335).

2.3.1 Oxidation and Reduction

Oxidation and reduction always work together in a redox reaction or a net reaction. The number of electrons generated in an oxidation half-reaction is equal to the number accepted in the reduction half-reaction. Electrons are neither created nor destroyed but are transferred directly on atomic contact (Broster and James: 1989:182; Ogude, 1991:6; Pienaar and Walters 1977:334).

Consider the following example(Figure 2.1) of a Galvanic cell with copper and zinc electrodes:-

Figure 2.1 A Cu-Zn cell as an example of a Galvanic cell



Electrons flow from the Zn electrode through the voltmeter to the Cu electrode.

At the Zn electrode the following half reaction takes place:

- It loses electrons.
- Oxidation occurs.
- It Zn electrode becomes the anode.
- It is known as the negative pole.
- The mass of the Zn electrode decreases.
- The oxidation half-reaction is: $Zn \longrightarrow Zn^{2+} + 2e^-$

Electrons flow through the external conductor to the copper electrode where they are accepted by the copper ions in solution.

At the Cu electrode the following half reaction takes place:

- Electrons are taken up by Cu^{2+} ions.
- Reduction takes place.
- The copper electrode becomes the cathode.
- It is known as the positive pole.
- The mass of the Cu increases.
- The reduction half-reaction is: $Cu^{2+} + 2e^- \rightarrow Cu$

The total net reaction that takes place can be illustrated as follows:

$$Cu^{2+} + 2e^- \rightarrow Cu$$
$$Zn \rightarrow Zn^{2+} + 2e^-$$
$$\overline{Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu}$$

2.3.2 The salt bridge

The salt bridge consist of an ionic solution that is an electrolyte such as KNO_3 or KCl.

The functions of the salt bridge are:

- It provides an electrical connection between the two half cells of a voltaic cell.
- It keeps the two electrolytes separate so that they do not mix.
- It ensures that the positive and negative charges are equal at all times during the operations of a galvanic cell.

- It acts as a pathway in which ions can move to ensure electrical neutrality in the electrolytes in both half cells; i.e. it acts as an ion exchanger.

2.3.3 Electrical changes

The electrical wire and the voltmeter serve as paths for the electrons but they do not undergo any physical or chemical changes due to conduction. The electric current in the operational cell takes place due to a movement of electrons in the electrode and a movement of ions in the electrolyte.

2.4 Implications for this dissertation

In Part A of this chapter an overview has been presented of the problems experienced by students in learning different aspects of basic electrochemistry. These literature findings have the following implications for the development of the thesis:

- Because Garnett and Treagust (1992a: 121) found that final year Australian high school chemistry students experienced problems in identifying oxidation-reduction equations, this research will also investigate student understanding of oxidation-reduction equations with grade 12 physical science students in Cape Town in order to determine whether South African students also experience similar conceptual and content difficulties in similar ways, for the purpose of teaching them more effectively.

- Garnett and Treagust (1992b: 1079) found with final year Australian high school chemistry students, Ogude (1991:110) found with final year high school students, and Sanger and Greenbowe (1997b: 820) found with freshman-level students at a Midwest American University, that students experienced difficulties in identifying the difference between the anode and the cathode. The research will investigate if Cape Town grade 12 physical science students have similar problems in identifying the difference between the anode and the cathode for the purpose of re-teaching this topic more effectively.

- Ogude and Bradley (1998:116) have found that college and pre-college students in Gauteng, South Africa, did not understand the function of the salt bridge. The research will further investigate the problems experienced with grade 12 physical science students in Cape Town for the purpose of overcoming them through a more focussed and clearly directed programme of teaching intervention.

PART B - THE COMPARATIVE TEACHING OF STUDENTS AS GROUPS, PAIRS OR INDIVIDUALS.

2.5 An overview of research on the comparative teaching of students in groups, in pairs, and as individuals

Gilbert and Pope (1986:62) found that 14 German pupils aged 10-12 years were willing to discuss, as a group, matters that were of importance in the teaching and learning of science. The way in which they did, and hence the quality of the process, depended on the composition of the group. The functioning of a group depended to some extent on the interactive skills available to its members. Although some of the pupils in these groups demonstrated the skills associated with teaching for conceptual development as they discussed issues with their peers, the systematic development of those skills would be needed if they were to use the approach effectively.

Wallace (1986) organized practical work with a second year science class working in pairs. She found that students agreed on perceptions such as colors, measurements or tastes, which made them more sure about their judgements.

Meyer and Woodruff (1996:173) worked with nineteen Grade 7 science students on light phenomena in an urban school near Toronto. With large and small groups consensus-building discussion afforded space for generating, refining and connecting ideas.

When working on a chemistry experiment involving the ideas produced by 131 Egyptian science teachers, Swain (1999:389) found that pair work provided optimum conditions for participant effort and productiveness of ideas, while whole class talk was more focused and more productive in terms of individual ideas, and covered a greater percentage of possible ideas. However, whole class work showed a low participation rate, while individual work demanded the most effort but produced idiosyncratic results.

2.6 Co-operative learning

'Co-operative learning is the instructional use of small groups so that students work together to maximize their own and other's learning.' (Johnson, Johnson and Holubec, 1994:6)

According to Deutch (1949), cited in Gabel (1994:113), the roots of co-operative learning originate in a social psychological theory concerned with problems of co-operation and competition.

Johnson and Johnson (1985:23), cited in Gabel (1994:79), reviewed over a thousand studies dating back to the late 1800s.They found that co-operative learning experiences tended to promote more learning than competitive or individualistic learning experiences, and that it was linked with higher self-esteem among students. They also found, in contrast to individualistic activities, that co-operative learning experiences tended to promote higher motivation to learn, that it produced more positive attitudes toward learning experiences, and that it resulted in a stronger perception that students care about learning and assisting one another.

Not only did co-operative learning methods enhance students' academic achievements and self-esteem, but they also improved students' classroom learning environment according to Sharan (1980), Johnson, Johnson, Maruyama, Nelson and Skon (1981) and Webb (1982) cited in Gabel (1994:113).

Johnson (1976), Humphries, Johson and Johnson (1982), Lazarowitz (1991), Lazarowitz et al. (1985), Lazarowitz and Karsenty (1990), cited in Gabel (1994:113), found that studies performed in science classrooms with junior and senior high school students showed that, when a co-operative learning approach was implemented, students' academic achievement, inquiry skills and self-esteem increased; their on-task behavior was higher; and the classroom learning environment became more positive.

Slavin (1984) cited in Gabel (1994:79) reviewed 46 studies of learning in groups. He found that 29 studies showed co-operative learning to have a significantly positive effect on student achievement, 15 studies showed no difference, and two studies showed significantly higher achievement for a control group than for a co-operative group.

In co-operative learning, students take responsibility for their own learning and become actively involved (Cooper,1995:162). Instead of being passive listeners to their teachers, students are free to be learners, that is to study, ask and seek knowledge, and to interact with their fellow students and with teachers. They are responsible for their own learning (Gabel, 1994: 114).

Teamwork enables students to get to know each other, and it teaches students to work with others (Gibbs, 1995:6; Johnson and Johnson 1985; cited in Gabel 1994:79), noted that when students were working together they could resolve controversies during their interaction. This would result in students sharing ideas with one another, and they could work together to obtain a final solution to a problem.

When students work together as a team, the larger and more complex work - as well as the open-ended tasks - can be tackled more easily than when students work alone (Gibbs,1995:6). The group will tend to be able to accomplish more than the individuals because of the cross-fertilization of ideas that result from their interaction (Cooper,1995:162).

Students who are average and weak tend to benefit when they work in a group because they get the opportunity to study with others who are more able. This can be helpful and stimulating. They can observe how successful students go about their work and this may result in them gaining informal peer tutoring and peer feedback (Gibbs,1995:6).

Students who normally have a withdrawal attitude in the traditional classroom may become actively involved when they work in a smaller group. Traditional classroom practices sometimes tend to favour the more assertive student. In co-operative learning participation is encouraged in a group of non-competitive peers. It may also help remove stereotyping by race, sex or background (Cooper,1995:162).

Co-operative learning aims to enhances positive interdependence among members of the group. Members of a group may come to an understanding that they have a responsibility towards other members of the group. Members of the group should come to recognize that every one in the group shares a common fate: "We sink or swim together" (Johnson, Johnson and Holubec, 1994:6).

Among the research on classroom environments, the work on the relative effectiveness of co-operation in learning stands out because of the volume of studies completed, e.g. Johnson and Johnson (1987), cited in Gabel (1994:506). While many past studies found that cooperative learning is more successful than competitive learning or individualistic learning, the evidence is not always consistent. In a study involving an analysis of 122 studies Johnson et al (1981), cited in Gabel. (1994:506), showed that co-operative learning approaches yield more positive results on student achievement than the other methods, but not even this impressive synthesis is totally conclusive and generalizable.

During the past few decades, many science teachers have proposed co-operative learning to enhance learning in the science classroom, for example Chang and Mao (1999:340) and Brombacher (2000:9). It stems from the idea that it is a basic part of our survival as a species to lead co-operative lifestyles (Sunday Times 2000:2). Researchers have compared the outcomes of co-operative strategies to the more traditional teaching method (which is 'chalk and talk teaching') - showing mixed results. Some found that co-operative learning strategies enhanced learning and positive student attitudes (Hall and McCurdy, 1990; Geban, Askar and Ozkan, 1992). By contrast, other studies showed that this teaching strategy had no significant effects on enhancing learning and student attitudes, as reported in Germann (1989).

There is also the negative side of co-operative learning. The progress of hardworking and good students can be retarded by poor or lazy students (Gibbs,1995:6). Lazy students might 'hitchhike' on good students' work (Cooper,1995:162). The problem of social slackness can come to the fore. This occurs when individual members of a group reduce their effort, which results in many members of the group working less hard (Johnson, Johnson and Holubec,1994: 38). In a distinctive task, when all members receive benefits if one member does it, this could lead to free riding or getting something for nothing (Johnson, Johnson and Holubec,1994: 38).

When individuals work alone they are free to undertake every aspect of an assignment themselves, and they are free to learn about every possible angle; but when they work in a group, they may learn to undertake only one or two components and learn less about the others (Gibbs,1995: 6). When a group is too large, it may cause each member to participate less (Johnson, Johnson and Holubec,1994: 39).

2.7 Gayford's Theory

2.7.1 Group solving approach

Gayford (1989) investigated a methodology for the teaching and subsequent assessment of group problem-solving activities with pupils of 15 years of age in selected schools in the United Kingdom.

Gayford first reviewed other approaches before implementing into the group problem-solving approach. He discovered that motivation by pupils did not mean that valuable learning took place. In one particular experience, after following a problem-solving approach in a physics course for several years, although there was a great deal of enthusiasm from pupils, nevertheless there was little evidence of scientific activity when they engaged in their work (Wiltshire County Council, 1986: 7). In that case pupils showed a predominantly intuitive approach.

Gayford concluded that certain types of problem-solving may have a negative effect on pupils' understanding of the nature of the scientific activity by emphasizing the intuitive component at the expense of proper measurement and evaluation.

In other cases Gayford argued that, where pupils were given problems to solve, there was a tendency to set the problem and then expect pupils to work towards a solution, using a logical methodology, rather than basing their approach on intuition.

In reality, he says, pupils who lacked the requisite training seemed quickly to fall back on non-scientific approaches. He then formulated a study (Gayford: 1989) in which pupils were assessed while they were engaged in open-ended problem-solving activities in small co-operative groups. The nature of students' work in small groups was observed in this study and the adoptions of spontaneous leadership styles were identified. These different styles appeared also to have an important positive effect on the learning and motivation of all members of the group. He further stated that one of the important outcomes of a problem-solving approach was that it could be used to help encourage co-operation amongst pupils working in groups, but it can be lost if traditional methods of individual assessment were persisted with. He further argued that the ability to work as a member of a team was becoming increasingly important in situations out of school and there were good reasons why this should be encouraged in a variety of ways within schools. He also added that, unless assessment and evaluation of pupil performance were to include dimensions relating to group work, then it was unlikely that this aspect of a child's development would be neglected, probably in favour of more individualistic and more competitive aspects of education.

2.7.2 Leadership within study groups

In 1992 Gayford pursued the study of Solomon (1989) who studied the overt performance of pupils carrying out practical work in groups. Solomon's emphasis was more on a study of the pupils' social behavior, such as group dynamics, instead of on their task-related behavior. However Gayford reasoned that social behavior and task-related behavior are linked.

The 1992 study of Gayford was to see whether there was evidence for identifiable and repeatable styles of leadership and behavior within groups when solving problems. It also sought to determine whether such patterns of behavior, if they existed, had a constant effect on learning and motivation.

Gayford studied 421 15-year-old British students who were involved with problem-solving activities. The pupils selected their own groups. They were encouraged to work in groups of four but there were also three pupils in a group. There were altogether 104 groups in total but 68 were classified in the same way. The five main styles of group behavior were identified and classified as follows:

Type A: The leader plans without involving the others in the group and then proceeds to do most of the work, but tells the others what he/she is doing. He/she may enlist the help of others from time to time. The leader does most of the work.

Type B: The leader does most of the planning and then explains to the others what needs to be done. He/she then directs the work of the group.

Type C: The leader discusses a plan with the rest of the group and then negotiates with members of the group their individual roles in completing the task.

Type D: There is a degree of discussion in which there is no clearly identifiable leader. A course of action emerges and then the group contributes as a team with a degree of consensus. All contribute as a team. There is no obvious leader.

Type E: One or two students, not necessarily the leader, carry out most of the work whilst others watch, criticize or advise.

Significant differences occurred between those who worked in ‘democratic teams’

(Type D groups) and those who worked with 'dominating leaders' Type A groups, ($p<0.05$) and also those who worked under the direction of 'critical group members' (Type E; groups, $p<0.05$). There was also a significant difference between groups with 'negotiated' leadership (Type C groups) and groups with 'dominating leaders' (Type A group $p<0.05$).

This 1992 study of Gayford showed that particular styles of group behavior and leadership often appeared to be consistent and were related to both the learning that took place and the motivation of the students. Gayford also suggested that, since pupils usually work within the class in groups, it would be wise to consider ways of promoting appropriate group behavior to help optimize learning.

Gayford also concluded by referring to the claim of Kuhn(1962) that scientific investigation also involves groups of teams of workers; and he argued that co-operation and team work, as well as effective leadership are likely to be qualities of importance amongst scientists.

2.7.3 Eight skills emerging from discussion-based learning in science

In 1993 Gayford made a study in which he concluded that discussion-based learning is an effective method for providing students with the opportunity to develop learning skills which have a wide application across the curriculum.

Gayford studied 472 15-year-old British students. They were divided into 62 groups, with four to five students per group. The topics under discussion were: (a) the generation and use of nuclear energy, and (b) noise pollution.

Of the 12 skills mentioned in the NCC Curriculum Guidance document NO 7 (1990b), Gayford's study identified eight skills which were related directly to discussion-based learning.

The eight skills were:

Communication skills

1. Expressing views and ideas about the environment through different media including oral communication.
2. Arguing clearly and concisely about an environmental issue.

Numeracy skills

3. Analyzing data.
4. Interpreting statistics.

Study skills

5. Interpreting and evaluating information about the environment from a variety of sources.
6. Identifying the causes and consequences of environmental problems.
7. Forming reasoned opinions and developing balanced judgement about environmental issues.

Personal and social skills

8. Working co-operatively with others.

Gayford concluded that a discussion-based approach was successful in developing these eight skills, identified as part of the non-statutory guidance for environmental education across the curriculum. It enabled teachers to address controversial areas of the science curriculum in an appropriate way and students who were usually restless, and who found concentration difficult, were well involved in the task. Motivation was an important. element. The students clearly enjoyed this type of activity and readily responded to it.

2.7.4 Group learning versus individual learning in science

In 1995, Gayford worked with 216 16-year-olds in schools in the U.K.
He used the Greenhouse effect as a case study. Students were invited to consider the nature of the phenomenon and then had to identify the various contributing social and other issues.

As an approach to learning one of the objectives of this study was to provide an opportunity for students to share information and ideas within peer groups in order to enable them to refine their own concepts.

Gayford studied two types of groups:

(a) an experimental group who experienced the *group learning* approach, and

(b) a control group who worked with materials similar to those of the experimental group, but whose members worked *individually*, asking clarification from the teacher whenever they wished.

Gayford reasoned that the basic theory of group work requires an approach in which teachers refrain from using their positions of authority in the classroom to promote particular opinions, but the students are left free to explore their own individual ideas, but in the context of the ideas of their peers as well. It is essential that the teacher gives an input of information on which students can draw, and which requires them to practice critical and analytical abilities.

Gayford showed from the results that those students who worked in small peer groups learned more effectively than those who worked individually. The majority of students, particularly the lower 50 percent in terms of ability, performed significantly better in the experimental group where discussion was encouraged. From the behavior of the groups it was also observed that a considerable amount of learning was occurring which was related mainly to the more able and more knowledgeable students explaining information to others.

Gayford also suggested that the communication of ideas by the more knowledgeable students was unlikely to be only a one way beneficial process, since explaining their understanding of the issues to their less able peers may have helped *to clarify further their own understanding*.

Gayford concluded that the *amount of questioning* and *answering* that was possible in the experimental groups was *far greater* than would have been possible with a more traditional teacher-led session. The opportunity to challenge assumptions and clarify ideas was far greater.

It was also observed that *motivation* was considerably higher among the experimental groups, and this would have consequences for subsequent learning.

2.8 Implication for this dissertation

In Part B an overview has been presented of the comparison effects of teaching students as group clusters, as pairs or as individuals. The implications of these findings for the development of this dissertation are as follows:-

- Swain (1999:389) worked with 131 Egyptian science teachers on a burning candle and found that pair work provided optimum conditions for participant effort and productiveness of ideas, while whole class talk was more focused and more productive in terms of individual ideas, and covered a greater percentage of possible ideas. Therefore this investigation will work with grade 12 physical science students from South Africa to find the effectiveness in teaching and testing of individuals, pairs and group clusters, but on the topic electrochemistry.

PART C - PRE-TESTING AND POST-TESTING

2.9 Literature on pre-tests and post-tests conducted in chemistry and group work:

Smith (1972:113) conducted an achievement pre-test and post-test with many junior high school students in chemistry. He found that: (1) In nearly every case on the pre-test, the number of students demonstrating the ability to transfer the statement increased with the number of concepts attained within the statement. (2) Teaching the specific concepts missed in the pre-test resulted in a significant percentage of learners being able to transfer the rules and statements which contain the concepts in the post-test.

In a pre- and post test study conducted by Gayford (1995:139) on their knowledge of the greenhouse effect, using an experimental group (clusters) and control group (individuals), the statistically significant difference between the groups was $p<0.05$ (Siegel, 1956).

2.10 Chapter summary

This chapter comprised three sections - Part A, Part B and Part C.

In Part A the teaching of electrochemistry was discussed and students' misconceptions and misunderstandings were identified.

In Part B group learning as well as individual learning were discussed as well as the opinions and findings of many researchers on the subject

In Part C the implementation of pre-tests and post-tests in chemistry was discussed.

The implications of the findings of these earlier studies for the development of the dissertation were summarised.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the overall methods used in the study. It outlines the procedure followed by the three pilot studies leading to the final formulation of the questionnaire, the procedure followed in conducting the formative pre-tests and summative post-tests, the methodology engaged for the supplementary teaching assistance programme; and the methods adopted for the quantitative and qualitative analyses.

3.2 Implementation of the experimental design

The investigation involved 760 Grade 12 boys and girls in the age range 16-18 years in twenty three schools in the Western Cape, South Africa.

Tables 3.1 to 3.3 summarise details of the samples, the different formats of tests utilised, the number of schools, the geographical areas in which the testing was administered and the times of the testing and re-testing..

Table 3.1 : Administrative details of the three pilot studies

Study undertaken	No.of schools	Areas in the Western Cape	No.of students	Dates of testing
Pilot study no.1	3	Lansdowne, Maitland	63	April 2000
Pilot study no.2	2	Rondebosch East, Wetton	34	May 2000
Pilot study no.3	3	Claremont, Mitchells Plain	79	May 2000

Table 3.2 : Administration of the first formative pre-test (phase 1)

Study undertaken	No.of schools	Areas in the Western Cape	No.of students	Dates of testing
Formative pre-test	10	Mitchells Plain, Pinelands, Wynberg, Retreat, Athlone Khayelitsha, Cape Town.	437	July 2000 to September 2000

Table 3.3 Administration of the second formative pre-test and the summative post-test (phase2)

Study undertaken	No.of schools	Areas in the Western Cape	No.of students	Dates of testing
Formative pre-test	5	Mitchells Plain, Athlone, Wynberg.	147	March 2001 to May 2001
Summative post-test	5	Mitchells Plain, Athlone Wynberg	147	March 2001 to May 2001

3.3 The graded measures

Students, who had already completed the chapter on electrochemistry with their respective teachers, were invited to progress through a succession of graded diagnostic, piloted and refined evaluative tasks and questions. These are reproduced in Figure 3.1. These tasks were designed to evaluate the students' understanding of the operational details of a large picture of a Galvanic electrochemical zinc-copper cell (Figure 3.2), and a redox table with the EMF values of 48 chemical elements (Figure 3.3). These tasks comprised both the formative pre-test and the summative post-test.

3.4 The development of the formative and summative evaluative tasks and questions

In January 2000 the various misunderstandings and misconceptions which students experience in electrochemistry were identified by the researcher through the various findings of researchers. The following items were identified as the main items with which students find problems with :

(a) Identification of the differences between the anode and the cathode, (Garnett and Treagust,1992b:1079; Sanger and Greenbowe,1997b:820; Ogude,1991:110).

(b) Student understanding of oxidation-reduction equations, (Garnett and Treagust, 1992a:121).

(c) The function of the salt bridge (Sanger and Greenbowe,1997:377; Ogude and Bradley,1998:116; Ogude and Bradley cited in Sanger and Greenbowe,1997b:820); Garnett and Treagust, cited in Sanger and Greenbowe,1997b:820).

The formative pre-test was formulated using the following reference works:

Items 1,2,3,4,5.1,5.2 : Garnett and Treagust (1992b:1085), van Zyl (1999:374-391).

Items 10.1,10.2,10.3 :Garnett and Treagust (1992a:124), Sanger and Greenbowe (1997a:382-384), Jordaan and Jordaan (1999).

Item 9 : Garnett and Treagust (1992b:1085), Sanger and Greenbowe (1997a:382-384), Bester (1997:45), Jordaan and Jordaan (1999).

Items 6,7,8 : van Zyl et al (1999:374-389), Jordaan and Jordaan (1999).

3.5 Pilot studies

Three pilot studies were conducted in order to identify and reduce possibly faulty wording in the draft versions of the formative pre-test.

Pilot study no.1

The first pilot study was conducted using version 1 (Appendix 1) with 63 students for the purpose of trialing the wording of each diagnostic question for clarity, accuracy, ambiguity, etc. For example, Question no.6 required revision. Many students gave the answer as 'positive and negative electrode' or 'anode and cathode' instead of naming the metals. The question was changed to read: "Question 6: Complete the empty spaces in this statement by *writing down the names of the metals.*"

Pilot study no.2

In the second pilot study the revised version (Appendix 2) of the electrochemistry test was administered to a different sample of 34 students. It was found that question no.9 had too little space available for supplying the four required answers. Additional writing space was made available for the next version of the diagnostic electrochemistry test.

Pilot study no.3

In the third pilot study the revised version (Appendix 3) of the electrochemistry test was administered to a new sample of 79 students. They were grouped according to the three intended types of experimental arrangements. It was found that there was little difference between the achievement scores of *individuals, pairs* and *cluster groups* on each of the short answer questions. It was decided to add more open-ended questions: -

Question 11. What will happen if the salt bridge is removed (2 marks)

and

Question 12. How might the electrochemical cell be used in the technological world/industries? (7 marks).

Thus version no.4 , the formative/summative evaluation test (Figure 3.1) constituted the final version of the data collection instrument. This will also be known as "the full achievement test", totalling 30 marks. It includes the three "component tests" each worth 6 marks, an open-ended question worth 7 marks as well as other questions concerning electrochemistry worth 5 marks.

3.6 Null hypotheses

Phase 1 : Sample 1 (n = 437)

Formative achievement only

Ho1 When 437 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour, there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on :

(a) the full achievement test (scored out of 30);

(b) the component test of understanding of the anode and the cathode (scored out of 6);

(c) the component test of understanding of oxidation-reduction equations (scored out of 6);

(d) the component test of the understanding of the functions of the salt bridge (scored out of 6);

(e) the open ended question (scored out of 7).

Phase 2 : Sample 2 (n = 147)

- **Formative pre-test:**

Ho2 When 147 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour, there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on :

(a) the full achievement test (scored out of 30);

(b) the component test of understanding of the anode and the cathode (scored out of 6);

(c) the component test of understanding of oxidation-reduction equations (scored out of 6);

(d) the component test of the understanding of the functions of the salt bridge (scored out of 6).

(e) the open ended question (scored out of 7)

- **Summative Post-test:**

Ho3 After the 147 participant students complete a 30 minute supplementary programme of assisted-teaching in electrochemistry, and they are then re-grouped to study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on

(a) the full achievement test (scored out of 30);

(b) the component test of understanding of the anode and the cathode (scored out of 6);

(c) the component test of understanding of oxidation-reduction equations (scored out of 6);

(d) the component test of the understanding of the functions of the salt bridge (scored out of 6);

(e) the open ended question (scored out of 7).

- **A comparison of the pre-test formative to post-test summative electrochemistry performance score gains made by different sized groups under a programme of supplementary intervention instruction**

Ho 4 After 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, between the three types of instructional grouping arrangement on :-

(a) the full achievement test (scored out of 30) by:

(i) the individuals
(ii) the pairs
(iii) the cluster groups;

(b) the component test of understanding of the anode and the cathode (scored out of 6)

by:

(i) the individuals
(ii) the pairs
(iii) the cluster groups;

(c) the minor component of understanding of oxidation-reduction equations (scored out

of 6) by:

(i) the individuals
(ii) the pairs
(iii) the cluster groups;

(d) the component test of understanding of the functions of the salt bridge (scored out of

6) by:

(i) the individuals
(ii) the pairs
(iii) the cluster groups; and

(e) the open ended question (scored out of 7) by:

(i) the individuals
(ii) the pairs
(iii) the cluster groups

3.7 Procedure

3.7.1 The following experimental procedure was adopted for the administration of both pre-tests:

Instructions to the teacher.

The class is to be divided randomly into a system of three groupings. For example, as the students come into the classroom they are to be divided into various groups; or they are to be divided into their groups as they sit at their desks.

The students are to be divided in the following ways:

(1) working as individuals; or

(2) working as pairs; or

(3) working in clusters;

For example: If we take a class of 30 students there will be:

- one group composed of ten individuals: 1x10 = 10 students; plus
- one group composed of five pairs: 5 x 2 = 10 students; plus
- one group of five students composed of two clusters: 2 x 5 = 10 students.

Instructions given orally to the class (after they have been formed into groups):

The formative evaluation:

Step1: On your desk/table you will find two things: a large picture of a zinc-copper electrochemical cell, as well as redox table of EMF values of the 48 chemical elements.

Step2: Have you seen this apparatus before? Yes/No. If you have not, we will teach you the working by the end of the lesson.

Step3: Any questions?

Step4: Pick up you pen/pencil.

Step5: Pick up the worksheet, which contains 15 questions, and answer them on the sheet in spaces provided.

If you want to change your written answer to a question, cross it out and re-write your answer on the bottom of page 4 in the blank space provided.

If you are in a big group, appoint only one student to do the written work, and one student who will dictate the groups' agreed answer to the student writer.

If you are working in pairs, one student must do the writing and one should do the dictation to the other.

If you are working on you own, you are not allowed to discuss the questions with anybody until after you are told to do so.

Step6: Write the following clearly on your answer sheet:

Your names / nicknames

Male / female (next to your name / nickname)

Your intended career.

Step7: Any questions?

Step8: You may start by answering the questions on the answer sheet.

The class teacher or/and the researcher will move around in the classroom to see that the correct procedure is followed.

3.7.2 The completion of the formative and summative assessment sheets

The pre- and post-test assessments were completed by the students as follows :

- The first formative pre-test Figure 3.1 was administered on **white** paper to the first sample of 437 students.

  Each individual student completed his/her own worksheet

  Only one of the students in the student pairs filled in the worksheet for both partners.

  In the group clusters one person filled in the worksheet for the whole group.

- The second formative pre-test Figure 3.1 was administered on **yellow** paper to the second sample of 147 students.

  Each individual completed his/her own worksheet

  Both students in all the student pairs completed his/her own worksheet after the discussion was complete.

  Every student in the group clusters filled in his/her own worksheet personally after the group discussion was complete.

- The summative post-test Figure 3.1 was administered on **green paper** to the second sample of 147 students

A similar administrative procedure was followed for the post-test as for the pre-test.

3.7.3 The numbers of completed worksheets obtained were as follows:

- From the first formative pre-test :

  Individuals : 99 students handed in 99 answer sheets.

  Student pairs: 86 students handed in 43 answer sheets.

  Group clusters: 252 students handed in 66 answer sheets.

- From the second formative pre-test :

  Individuals : 49 students submitted 49 answer sheets.

  Student pairs : 48 students submitted 48 answer sheets.

  Group clusters : 50 students submitted 50 answer sheets.

  All second pre-test questionnaires/ answer sheets were *yellow* in colour to distinguish between the pre-test and post-test answer sheets.

- From the summative post-test :

  Individuals : 49 students handed in 49 answer sheets.

  Student pairs: 48 students handed in 48 answer sheets.

  Group clusters: 50 students handed in 50 answer sheets.

  All post-test questionnaires/ answer sheets were *green* in colour. to distinguish between the pre-test and post-test answer sheets.

3.7.4 The final version of the assessment worksheet used for the formative pre-test and the summative post-test evaluation

This is reproduced in Fig. 3.1 on the pages which follows, including the diagram of the Cu-Zn cell, the table of standard electrode potentials and the mark memorandum.

Figure 3.1 The formative and summative assessment materials

ELECTROCHEMICAL CELL (GALVANIC) ANSWER SHEET

Write all YOUR answers on the question paper in the spaces provided.

Good Luck!

Answer the following questions about the cell experiment when it is operating under normal circumstances:

1. Using the six labels provided in the diagram, say which metal is the cathode?

....(1)

2. Is this metal cathode the negative or positive electrode of the cell?

....(1)

3. Of the six labels provided in the diagram, say which metal is the anode?

....(1)

4. Is this metal anode the negative or positive electrode of the cell?

....(1)

5. Choose the correct word in brackets by writing your selected answer in the space provided: -

5.1 The anode is the electrode at which (oxidation / reduction) takes place.

....(1)

5.2 The cathode is the electrode at which (oxidation/reduction) takes place.

....(1)

6.Complete the empty spaces in this statement by writing down the *names of the metals*: -

Current flows from the...............electrode to the ....electrode (2)

7. Read the following list of different forms of energy: kinetic; heat; light; chemical; potential; electrical; nuclear.

Now select two of these forms of energy and write them down in the missing spaces in the following sentences:

In this electrochemical cell ....potential energy is converted

to .... potential energy. (2)

8. Which of the two metals undergoes an observable increase in mass while the cell functions after a few minutes at room temperature?

....(1)

9. Suggest as many different functions of the salt bridge as you can.

....

....

....

....

....

....

....

....

....

....(4)

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction...(1)

10.2 The oxidation half reaction...(1)

10.3 The balanced cell (or redox) reaction

....(4)

11. What will happen if the salt bridge is removed?

....

....

....

....(2)

12. How might the electrochemical cell be used in the technological world/

industries?

....

....

....

....

....

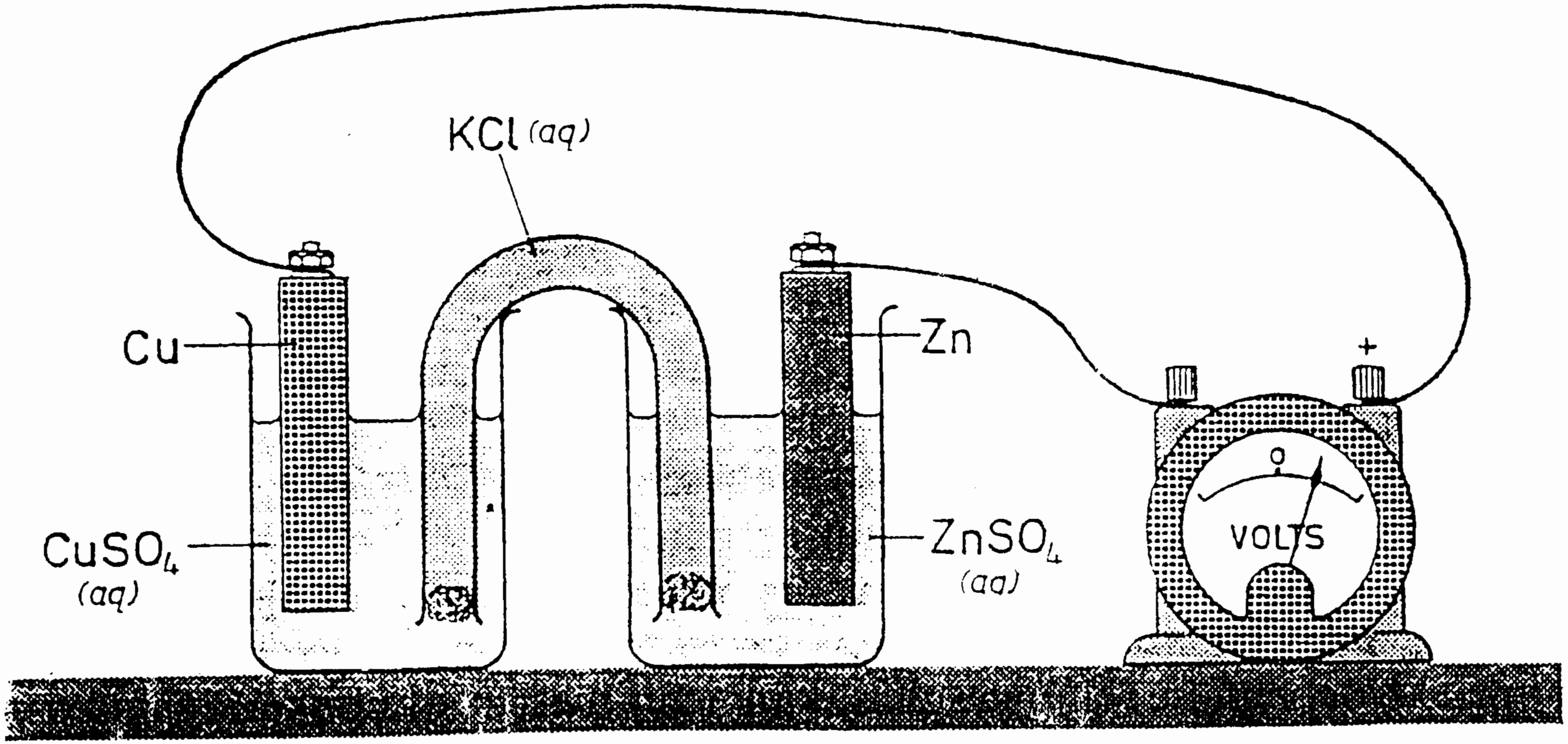
....(7)

Total: 30 marks

List several careers in science / technology in which you will be interested in to pursue your future:
e.g. food technician: Antarctic meteorologist; rust proofing expert: paint technologist: etc.

Name/Nickname:	Gender:	Career:
....	....	1..
		2..
		3..
		4..
		5..
		6..

Figure 3.2 Cu-Zn Cell



The following diagram represents a Cu-Zn cell under standard conditions

TABEL 5B : STANDAARD ELEKTRODEPOTENSIALE
TABLE 5B : STANDARD ELECTRODE POTENTIALS

Halfreaksie / Half-reaction	$E^\ominus$ / volt
$Li^+ + e^- \rightleftharpoons Li$	−3,05
$K^+ + e^- \rightleftharpoons K$	−2,93
$Cs^+ + e^- \rightleftharpoons Cs$	−2,92
$Ba^{2+} + 2e^- \rightleftharpoons Ba$	−2,90
$Sr^{2+} + 2e^- \rightleftharpoons Sr$	−2,89
$Ca^{2+} + 2e^- \rightleftharpoons Ca$	−2,87
$Na^+ + e^- \rightleftharpoons Na$	−2,71
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	−2,37
$Al^{3+} + 3e^- \rightleftharpoons Al$	−1,66
$Mn^{2+} + 2e^- \rightleftharpoons Mn$	−1,18
$2H_2O + 2e^- \rightleftharpoons H_2 + 2OH^-$	−0,83
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	−0,76
$Cr^{3+} + 3e^- \rightleftharpoons Cr$	−0,74
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	−0,44
$Co^{2+} + 2e^- \rightleftharpoons Co$	−0,28
$Ni^{2+} + 2e^- \rightleftharpoons Ni$	−0,25
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	−0,14
$Pb^{2+} + 2e^- \rightleftharpoons Pb$	−0,13
$Fe^{3+} + 3e^- \rightleftharpoons Fe$	−0,04
$2H^+ + 2e^- \rightleftharpoons H_2$	0,00
$S + 2H^+ + 2e^- \rightleftharpoons H_2S$	+0,14
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0,15
$Cu^{2+} + e^- \rightleftharpoons Cu^+$	+0,16
$SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons SO_2 + 2H_2O$	+0,17
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0,34
$2H_2O + O_2 + 4e^- \rightleftharpoons 4OH^-$	+0,40
$Cu^+ + e^- \rightleftharpoons Cu$	+0,52
$I_2 + 2e^- \rightleftharpoons 2I^-$	+0,54
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0,68
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0,77
$Hg^{2+} + 2e^- \rightleftharpoons Hg$	+0,79
$NO_3^- + 2H^+ + e^- \rightleftharpoons NO_2 + H_2O$	+0,80
$Ag^+ + e^- \rightleftharpoons Ag$	+0,80
$NO_3^- + 4H^+ + 3e^- \rightleftharpoons NO + 2H_2O$	+0,96
$Br_2 + 2e^- \rightleftharpoons 2Br^-$	+1,09
$MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	+1,21
$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$	+1,23
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1,33
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1,36
$Au^{3+} + 3e^- \rightleftharpoons Au$	+1,50
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1,51
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1,77
$F_2 + 2e^- \rightleftharpoons 2F^-$	+2,87

Memorandum

1. Cu (1)

2. Positive electrode (1)

3. Zn (1)

4. Negative electrode (1)

5.1 Oxidation (1)

5.2 Reduction (1)

6. Zinc electrode to the copper electrode (1 + 1 = 2)

7. Chemical potential energy to electrical potential energy. (1 + 1 = 2)

8. Copper (1)

9. It provides an electrical connection between the two half cells of a voltaic cell.

It keeps the two electrolytes separate so that they do not mix.

It ensures that the positive and negative charges are equal at all times during the operations of a galvanic cell.

It acts as a pathway in which ions can move to ensure electrical neutrality in the electrolytes in both half cells, i.e. it acts as an ion exchanger. (4 x 1 = 4)

10.1 $Cu^{2+} + 2e^- \rightarrow Cu$ (1)

10.2 $Zn \rightarrow Zn^{2+} + 2e^-$ (1)

10.3 $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$ (4 x 1 = 4)

11. The reading on the voltmeter will be zero(0)

There will be no movement of electrons from the zinc electrode to the copper electrode

The circuit is no longer complete (2 x 1 = 2)

12.

- Electro-plating : covering metals or other conducting materials with a thin layer of metal,
- Preparation of one of the following elements:

  Iodine

  Copper

  Chlorine gas can be prepared from chloride.

  Aluminium can be extracted electrolytically from melts.
- Batteries / dry cells
- Production of *caustic soda,* which is an important chemical for the manufacture of paper, rayon and photographic film.
- Electrolysis is used in the electrolytic furnace to manufacture :

  Magnesium

  Sodium
- Electrolytic methods are used to refine:

  Lead or Tin

  Gold and silver (1 mark for each metal/product)

The answers were categorized as follows:

Anode and cathode functions:

Questions: 1,2.3,4, 5.1 and 5.6 (6 marks)

Oxidation-reduction equations:

Questions: 10.1, 10.2, and 10.4 (6 marks)

The salt bridge:

Questions: 9 and 11 (6 marks)

The open ended question

Question: 12 (7 marks).

3.8 The methodology for the supplementary programme of re-teaching with sample 2.

In **phase 2** a total sample of 147 participant students undertook a 30 minute supplementary programme of assisted teaching in electrochemistry immediately after they had been formatively pre-tested. This intervention programme was conducted by the invited researcher, during normal scheduled school lesson time, in five different schools. Details of the re-teaching programme are summarised in Table 3.4.

Table 3.4 : Lesson plan summary for the supplementary programme of re-teaching.

Subject Content	Teaching Method	Teaching Apparatus
Apparatus of the Zn-Cu cell.	Teacher explains the apparatus to the class by pointing to the labels on the picture	Practical apparatus in front of class: 2 glass beakers; zinc and copper plate; $CuSO_4$ and $ZnSO_4$ U-tube filled with KCl cotton wool, electric wire voltmeter; picture of apparatus as well as Table of standard Electrode Potentials for each student.
Oxidation and reduction	Teacher informs class about the differences between oxidation and reduction. Teacher uses flash-cards with the words LEO and GER to explain the differences. Teacher writes LEO and GER on board and asks pupils to write answer next to it.	Flashcards on board. LEO- loss of electrons oxidation; GER-gain of electrons reduction

Subject content	Teaching Method	Teaching Apparatus
Anode and cathode	Teacher uses flashcards to explain the difference between the anode and the cathode.	AA- Anode electrons move away CT- Cathode electrons move towards
Anode-Oxidation negative electrode	The teacher uses the flashcards to show the relationship between the anode, oxidation and the negative electrode	LEO-loss of electrons oxidation ↓ ↓ AA- Anode electrons move away ↓ ↓ Negative electrode

Subject content	**Teaching method.**	**Teaching apparatus**
Cathode-reduction Positive electrode	The teacher uses flashcards to show relationship between the cathode, reduction and the positive electrode	GER- gain of electrons reduction ↓ ↓ CT – cathode electrons move towards ↓ ↓ Positive electrode
Flow of the electric current	Teacher informs class that the flow of the electric current takes place from the zinc plate to the copper plate. Teacher points out that students must look at the voltmeter which will indicate the direction of the electric current. Teacher let students deduce which of the two metals is the anode and which is the cathode. Teacher guides students to the correct answer.	Apparatus of Zn-Cu cell. Flashcards as indicated above.

Subject Content	Teaching method	Teaching Apparatus
$Cu^{2+} + 2e^- \rightarrow Cu$ $Zn \rightarrow Zn^{2+} + 2e^-$ $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$	Teacher explains to class the oxidation half-reaction of Zn and the reduction half-reaction of Cu. Teacher uses the deductive method to find the net reaction. Teacher guides students to the correct answer.	Chalkboard.
Function of the saltbridge	Teacher removes the salt-bridge and asks the class what they observe. Teacher then leads class to the correct answers.	Zn- Cu cell apparatus.
Uses of electrochemistry in the industry.	Teacher replaces the voltmeter with a small electric bulb. Teacher asks class to observe electric bulb Teacher leads class to various uses of electro - chemistry in the industries	Zn-Cu cell apparatus. Small electric bulb.

3.9 Proposed treatment of the data

3.9.1 Analysis of the test results : quantitative

- **Formative pre-test assessment of the first sample of 437 students**

An ANOVA F ratio will be used to determine whether the differences in achievement between the three types of grouping arrangement (individuals; student pairs; group clusters) are significant for the following aspects of formative assessment:

(a) For the total electrochemistry test (scored out of 30);

(b) For the component test of the understanding of the anode and the cathode (scored out of 6);

(c) For the component test of understanding of oxidation-reduction equations (scored out of 6);

(e) For the component test of the understanding of the functions of the salt bridge (scored out of 6); and

(e) For the open ended question (scored out of 7).

- **Formative pre-test assessment with the second sample of 147 students**

An ANOVA F ratio will be used to determine whether the differences in achievement between the three types of grouping arrangement (individuals; student pairs; group clusters) are significant for the following aspects of formative assessment:

(a) For the total electrochemistry test (scored out of 30);

(b) For the component test of the understanding of the anode and the cathode (scored out of 6);

(c) For the component test of understanding of oxidation-reduction equations (scored out of 6);

(d) For the component test of the understanding of the functions of the salt bridge (scored out of 6); and

(e) For the open ended question (scored out of 7).

- **Summative post-test assessment with the second sample of 147 students**

An ANOVA F ratio will be used to determine whether the differences in achievement between the three types of grouping arrangement (individuals; student pairs; group clusters) are significant for the following aspects of the summative assessment:

(a) For the total electrochemistry achievement test (scored out of 30);

(b) For the component test of the understanding of the anode and the cathode (scored out of 6);

(c) For the component test of understanding of oxidation-reduction equations (scored out of 6);

(d) For the component test of the understanding of the functions of the salt bridge (scored out of 6); and

(e) For the open ended question (scored out of 7).

- **The 147 students' gains in achievement from the formative pre-test to the summative post-test**

(a) A t-test will be used to determine the significance of the pre-test to post-test gains in achievement scores on the *full chemistry test* for the following:

(i) the individuals

(ii) the student pairs

(iii) the group clusters.

(b) A t-test will be used to determine the significance of the pre-test to post-test gains in achievement scores on the *student understanding of the anode and the cathode* for the following:

(j) the individuals

(ii) the student pairs

(iii) the group clusters.

(c) A t-test will be used to determine the significance of the pre-test to post-test gains in achievement scores on the *student understanding of oxidation-reduction equations* for the following:

(i) the individuals

(ii) the student pairs

(iii) the group clusters.

(d) A t-test will be used to determine the significance of the pre-test to post-test gains in achievement scores on the *student understanding of the functions of the salt bridge* for the following:

(i) the individuals

(ii) the student pairs

(iii) the group clusters.

(e) A t-test will be used to determine the significance of the pre-test to post-test gains in achievement scores on the *student understanding of the open ended question* for the following:

(i) the individuals

(ii) the student pairs

(iii) the group clusters.

Note : When scores are found to be skew , i.e. non-normally distributed, a statistically less stingent chi-square significance test will used.

3.9.2 Analysis of test results: qualitative (error analysis)

Students' responses will be analyzed under the following:

(1) evidence of conceptual difficulties

(2) evidence of perceptual difficulties

(3) students' misunderstandings of the functions of the anode and the cathode

(4) students' misunderstandings of the oxidation-reduction equations

(5) students' misunderstandings of the functions of the salt bridge

(6) students' misunderstandings of the open ended question

3.10 Chapter summary

This chapter has presented and described the administration and purpose of three pilot studies, the procedure for administering the two pre-tests as well as describing the details, methodology and procedure of the supplementary programme of re-teaching the function of the Zn-Cu galvanic electrochemical cell. It also described the intended procedures for the analysis of the investigation.

The results and findings of the investigation will follow in **chapter 4.**

CHAPTER 4

PRESENTATION AND ANALYSIS OF THE RESULTS

4.1 Introduction

This chapter comprises three sections A, B and C. Section A reports the quantitative findings of the empirical study undertaken to examine the differences between the electrochemistry pre-test scores achieved by a cohort of 437 physical science students when they were randomly seperated and tested formatively either in an individual mode, or in a pair mode, or in a group cluster mode. The cohort was drawn from ten secondary schools in the Western Cape of South Africa. The statistical analysis testing the hypotheses detailed in Chapter 3 is presented.

Section B reports the effects of a supplementary programme of additional instructional intervention. It presents the formative and summative scores obtained by a second cohort of 147 students when they were both pre-tested and post- tested either in an individual mode (twice), or in a pair mode (twice) or in a group cluster mode (twice) in five high school in the Western Cape, South Africa. The improved results of the post-test are interpreted to be a reflection of the effectiveness of the re-teaching programme which was commenced and conducted for 20 – 30 minutes after the pre-test had been administered.

Section C presents the qualitative findings obtained for the 14 items in the electrochemistry test from students in both cohorts.

A discussion of the results contained in this chapter, and an attempt to provide answers to the research questions posed at the beginning of the investigation will follow in Chapter 5. A presentation of the implications of the results, as well as a summary, conclusions and recommendations will follow in Chapter 6.

The preliminary findings reported in this chapter have already been refereed and published in the proceedings of the Patt International Conference on Technology Education (2001:173-178). A copy of this paper is attached in Appendix 5.

Note: In this chapter, t-test results are reported, assuming normal distributions for compared scores. For clearly non-normally distributed scores, Fisher's z-transformations have not been used, since this calculation modification was not available on the Statistica package utilised. Instead, less stingent chi-square tests have been employed.

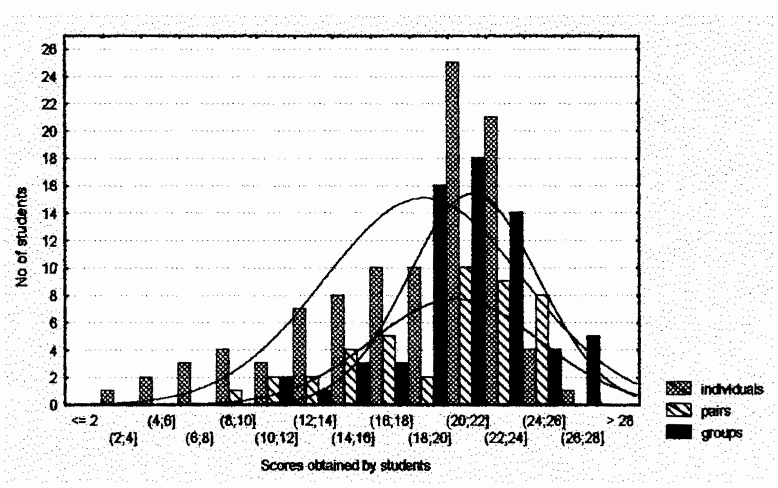
4.2 SECTION A Formative Pre-testing of 437 students (cohort 1)

4.2.1 Null hypothesis Ho1 a states that when 437 students are randomly arranged in groups to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the full electrochemistry achievement test (scored out of 30).

Table 4.1 Achievement scores in the *full electrochemistry test* (out of 30) obtained by 437 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 99 individuals (n = 99)	Mode 2 43 student pairs (n = 86)	Mode 3 66 clusters of 3-6 students (n = 252)
Mean $\pm$ SD 18.75 $\pm$ 5.22	Mean $\pm$ SD 20.40 $\pm$ 4.42	Mean $\pm$ SD 21.30 $\pm$ 3.41
$F = 6.557$; $p < 0.01$; significant difference Scheffe$_{1\,3}$ $p < 0.01$; significant difference		

Figure 4.1 Simplified plot of distributions of scores obtained by the **individuals, pairs and group clusters** in their *full electrochemistry* test scored out of 30



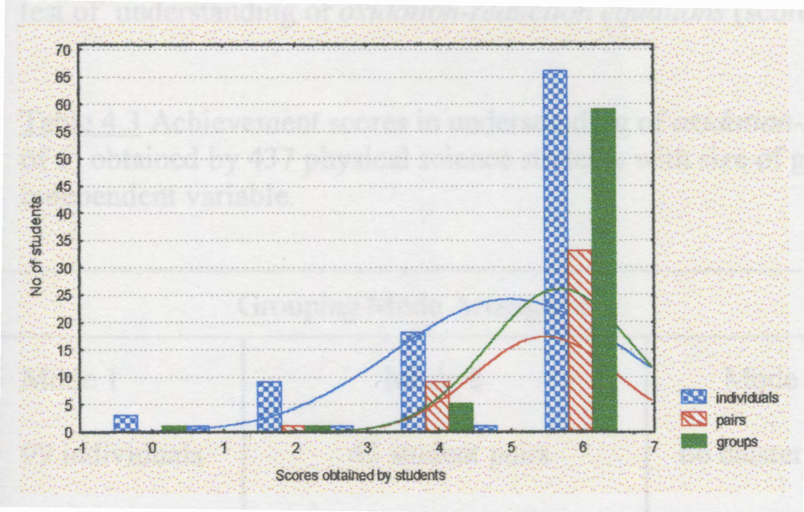
Null hypothesis Ho1 a is partially tenable. Table 4.1 and Figure.4.1 present the results of the achievement scores obtained by the cohort of 437 physical science students according to grouping mode *in the full electrochemistry achievement test.* It is found that there that are no significant difference in achievement between grouping **mode 1(individuals)** and grouping **mode 2 (pairs)** as well as grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters)**. *However there is a significant difference in achievement between grouping **mode 1 (individuals)** and grouping **mode 3 (group clusters).** The **group clusters** have the highest average achievement mark followed by the **student pairs** and then the **individuals.***

4.2.2 Null hypothesis Ho1 b states: When 437 students are randomly arranged in groups to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of the *anode* and the *cathode* (scored out of 6);

Table 4.2 Achievement scores in understanding of the *anode* and *cathode* (out of 6) obtained by 437 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 99 individuals (n = 99)	Mode 2 43 student pairs (n = 86)	Mode 3 66 clusters of 3-6 students (n = 252)
Mean + SD 5.00 $\pm$ 1.62	Mean $\pm$ SD 5.48 $\pm$ 0.98	Mean $\pm$ SD 5.69 $\pm$ 1.00
F = 5.796; $p < 0.01$; significant difference Scheff'e$_{1\ 3}$ $p < 0.01$; significant difference		

<u>Figure 4.2</u> Simplified plot of the distributions of scores obtained by the **individuals, pairs** and **groups clusters** in their understanding of *anode* and *cathode* scored out of 6.



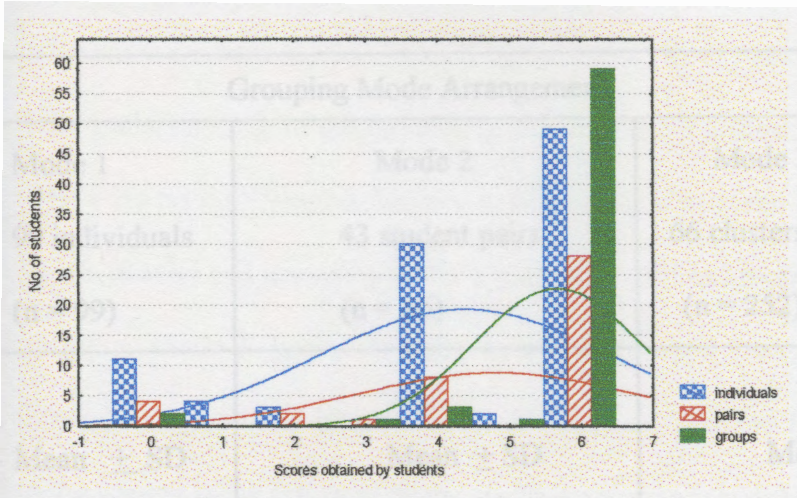
Null hypothesis Ho1 b is partially tenable Table 4.2 and Figure 4.2 present the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of the *anode and the cathode* according to grouping mode. It is found that there is no significant difference in achievement between grouping **mode 1 (individuals)** and grouping **mode 2 (pairs)** as well as grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters).** However there *is a significant difference in achievement between grouping **mode 1 (individuals)** and grouping **mode 3(group clusters).** The **group clusters** have the highest average achievement mark followed by the **student pairs** and then the **individuals**.*

4.2.3 Null hypothesis Ho1 c states: When 437 students are randomly arranged in groups to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of *oxidation-reduction equations* (scored out of 6).

Table 4.3 Achievement scores in understanding of *oxidation-reduction equations* (out of 6) obtained by 437 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 99 individuals (n = 99)	Mode 2 43 student pairs (n = 86)	Mode 3 66 clusters of 3-6 students (n = 252)
Mean $\pm$ SD 4.38 $\pm$ 2.04	Mean $\pm$ SD 4.81 $\pm$ 1.93	Mean $\pm$ SD 5.66 $\pm$ 1.15
$F = 10.304$; $p < 0.001$; highly significant difference Scheffe$_{1\,3}$ $p < 0.001$; highly significant difference		

Figure 4.3 Simplified plot of the distributions of scores obtained by the **individuals, pairs** and **group clusters** in their understanding of the *oxidation-reduction equations* scored out of 6.



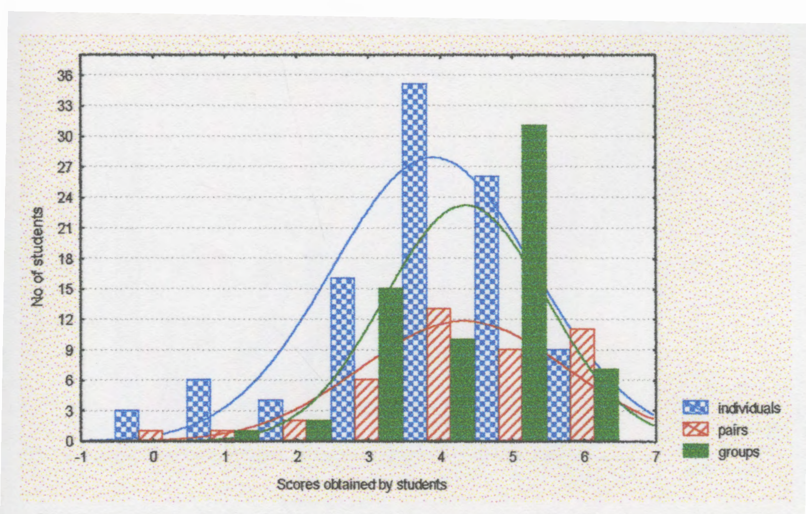
Null hypothesis Ho1 c is partly tenable. Table 4.3 and Figure 4.3 present the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of *oxidation-reduction equations* according to grouping mode. It is found that there is no significant difference in achievement between grouping **mode 1(individuals)** and grouping **mode 2 (pairs).** *However there is a highly significant difference in achievement between grouping* ***mode 1(individuals)*** *and grouping* ***mode 3 (group clusters)*** *and a significant difference between grouping* ***mode 2 (pairs)*** *and grouping* ***mode 3 (group clusters).*** *The* ***group clusters*** *have the highest average achievement mark followed by the* ***student pairs*** *and then the* ***individuals.***

4.2.4 Null hypothesis Ho1 d states: When 437 students are randomly arranged in groups to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of the *functions of the salt bridge* (scored out of 6).

Table 4.4 Achievement scores in understanding of the functions of the *salt bridge* (out of 6) obtained by 437 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 99 individuals (n = 99)	Mode 2 43 student pairs (n = 86)	Mode 3 66 clusters of 3-6 students (n = 252)
Mean $\pm$ SD 3.89 $\pm$ 1.41	Mean $\pm$ SD 4.32 $\pm$ 1.44	Mean $\pm$ SD 4.35 $\pm$ 1.13
F = 2.827; p = 0.0614; no significant difference		

Figure 4.4 Simplified plot of the distributions of scores obtained by the **individuals, pairs** and **group clusters** in their understanding of the functions of the *salt bridge* scored out of 6.



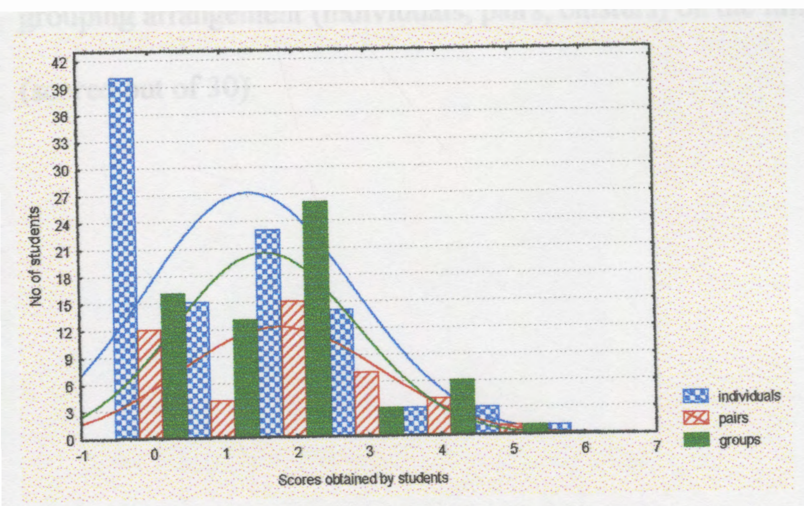
Null hypothesis Ho1 d is partly tenable. Table 4.4 and Figure 4.4 present the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of the *function of the salt bridge* according to grouping mode. There are no significant difference in achievement between grouping **mode 1 (individuals)** and grouping **mode 2 (pairs)** as well as grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters)** as well as *between grouping **mode 1 (individuals)** and grouping **mode 3 (group clusters)**. The **group clusters** have the highest average achievement mark followed by the **student pairs** and then the **individuals**.*

4.2.5 Null hypothesis Ho1 e states: When 437 students are randomly arranged in groups to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in the formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the test of student understanding of the *open ended question* (scored out of 7).

Table 4.5 Achievement scores in understanding of the *open- ended question* (out of 7) obtained by 437 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 99 individuals (n = 99)	Mode 2 43 student pairs (n = 86)	Mode 3 66 clusters of 3-6 students (n = 252)
Mean $\pm$ SD 1.37 $\pm$ 1.44	Mean $\pm$ SD 1.76 $\pm$ 1.39	Mean $\pm$ SD 1.66 $\pm$ 1.41
F = 1.474; p = 0.231; no significant difference		

Figure 4.5 Simplified plot of the distributions of scores obtained by the **individuals, pairs** and **group clusters** in their understanding of the *open ended question* scored out of 7



Null hypothesis Ho1 e is partly tenable Table 4.5 and Figure 4.5 present the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of the *open ended question*. It is found that there is no significant difference in achievement between grouping **mode 1 (individuals)** and grouping **mode 2 (pairs)** and grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters)** and grouping **mode 1(individuals)** and grouping **mode 3 (group clusters).** All students scored a low mark in this section. *The **student pairs** have the highest average achievement mark followed by the **group clusters** and then the **individuals**.*

4.3 SECTION B : PART 1 : Formative testing of 147 students (cohort 2)

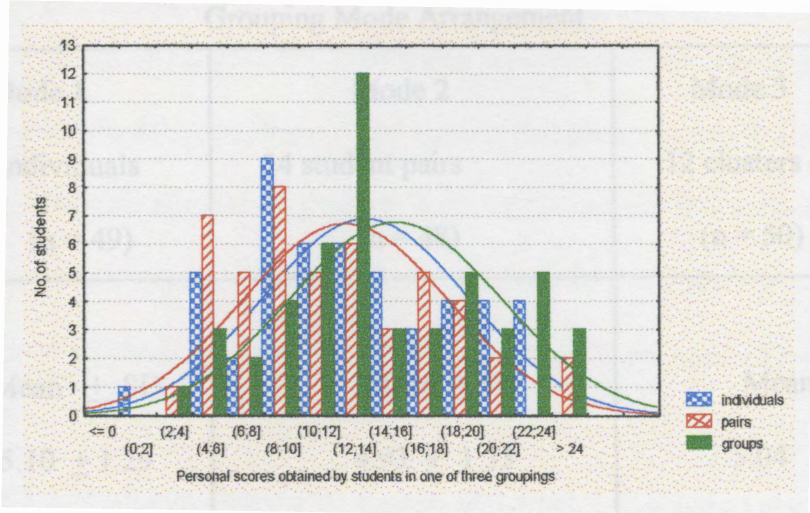
Note: Students in cohort 2 were tested both formatively and summatively.

4.3.1 Null hypothesis Ho2 a states that when 147 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the full achievement test (scored out of 30).

Table 4.6 Pre-test achievement scores in the *full electrochemistry test* (out of 30) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 24 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 13.67 $\pm$ 5.66	Mean $\pm$ SD 12.54 $\pm$ 5.69	Mean $\pm$ SD 15.34 $\pm$ 5.89
$F = 2.945$; $p = 0.0557$; no-significant difference		

Figure 4.6 Simplified plot showing the pre-test achievement scores in the *full electrochemistry test* (out of 30) obtained by the **individuals, pairs and group clusters**



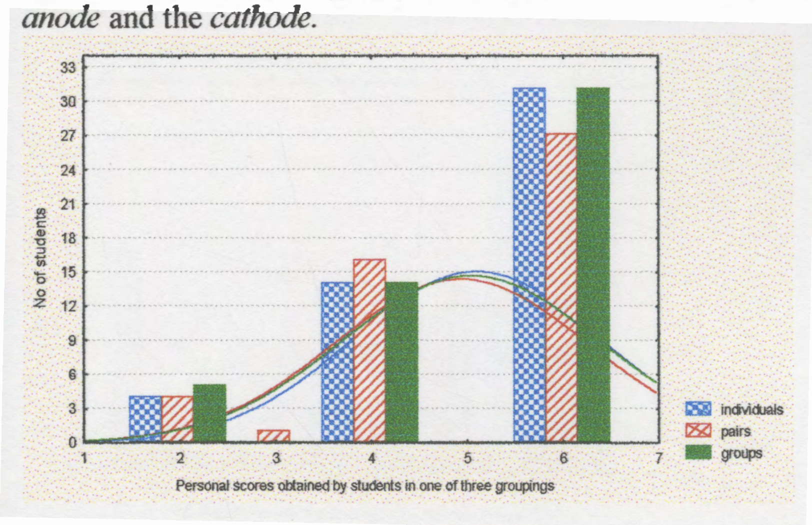
Null hypothesis Ho2 a is tenable. Table 4.6 and Figure 4.6 present the results of the personal achievement scores obtained by the cohort of 147 physical science students in their understanding of the *full chemistry test* according to grouping mode. There is no significant difference in achievement between grouping **mode 1 (individuals)** and grouping **mode 2 (pairs),** nor between grouping **mode 1 (individuals)** and grouping **mode 3 (group clusters),** nor between grouping ***mode 2 (pairs)*** *and grouping* ***mode3 (group clusters).*** *The* ***group clusters*** *have the highest average achievement mark, followed by the* ***individuals*** *and then by the* ***student pairs***.

4.3.2 Null hypothesis Ho2 b states that when 147 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of the *anode and the cathode* (scored out of 6).

Table 4.7 Pre-test achievement scores of understanding of the *anode* and *cathode* scored (out of 6) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 Individuals (n = 49)	Mode 2 24 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 5.10 $\pm$ 1.29	Mean $\pm$ SD 4.93 $\pm$ 1.33	Mean $\pm$ SD 5.04 $\pm$ 1.35
F = 0.190; p = 0.827; no significant difference		

Figure 4.7 Simplified plot showing the different scores obtained in a pre-test by the **individuals, pairs and group clusters** in their understanding of the function of the *anode* and the *cathode.*



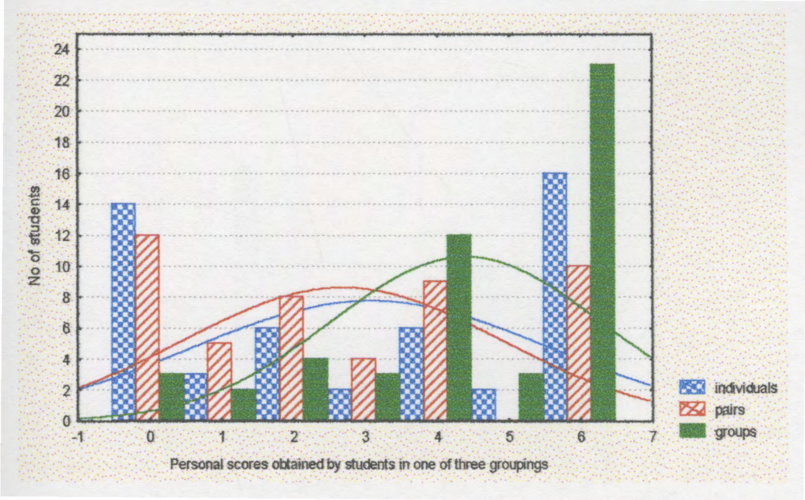
Null hypothesis Ho2 b is tenable. Table 4.7 and Figure 4.7 present the results of the achievement scores obtained by the cohort of 147 physical science students in a pre-test on their understanding of the *anode and cathode* according to grouping mode. There are no significant difference in achievement between grouping **mode 1 (individuals),** grouping **mode 2 (pairs)** and grouping **mode 3** ***(group clusters).*** An appreciable number of students scored full marks in this section. A small number of students scored a low mark. *The* ***individuals*** *have the highest average achievement mark followed by the* ***group clusters*** *and then by the* ***student pairs.***

4.3.3 Null hypothesis Ho2 c states that when 147 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of *oxidation-reduction equations* (scored out of 6).

Table 4.8 Pre-test achievement scores of understanding of the *oxidation-reduction* equation scored (out of 6) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 Individuals (n = 49)	Mode 2 24 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 3.08 $\pm$ 2.50	Mean $\pm$ SD 2.68 $\pm$ 2.21	Mean $\pm$ SD 4.40 $\pm$ 1.87
$F = 8.110$; $p < 0.01$; significant difference Scheffe $_{13}$ $p < 0.05$; significant difference Scheffe $_{23}$ $p < 0.01$; significant difference		

Figure 4.8 Simplified plot showing the different scores obtained in a pre-test by the **individuals, pairs and group clusters** in their understanding of the *oxidation-reduction equations.*



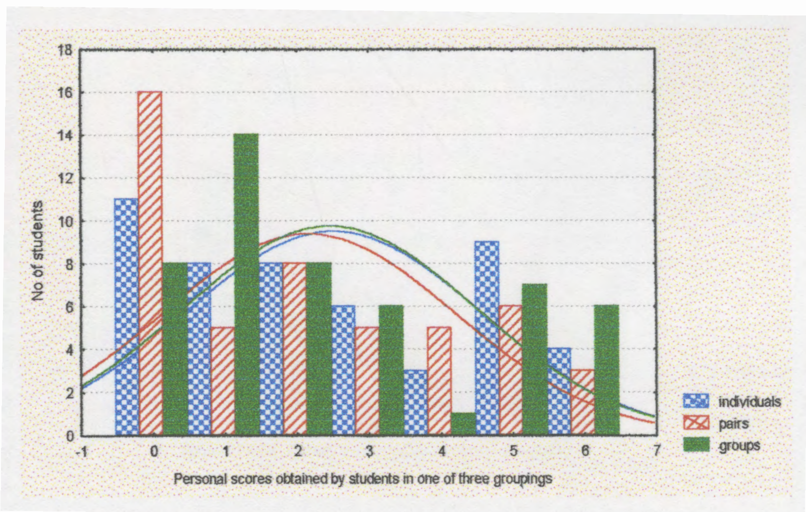
Null hypothesis Ho2 c is partially tenable. Table 4.8 and Figure 8 present the results of the achievement scores obtained by the cohort of 147 physical science students in a pre-test on their understanding of the *oxidation-reduction* equations according to grouping mode. There is no significant difference in achievement between grouping **mode 1(individuals)** and grouping **mode 3 (group clusters).** *However there is a significant difference between grouping* ***mode 1 (individuals)*** *and grouping* ***mode 3 (group clusters),*** *as well as between grouping* ***mode 2 (pairs)*** *and grouping* ***mode3 (group clusters).*** *The* ***group clusters*** *have the highest average achievement mark followed by the* ***individuals*** *and then the* ***student pairs.***

4.3.4 Null hypothesis Ho2 d states that when 147 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of the understanding of the *functions of the salt bridge* (scored out of 6) .

Table 4.9 Pre-test achievement scores of student understanding of the functions of the *salt bridge* scored (out of 6) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 24 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean ± SD 2.51 ± 2.05	Mean ± SD 2.16 ± 2.04	Mean ± SD 2.46 ± 2.04
F = 0.399; p = 0.671; no significant difference		

Figure 4.9 Simplified plot showing the different scores obtained in a pre-test by the **individuals, pairs and group clusters** in their understanding of the function of *the salt bridge.*



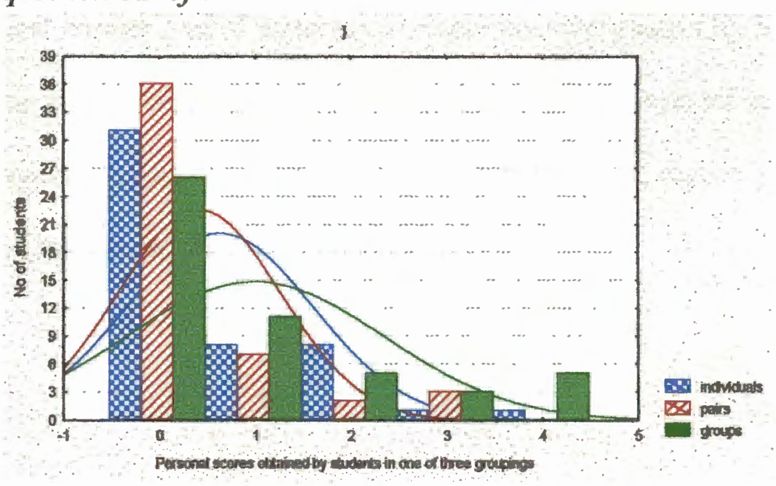
Null hypothesis Ho2 d is tenable. Table 4.9 and Figure 4.9 present the results of the achievement scores obtained by the cohort of 147 physical science students in a pre-test of their understanding of the functions of the *salt bridge* according to grouping mode. There are no significant difference between grouping **mode 1 (individuals),** grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters).** The majority of students scored a low mark in this section. ***The individuals** scored the highest average achievement mark followed by the **group clusters** and then the **student pairs.***

4.3.5 Null hypothesis Ho2 e states that when 147 students are randomly grouped to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in formative achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the open ended question (scored out of 7)

Table 4.10 Pre-test achievement scores in understanding of *the open ended* question (out of 7) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 Individuals (n = 49)	Mode 2 24 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 0.63 $\pm$ 0.98	Mean $\pm$ SD 0.42 $\pm$ 0.84	Mean $\pm$ SD 1.00 $\pm$ 1.34
$F = 3.685$ $p < 0.05$; significant difference Scheff'e$_{2\,3}$ $p < 0.05$; significant difference		

Figure 4.10 Simplified plot of the different scores obtained in a pre-test by the **individuals, pairs and group clusters** in their understanding of the *open ended question out of 7*



Null hypothesis Ho2 e is partially tenable. Table 4.10 and Figure 4.10 present the results of the achievement scores obtained by the cohort of 147 physical science students in a pre-test on their understanding of the *open ended question* according to grouping mode. There are no significant differences between grouping **mode 1 (individuals),** grouping **mode 2 (pairs)** nor grouping **mode 3 (group clusters);** *however there is a significant difference between grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters).*** The majority of students scored a low mark in this section. ***The group clusters** have the highest average achievement mark followed by the **individuals** and then the **student pairs.***

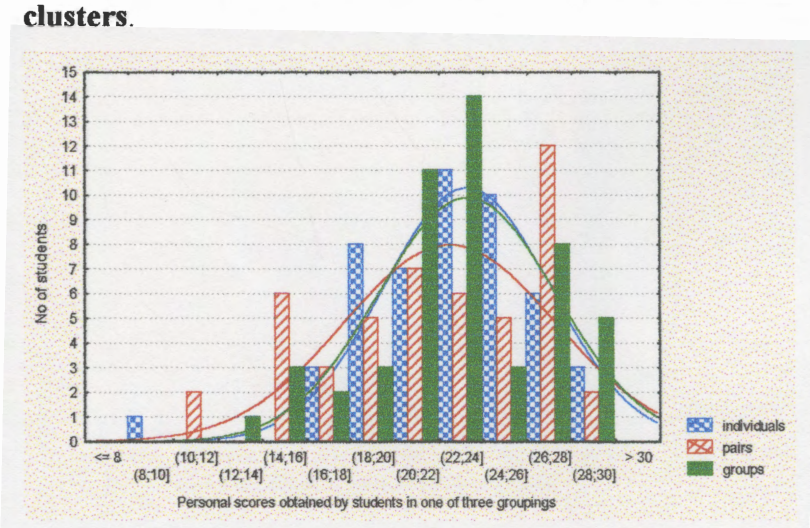
4.4 SECTION B : PART 2 :Summative testing of the 147 students (cohort 2)

4.4.1 Null hypothesis Ho3 a states that after the 147 participant students complete a 30 minute supplementary programme of assisted-teaching in electrochemistry, and they are then re-convened into their same groupings to study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in the post-test achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on *the full achievement test* (scored out of 30).

Table 4.11 Post-test achievement scores *in the full electrochemistry test* (out of 30) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 14 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 23.27 $\pm$ 3.79	Mean $\pm$ SD 22.50 $\pm$ 4.79	Mean $\pm$ SD 23.28 $\pm$ 4.02
F = 0.542; p = 0.582; no significant difference		

Figure 4.11 Simplified plot showing the post-test achievement scores in the *full electrochemistry test* (out of 30) obtained by the **individuals, pairs and group clusters**.



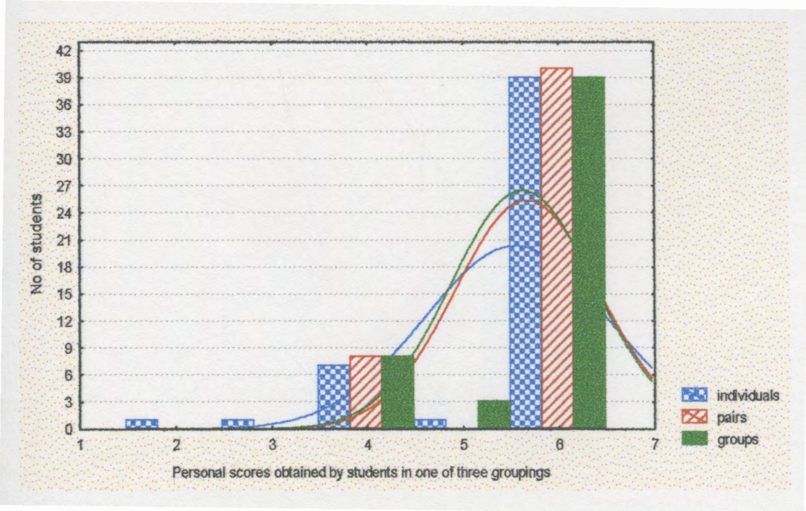
Null hypothesis Ho3 a is tenable. Table 4.11 and Figure 4.11 present the results of the achievement scores obtained by the cohort of 147 physical science students in the summative post-test for the *full electrochemistry test* according to grouping mode. There are no significant difference between grouping **mode 1 (individuals),** grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters).** The majority of students scored a high mark in this section. ***The group clusters** scored the highest average achievement mark followed by the **individuals** and then by the **student pairs.***

4.4.2 Null hypothesis Ho3 b states that after the 147 participant students complete a 30 minute supplementary programme of assisted-teaching in electrochemistry, and they are then re-convened in their same groupings to study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in the post-test achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of the *anode and the cathode* (scored out of 6).

Table 4.12 Post-test achievement scores of understanding of the *anode* and *the cathode* obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 24 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 5.55 $\pm$ 0.95	Mean $\pm$ SD 5.66 $\pm$ 0.75	Mean $\pm$ SD 5.62 $\pm$ 0.75
F = 0.240; p = 0.786; no significant difference		

Figure 4.12 Simplified plot showing the different scores obtained in a post-test by the **individuals, pairs and group clusters** in their understanding of *the anode and cathode.*



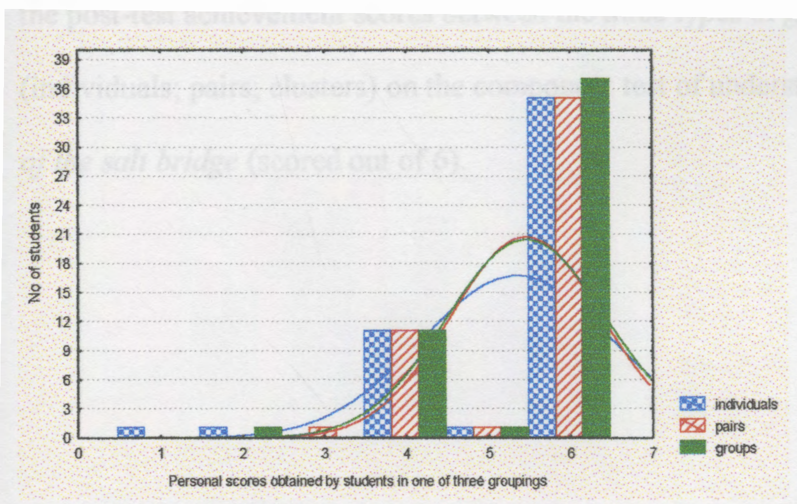
Null hypothesis Ho3 b is tenable. Table 4.12 and Figure 4.12 present the results of the achievement scores obtained by the cohort of 147 physical science students in the summative post-test on their understanding of the *anode and the cathode* according to grouping mode. There are no significant difference between grouping **mode 1 (individuals),** grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters).** The majority of students scored full marks. *The* ***student pairs*** *have the highest average achievement mark followed by the* ***group clusters*** *and then the* ***individuals.***

4.4.3 Null hypothesis Ho3 c states that after the 147 participant students complete a 30 minute supplementary programme of assisted-teaching in electrochemistry, and they are then re-convened into their same groupings to study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in the post-test achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding *of oxidation-reduction equations* (scored out of 6).

Table 4.13 Post-test achievement scores of understanding of the *oxidation reduction equations* obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 14 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 5.35 $\pm$ 1.16	Mean $\pm$ SD 5.45 $\pm$ 0.92	Mean $\pm$ SD 5.46 $\pm$ 0.97
F = 0.196; p = 0.822; no significant difference		

Figure 4.13 Simplified plot of the different scores obtained in a post-test by the **individuals, pairs and group clusters** in their understanding of the *function of the oxidation-reduction equation*.



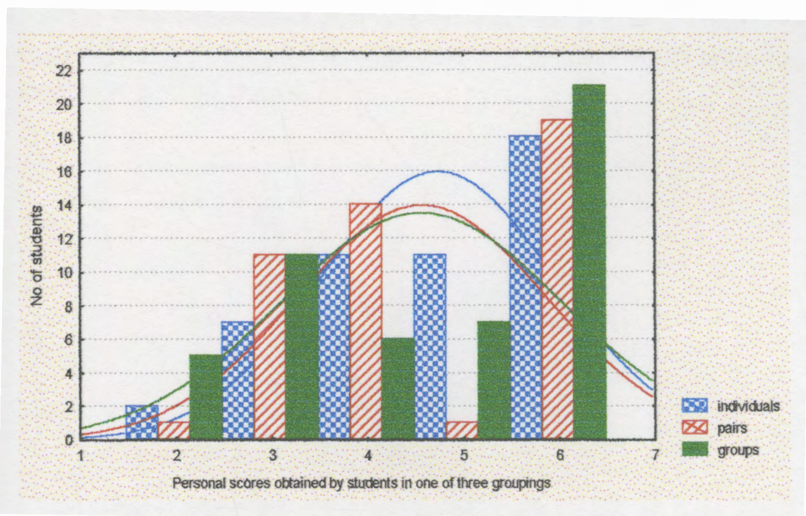
The null hypothesis Ho3 d is tenable. Table 4.13 and Figure 4.13 present the results of the achievement scores obtained by the cohort of 147 physical science students in the summative post-test of the understanding of the oxidation-reduction equations. There are no significant difference between grouping **mode 1(individuals),** grouping **mode 2 (pairs)** and grouping **mode 3 (group clusters).** The majority of students scored full marks, but a few mixed up the terms of oxidation and reduction and therefore lost two marks. *The **group clusters** scored the highest average achievement mark followed by the **student pairs** and then the **individuals.***

4.4.4 Null hypothesis Ho3 d states that after the 147 participant students complete a 30 minute supplementary programme of assisted-teaching in electrochemistry, they are then re-convened into their same groupings to study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in the post-test achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on the component test of understanding of the *functions of the salt bridge* (scored out of 6).

Table 4.14 Post-test achievement scores of understanding of the functions of the *salt bridge* obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 14 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 4.73 $\pm$ 1.22	Mean $\pm$ SD 4.41 $\pm$ 1.47	Mean $\pm$ SD 4.56 $\pm$ 1.47
F = 0.634; p = 0.531; no significant difference		

Figure 4.14 Simplified plot of the different scores obtained in a post-test by the **individuals, pairs and group clusters** in their understanding of the function of *the salt bridge*.



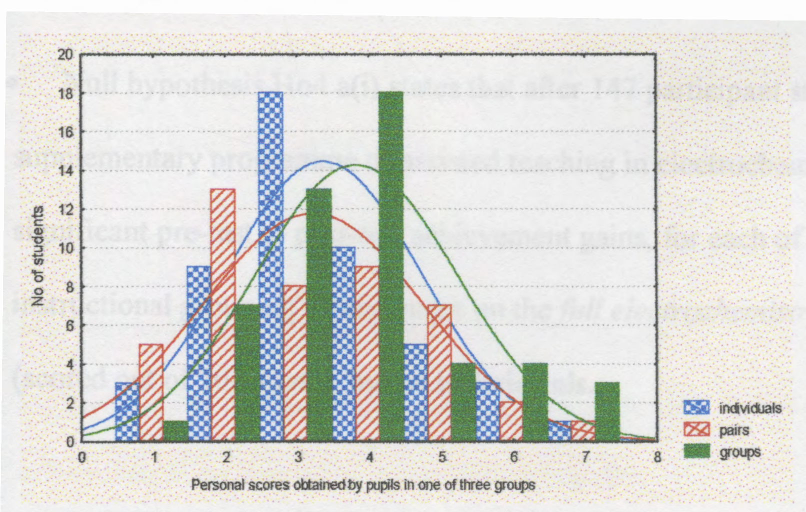
Null hypothesis Ho3 d is not tenable. Table 4.14 and Figure 4.14 presents the results of the achievement scores obtained by the cohort of 147 physical science students in the summative post-test of the understanding on the functions of the *salt bridge* according to grouping mode. There are no significant difference between grouping **mode 1 (individuals),** grouping **mode 2 (pairs)** and grouping **mode 3 (groups).** The results were evenly spread for all the groups. *The **individuals** have the highest average achievement mark followed by the **group clusters** and then the **student pairs.***

4.4.5 Null hypothesis Ho3 e states that after the 147 participant students complete a 30 minute supplementary programme of assisted-teaching in electrochemistry, and they are then re-convened into their same groupings study and answer graded materials in electrochemistry again for half an hour, there will be no significant differences in the post-test achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on *the open ended question* (scored out of 7).

Table 4.15 Post-test achievement scores of students' understanding of the *open ended* question (out of 7) obtained by 147 physical science students with size of grouping as an independent variable.

Grouping Mode Arrangement		
Mode 1 individuals (n = 49)	Mode 2 14 student pairs (n = 48)	Mode 3 12 clusters of 3-6 students (n = 50)
Mean $\pm$ SD 3.37 $\pm$ 1.34	Mean $\pm$ SD 3.02 $\pm$ 1.67	Mean $\pm$ SD 3.82 $\pm$ 1.39
F = 3.617 ; $p < 0.05$ significant difference scheffe'$_{2\,3}$ $p < 0.05$; significant difference		

Figure 4.15 Simplified plot of the different scores obtained in a post-test by the **individuals, pairs and group clusters** in their understanding of the *open ended question* scored out of 7.



The null hypothesis Ho3 e is partially tenable. Table 4.15 and Figure 4.15 present the results of the achievement scores obtained by the cohort of 147 physical science students in the summative post-test of the understanding of the open ended question according to grouping mode. There are no significant difference between grouping **mode 1 (individuals),**grouping **mode 2 (pairs)** as well as grouping **mode 1 (individuals)** and grouping **mode 3 (group clusters),** *however there is a significant difference between grouping* ***mode 2 (pairs)*** *and grouping* ***mode 3 (group clusterts).*** *The* ***group clusters*** *have the highest average achievement mark followed by the* ***individuals*** *and then the* ***student pairs.***

SECTION B : PART 3 : Pre-test to post-test gains (cohort 2)

4.5 Comparisons between the pre-test and post-test scores for cohort 2

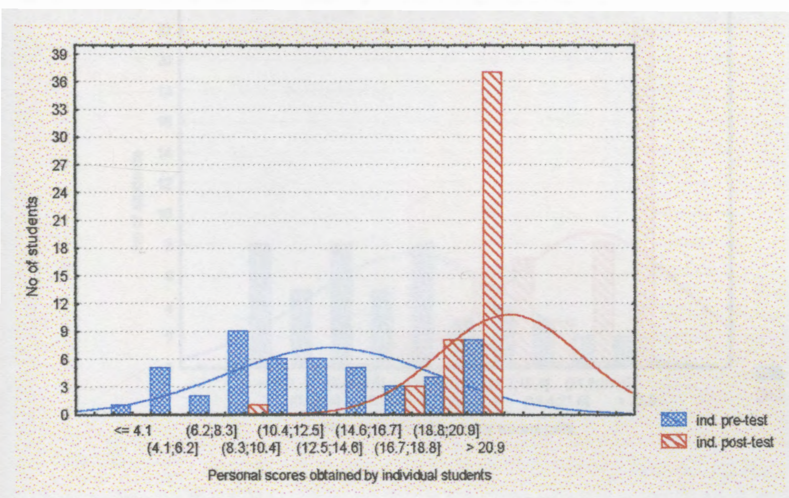
4.5.1 Achievement gains by the 147 students on the full electrochemistry knowledge test

- Null hypothesis Ho4 a(i) states that after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, for each of the three types of instructional grouping arrangement on the *full electrochemistry achievement test* (scored out of 30), firstly, by the **individuals.**

Table 4.16 t-tests analysis of the **49 individual** students mean pre-test to post-test gains in achievement scores on the *full electrochemistry test*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.30)	13.67	5.66	49		
Post-test (max.30)	23.27	3.79	49	9.85	<0.001
Mean achievement score gain	9.95				HSD

Figure 4.16 Simplified plot showing the achievement gains in respect to the pre-test and post-test scores of the **49 individuals** on the *full electrochemistry* test .



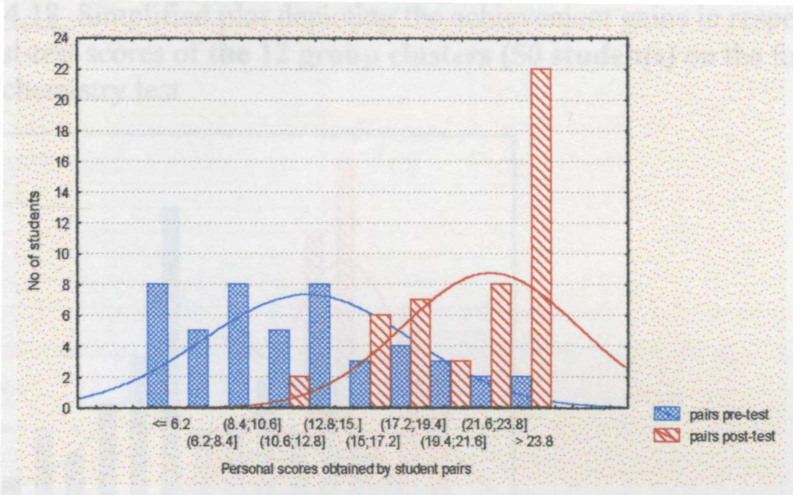
Null hypothesis Ho4 a(i) is not tenable. Table 4.16 and Figure 4.16 show that statistically *there is a highly significant difference between the pre-test and post-test scores for the* ***individuals.*** There is a highly significant improvement in the **49 individual** students' achievement scores on the full electrochemistry knowledge test.

- Null hypothesis Ho4 a(ii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, on the *full electrochemistry achievement test,* secondly, by the **student pairs.**

Table 4.17 t-tests analysis of the **24 students pairs' (48 students')** mean pre-test to post-test gains in achievement scores on the *full electrochemistry* knowledge test.

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.30)	12.54	5.69	48		
Post-test (max.30)	22.50	4.79	48	9.28	<0.001
Mean achievement score gain	9.96				HSD

Figure 4.17 Simplified plot showing achievement gains in respect to the pre-test and post-test scores of **24 student pairs (48 students)** on the *full electrochemistry* knowledge test



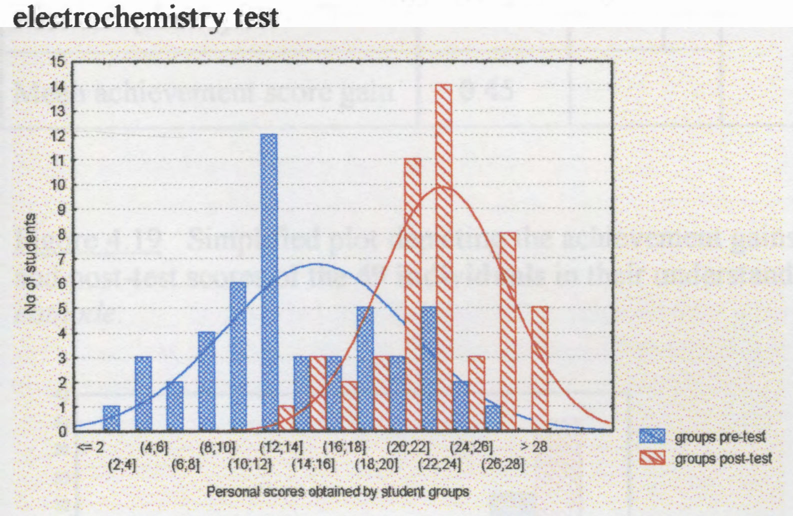
Null hypothesis Ho4 a(ii) is not tenable. Table 4.17 and Figure.4.17 show that *there is a highly significant difference between the pre-test and post-test scores for the **student pairs***. There is a statistically highly significant improvement in the **24 student pairs' (48 students')** achievement scores on the full electrochemistry knowledge test.

- Null hypothesis Ho4 a(iii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, *on the full electrochemistry achievement test* (scored out of 30), thirdly, by the **group clusters**.

Table 4.18 t-tests analysis of the **12 group clusters' (50 students')** mean pre-test to post-test gains in achievement scores on the *full electrochemistry* knowledge test

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.30)	12.54	5.69	50		
Post-test (max.30)	23.28	4.03	50	10.82	<0.001
Mean achievement score gain	10.74				HSD

Figure 4.18 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of **the 12 group clusters (50 students)** on the full electrochemistry test



Null hypothesis Ho4 a(iii) is not tenable. Table 4.18 and Figure.4.18 show that *there is a highly significant difference between the pre-test and post-test scores for the group cluster students*. There is a statistically highly significant improvement in the **12 group clusters' (50 students')** pre-test and post-test achievement scores on the full electrochemistry knowledge test.

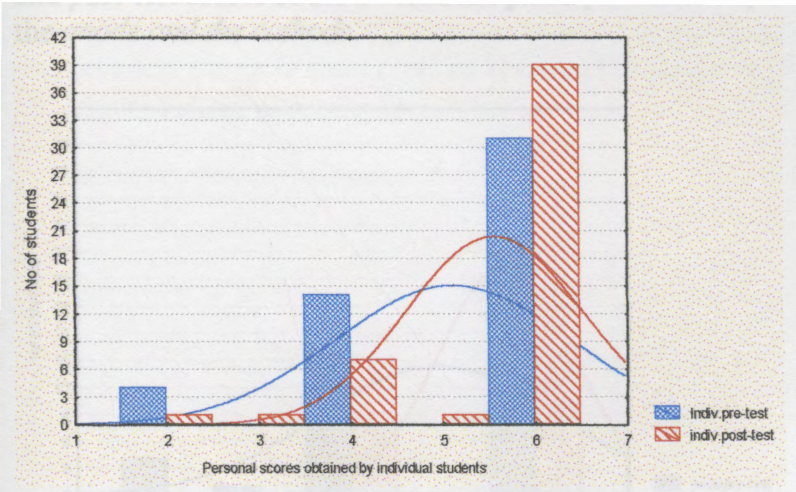
4.5.2 Achievement gains by the 147 students on the understanding of the anode and the cathode

- Null hypothesis Ho4 b(i) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, on the component test of understanding of the *anode and the cathode* (scored out of 6) by the **individuals**.

Table 4.19 Chi-square analysis of the **49 individuals'** mean pre-test to post-test gains in achievement scores in their understanding of the *anode and the cathode.*

Achievement variable	Mean	SD	n	chi-square value	p
Pre-test(max.6)	5.10	1.29	49		
Post-test (max.6)	5.55	0.93	49	2.45	0.12
Mean achievement score gain	0.45				NSD

Figure 4.19 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **49 individuals** in their understanding of the *anode* and the *cathode*.



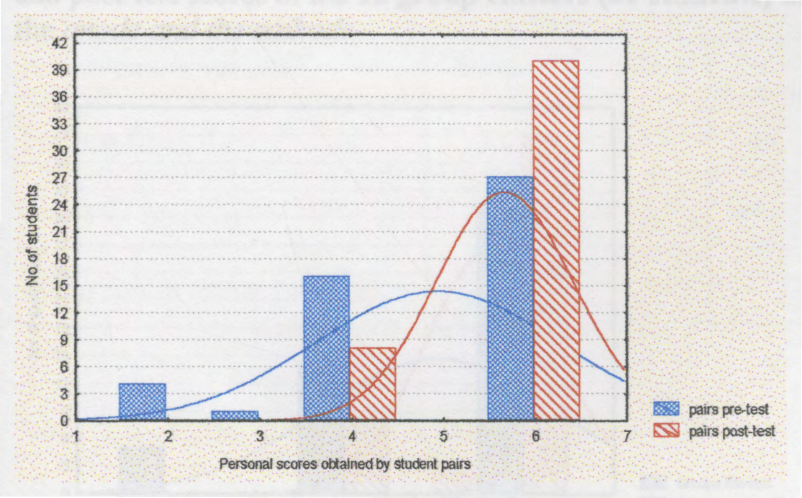
The null hypothesis Ho 4 b(i) is tenable. Table 4.19 and Figure 4.19 show that there is no significant difference between the pre-test and post-test scores for the **individuals** in their understanding of the *anode* and *cathode*. Because the scores are skewed , i.e. non-normally distributed, a chi-square significance test has been used.

- Null hypothesis Ho4 b(ii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains on the component test of understanding of the *anode and the cathode* (scored out of 6) by the **student pairs.**

Table 4.20 Chi-square analysis of the **24 student pairs' (48 students')** mean pre-test to post-test gains in achievement scores in their understanding of the *anode and the cathode*.

Achievement variable	Mean	SD	n	chi-square value	p
Pre-test(max.6)	4.93	1.33	48		
Post-test (max.6)	5.66	0.75	48	6.46	$p<0.05$
Mean achievement score gain	0.73				SD

Figure 4.20 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **24 student pairs (48 students)** in their understanding of the *anode and the cathode*.



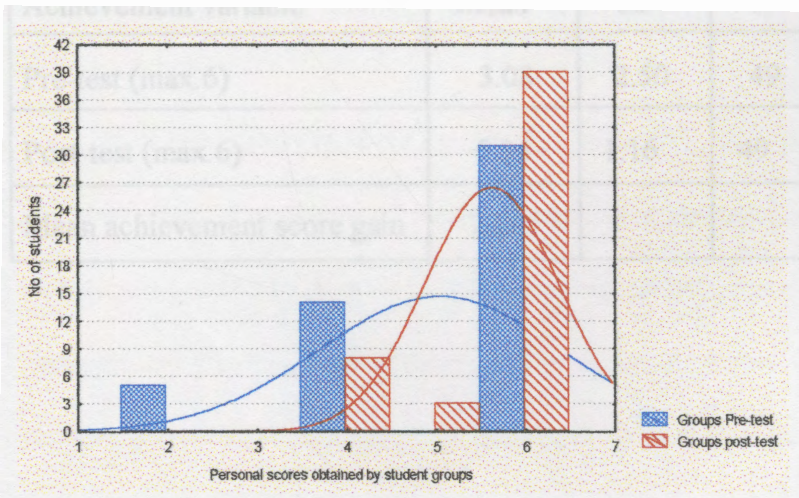
Null hypothesis Ho 4 b(ii) is not tenable. Table 4.20 and Figure 4.20 show that *there is a significant difference between the pre-test scores and post-test scores for* ***student pairs*** *in their understanding of the anode and cathode.*

- Null hypothesis Ho4 b(iii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the component test of understanding of the anode and the cathode (scored out of 6) by the group clusters.

Table 4.21 Chi-square analysis of the **12 group clusters' (50 students')** mean pre-test to post-test gains in achievement scores in their understanding of the *anode and the cathode*.

Achievement variable	Mean	SD	n	chi-square value	p
Pre-test(max.6)	5.04	1.35	50	2.33	0.13
Post-test (max.6)	5.62	0.75	50		
Mean achievement score gain	0.58				NSD

Figure 4.21 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **12 group clusters (50 students)** in their understanding of the *anode and the cathode*



Null hypothesis Ho 4 b(iii) is tenable. Table 4.21 and Figure 4.21 show that *there is no significant difference between the pre-test and post-test scores for the* ***group clusters*** *in their understanding of the anode and cathode.*

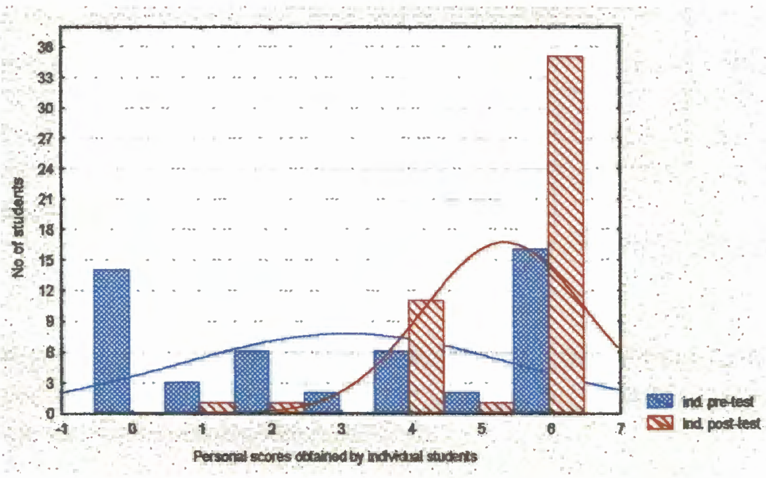
4.5.3 Achievement gains by 147 students on the understanding of the oxidation-reduction equations

- Null hypothesis Ho4 c(i) states, that after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the component test of understanding of the oxidation-reduction equations (scored out of 6) by the individuals.

Table 4.22 t-test and chi-square analysis of the **49 individuals'** mean pre-test to post-test gains in achievement scores in their understanding of the *oxidation-reduction equations*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.6)	3.08	2.50	49		
Post-test (max.6)	5.34	1.16	49	5.74	p<0.001
Mean achievement score gain	2.26				HSD
				chi-square	p<0.01
				13.25	HSD

Figure 4.22 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **49 individuals** in their understanding of the *oxidation-reduction equations*



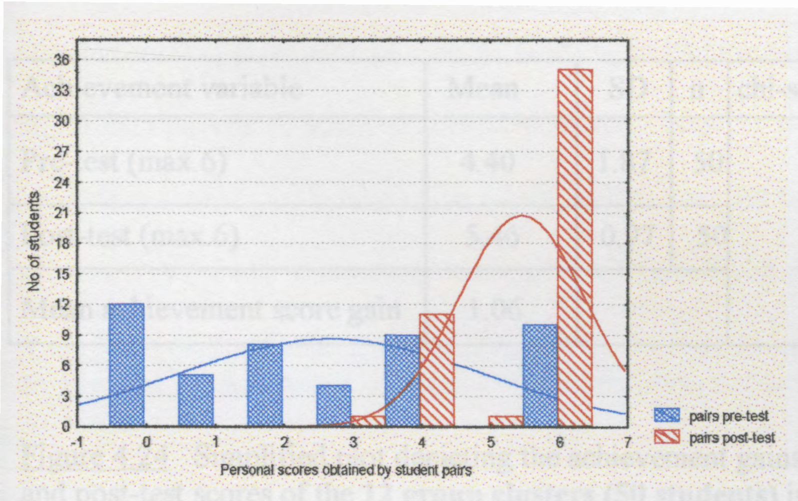
The null hypothesis Ho 4c (i) is not tenable. Table 4.22 and Figure 4.22 show that *there is a highly significant difference between pre-test and post-test achievement scores for* ***individual*** *students in their understanding of oxidation-reduction equations.* There is a statistically highly significant improvement in the 49 **individual** students' oxidation-reduction achievement scores.

- Null hypothesis Ho4 c(ii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the component test of understanding of the *oxidation-reduction equations* (scored out of 6) by the **student pairs.**

Table 4.23 t-test analysis of the **24 student pairs' (48 students')** mean pre-test to post-test gains in achievement scores in their understanding of the oxidation-reduction equations

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.6)	2.68	2.21	48		
Post-test (max.6)	5.45	0.92	48	8.00	$p<0.001$
Mean achievement score gain	2.77				HSD

Figure 4.23 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **24 student pairs (48 students)** in their understanding of the *oxidation-reduction equations*



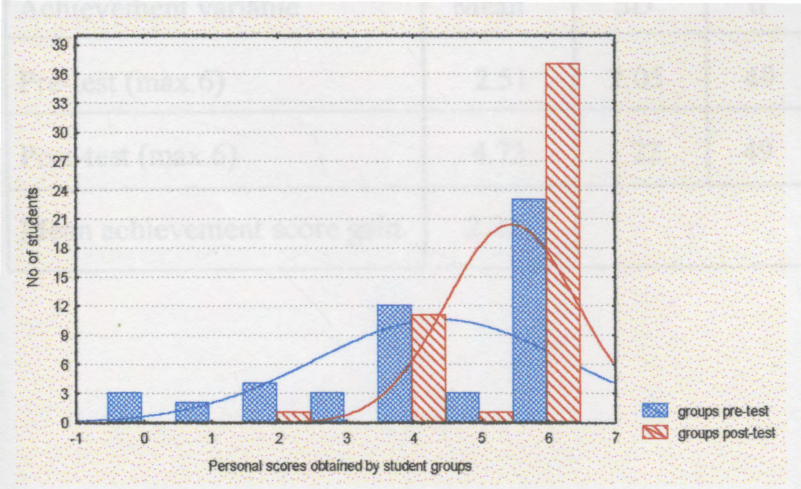
The null hypothesis Ho 4c (ii) is not tenable. Table 4.23 and Figure 4.23 show that *there is a highly significant difference between pre-test and post-test achievement scores for **student pairs** in their understanding of oxidation-reduction equations.* There is a statistically highly significant improvement in the **24 student pairs' (48 students')** achievement scores on oxidation-reduction equations.

- Null hypothesis Ho4 c(iii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, between the three types of instructional grouping arrangement on the component test of understanding of the *oxidation-reduction equations* (scored out of 6) by the **group clusters**.

Table 4.24 Chi-square analysis of the **12 group clusters' (50 students')** mean pre-test to post-test gains in achievement scores in their understanding of the *oxidation-reduction equations*

Achievement variable	Mean	SD	n	chi-square value	p
Pre-test (max.6)	4.40	1.87	50		
Post-test (max.6)	5.46	0.97	50	7.04	p<0.01
Mean achievement score gain	1.06				HSD

Figure 4.24 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **12 group clusters (50 students)** in their understanding of the *oxidation-reduction equations*



The null hypothesis Ho4c (iii) is not tenable. *There is a highly significant difference between pre-test and post-test achievement scores for* ***group clusters*** *in their understanding of oxidation-reduction equations.* There is a statistically highly significant improvement in the **12 group clusters' (50 students')** achievement scores on oxidation-reduction equations.

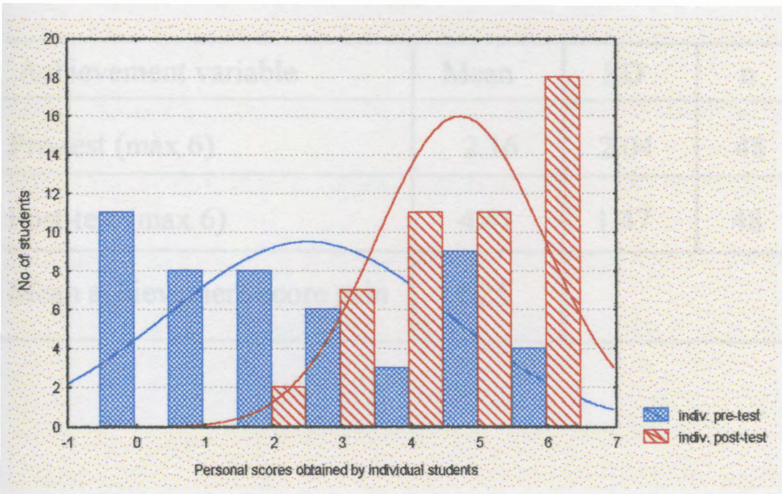
4.5.4 Achievement gains by the 147 students in their understanding functions of the salt bridge.

- Null hypothesis Ho4 d(i) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the component test of understanding of the functions of the salt bridge (scored out of 6) by the individuals

Table 4.25 t-test and chi-square analysis of the **49 individual students'** mean pre-test to post-test gains in achievement scores in their understanding of the functions of the *salt bridge.*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.6)	2.51	2.05	49		
Post-test (max.6)	4.73	1.22	49	6.52	p<0.001
Mean achievement score gain	2.22				HSD
				chi-square	p<0.01
				9.91	HSD

Figure 4.25 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **49 individual** students in their understanding of the functions of the *salt bridge*



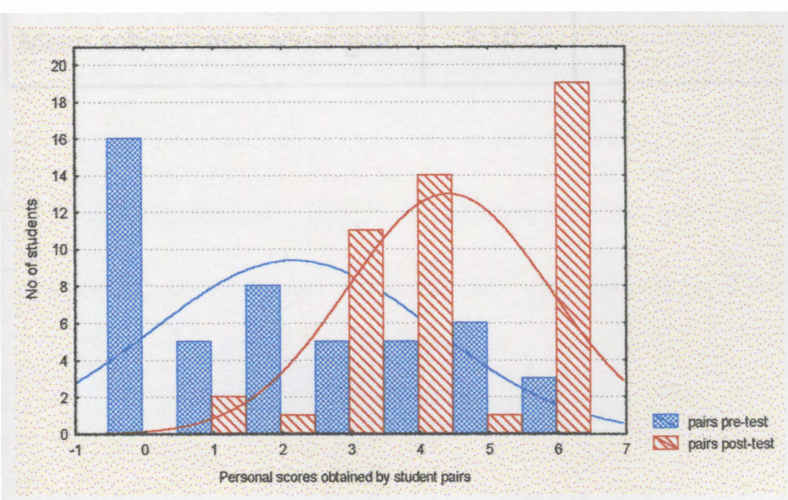
The null hypothesis Ho 4d (i) is tenable. Table 4.25 and Figure 4.25 show that *there is a highly significant difference between pre-test and post-test achievement scores for the* ***individual*** *students in their understanding of the functions of the salt bridge.* There is a statistically highly significant improvement in the **49 individual** students' achievement scores on their understanding of the functions of the salt bridge.

- Null hypothesis Ho4 d(ii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the component test of understanding of the functions of the salt bridge (scored out of 6) by the student pairs.

Table 4.26 t-test and chi-square analysis of the **24 student pairs' (48 students')** mean pre-test to post-test gains in achievement scores in their understanding of the functions of the *salt bridge*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.6)	2.16	2.04	48		
Post-test (max.6)	4.41	1.47	48	6.20	p<0.001
Mean achievement score gain	2.25				HSD
				chi-square	p<0.001
				13.27	HSD

Figure 4.26 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **24 student pairs (48 students)** in their understanding of the functions of the *salt bridge*



The null hypothesis Ho 4d(ii) is not tenable. Table 4.26 and Figure 4.26 show that *there is a highly significant difference between pre-test and post-test achievement scores for the **students pairs** in their understanding of the functions of the salt bridge.*

There is a statistically highly significant improvement in the **24 student pairs' (48**

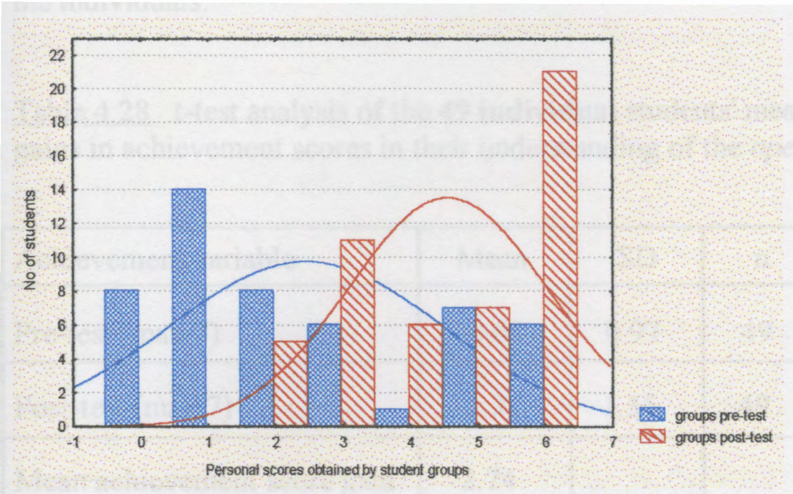
students') achievement scores on their understanding of the functions of the salt bridge.

- Null hypothesis Ho4 d(iii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the component test of understanding of the functions of the salt bridge (scored out of 6) by the group clusters.

Table 4.27 t-test and chi-square analysis of the **12 group clusters' (50 students')** mean pre-test to post-test gains in achievement scores in their understanding of the functions of the *salt bridge*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.6)	2.46	2.04	50		
Post-test (max.6)	4.56	1.47	50	5.90	$p<0.001$
Mean achievement score gain	2.10				HSD
				chi-square	$p<0.01$
				9.94	HSD

Figure 4.27 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **12 group clusters (50 students)** in their understanding of the functions of the *salt bridge*



The null hypothesis Ho4 d(iii) is not tenable. Table 4.27 and Figure 4.27 show that *there is a highly significant difference between pre-test and post-test achievement scores for the students pairs in their understanding of the functions of the salt bridge.* There is a statistically highly significant improvement in the **12 group clusters' (50 students')** achievement scores on their understanding of the functions of the salt bridge.

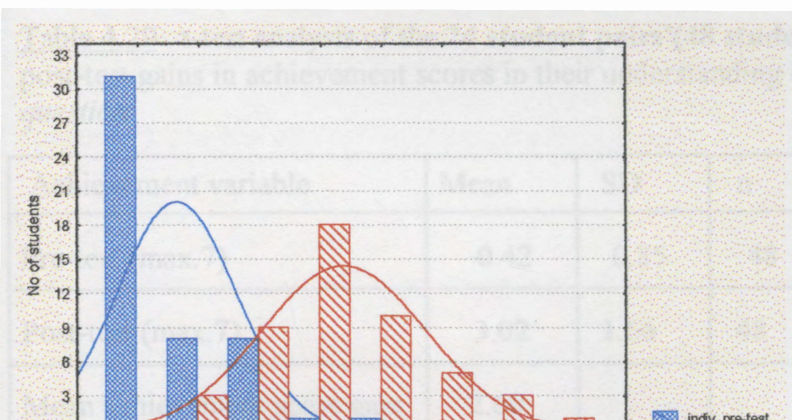
4.5.5 Achievement gains by the 147 students in their understanding of the open ended question

- Null hypothesis Ho4 e(i) states, that after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains between the three types of instructional grouping arrangement on the open ended question (scored out of 7) by the individuals.

Table 4.28 t-test analysis of the **49 individual** students' mean pre-test to post-test gains in achievement scores in their understanding of the *open ended question*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.7)	0.63	0.97	49		
Post-test (max.7)	3.37	1.35	49	11.51	p<0.001
Mean achievement score gain	2.74				HSD

Figure 4.28 _Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **49 individual** students in their understanding of the *open ended question*



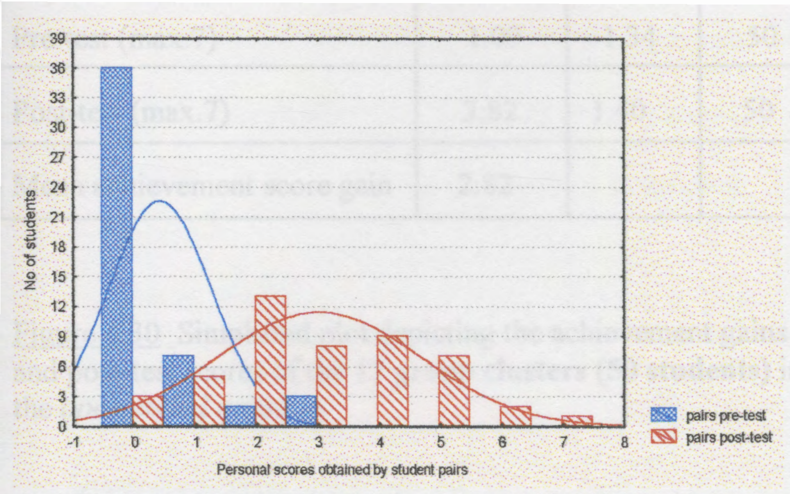
The null hypothesis Ho4 e(i) is not tenable. Table 4.28 and Figure 4.28 show that *there is a highly significant difference between pre-test and post-test achievement scores for the **individual** students in their understanding of the open ended question.* There is a statistically highly significant improvement in the **49 individual** students' pre-test and post-test achievement scores.

- Null hypothesis Ho4 e(ii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, between the three types of instructional grouping arrangement on the open ended question (scored out of 7) by the student pairs.

Table 4.29 t-test analysis of the **24 student pairs'(48 students')** mean pre-test to post-test gains in achievement scores in their understanding of the *open ended question*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.7)	0.42	0.85	48		
Post-test (max.7)	3.02	1.66	48	9.64	$p<0.001$
Mean achievement score gain	2.60				HSD

Figure 4.29 _Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **24 student pairs (48 students)** in their understanding of the *open ended question*



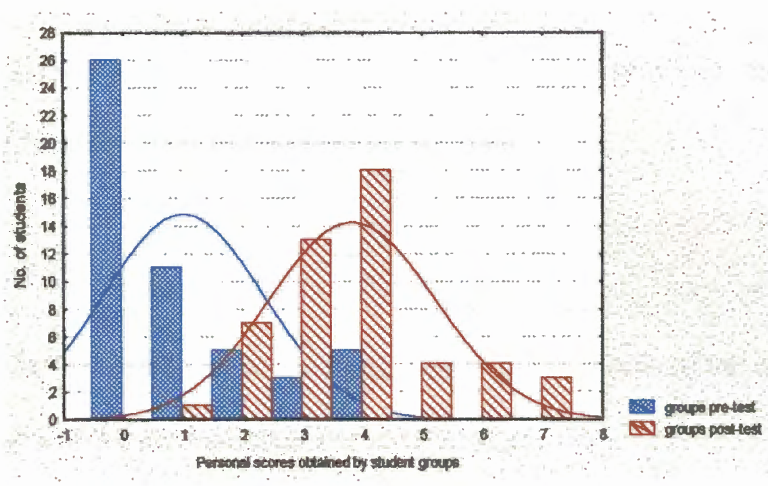
The null hypothesis Ho4 e(ii) is not tenable. Table 4.28 and Figure 4.28 show that *there is a highly significant difference between pre-test and post-test achievement scores for the* ***students pairs*** *in their understanding of the open ended question.* There is a statistically highly significant improvement in the **24 student pairs' (48 students')** pre-test and post-test achievement scores.

- Null hypothesis Ho4 c(iii) states that, after 147 participant students complete a supplementary programme of assisted teaching in electrochemistry, there will be no significant pre-test to post-test achievement gains, between the three types of instructional grouping arrangement on the open ended question (scored out of 7) by the group clusters.

Table 4.30 t-tests analysis of the **12 group clusters' (50 students')** mean pre-test to post-test gains in achievement scores in their understanding of the *open ended question*

Achievement variable	Mean	SD	n	t-value	p
Pre-test (max.7)	1.00	1.34	50		
Post-test (max.7)	3.82	1.40	50	10.30	p<0.001
Mean achievement score gain	2.82				HSD

Figure 4.30 Simplified plot depicting the achievement gains in respect to the pre-test and post-test scores of the **12 group clusters (50 students)** in their understanding of the *open ended question*



The null hypothesis Ho4 e(iii) is not tenable. Table 4.30 and Figure 4.30 show that *there is a highly significant difference between pre-test and post-test achievement scores for the* ***group clusters*** *in their understanding of the open ended question.* There is a statistically highly significant improvement in the **12 group clusters' (50 students')** pre-test and post-test achievement scores.

SECTION C : QUALITATIVE FINDINGS

4.6 Error analysis of the two formative pre-tests and the summative post-test.

The written responses of a total of 355 answer sheets received from a total of 584 students (from the two formative pre-tests) were analysed for different types of cognitive and perceptual errors. Photocopies of students' errors are reproduced in Appendix 4.The findings may be summarised as follows:

4.6.1 Student understanding of the anode and the cathode

- Question 1 reads :

Using the six labels provided in the diagram, say which metal is the cathode?

6% of the answers received were wrong.

- Question 2 reads:

Is this metal, cathode, the negative or positive pole of the cell?

7% of the answers received were wrong

- Question 3 reads:

Of the six labels provided in the diagram, say which metal is the anode?

7% of the answers received were wrong

- Question 4 reads:

Is this metal, anode the negative or positive pole of the cell?

7% of the answers received were wrong.

However 40% of the students who answered question 1 and question 3 wrongly had question 2 and question 4 correct.

- Questions 5.1 and 5.2 reads:

  Choose the correct word in brackets by writing your selected answer in the space provided: -

5.1 The anode is the electrode at which (oxidation / reduction) takes place.
5.2 The cathode is the electrode at which (oxidation/reduction) takes place.

5% of the answers received were wrong.

However 8% of the students who had question 5 correct answered question 1 and question 3 wrong.

The written responses of 10 % of the students expressed confusion with the scientific understanding of terms like *reduction.* These students wrongly perceived reduction as a loss of electrons, and then they automatically deduced that oxidation is the gaining of electrons.

. Two of the answer sheets had the pneumonic 'REDOX AND CAT' . 'RED'- reduction linked to 'C'- cathode and 'OX' - oxidation linked to 'A' - anode which meant that students did not differentiate the difference between the anode and cathode on reasoning or analysis, but applied a pneumonic taught to them by their teachers

4.6.2 Oxidation-Reduction equations

- Question 10.1 reads:

Pick up the redox table and use it to write down the following reactions occurring in the diagram:

The reduction half reaction...(1)

8% of the students wrote the reduction half reaction wrongly as follows:-

$Cu \rightarrow Cu^{2+} + 2e^-$ or $Zn \rightarrow Zn^{2+} + 2e-$

- Question 10.2 reads:

Pick up the redox table and use it to write down the following reactions occurring in the diagram:

The Oxidation half reaction...(1)

9% of the students wrote the oxidation half reaction wrongly

$Zn^{2+} + 2e^- \longrightarrow Zn$ or $Cu^{2+} + 2e^- \longrightarrow Cu$

Some students wrote the oxidation half-reaction wrongly by copying it directly from

table, e.g. : $Zn^{2+} + 2e^- \longrightarrow Zn$.

- Question 10.3 reads:

10.3 The balanced cell (or redox) reaction

....(4)

7% of the students wrote the reduction and oxidation half reaction wrongly but the redox reaction correctly, e.g.:-

The reduction half- reaction	$Zn \rightarrow Zn^{2+} + 2e^-$	(wrong)
The oxidation half- reaction	$Cu^{2+} + 2e^- \rightarrow Cu$	(wrong)
The redox reaction	$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$	(correct)

4.6.3 The salt bridge

- Question 9 reads :

Suggest as many different functions of the salt bridge as you can.

The following wrong answers were given by students:

...it serves as a pathway for the electrons..."

" electrons flow from the positive pole to the negative pole through it"

- Question 11 reads:

What will happen if the salt bridge is removed?

The following wrong answers were given by students:

"The cycle of electrons gets completed through it."

" An explosion will occur."

" ...Many of the positive and negative electrons will be unbalanced..."

" ... Nothing will take place..."

"Erosion will not occur"

" $CuSO_4$ will turn colourless"

One student wrote that the salt bridge transfers the KCl while another student wrote that the salt bridge does not take part in the action.

4.6.4 The flow of the electric current

Question 6 reads:

Complete the empty spaces in this statement by writing down the *names of the metals*:
-

Current flows from the........... ....electrode to the ....electrode. (2)

7% of the students wrongly claimed that the current flows from the copper electrode to the zinc electrode.

- Question 8 reads:

Which of the two metals undergoes an observable increase in mass while the cell functions after a few minutes at room temperature?
5% of these students did not know which metal increased in mass.

After the supplementary programme of re-teaching in which most students saw the needle reading indicator of the voltmeter, they could then work out the direction of the current as well as the metal which increased in mass. Students could also see the increase of the mass on the copper electrode when the live demonstration was done in the supplementary programme of re-teaching.

4.7 Chapter summary

This chapter has presented the results of the investigation , and the confirmation or refutation of the hypotheses have been set out. In **chapter 5** these findings are discussed in detail in relation to the existing literature on the teaching and learning of basic electrochemistry.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Introduction

This chapter discusses the empirical results and findings reported in chapter 4, and suggests further directions for research. An attempt is made to account for significant differences obtained among the achievement variables investigated. Explanations are suggested for the outcomes of the tested null hypotheses formulated in section 1.5 of chapter 1 as well as the research questions as formulated in section 1.4 of chapter 1. Photocopies of the students' written responses, quoted as evidence to support the discussion arguments, are reproduced in Appendix 4.

5.2 The overall performances of the students in general

Sometimes the *group clusters* and *student pairs* obtained better average achievement marks than the *individuals.* (See Table 4.1 ; Fig.4.1; Table 4.2; Fig. 4.2; Table 4.3; Fig. 4.3; Table 4.4; Fig.4.4; Table 4.13 and Fig.4.13). The highly significant difference in achievement between the *cluster groups* and the *individuals* is consistent with the differences in achievement gains found between *groups* and *individuals* recorded by previous researchers such as Swain (1999); Gayford (1989,1992,1993,1995); Gilbert and Pope (1986); Wallace (1986), Johnson and Johnson (1985: 25) cited in Gabel (1994:79); and Cooper (1995:162). All of them argued that the grouping arrangements of group clusters or pairs would produce better results than the *individuals.*

However sometimes the *individuals* also obtained better average achievement marks than the *group clusters* and the *student pairs* (See Table 4.7; Fig. 4.7; Table 4.9; Fig.4.9; Table 4.14; Fig 4.14). The *individuals* also sometimes gained better average achievement marks than the *student pairs.* (See Table 4.6 Fig. 4.6; Table 4.8; Fig. 4.8; Table 4.10; Fig.4.10; Table 4.15; Fig.4.15). This finding is consistent with that of Slavin (1984) cited in Gabel (1994:79) who discovered that in his 29 reviewed studies, two studies showed significantly higher achievement for a control group than for a cooperative group.

Johnson et al (1981) analyzed 122 studies and concluded that cooperative learning approaches showed more positive results for student achievement than the other forms of socialised learning methods, but not even this synthesis was totally conclusive and generalizable.

5.3 Student understanding of the anode and the cathode

Quantitative analysis

There was a significant difference between the achievement scores of the *individuals* and the achievement scores of the *group clusters* in the first pre-test (phase 1). (See Table 4.2; Fig.4.2). The *individuals,* working alone, were not consistent in their level of knowledge about the polarity of the negative and positive poles, and they did not all know clearly the differences between the anode and cathode. The confusion was reduced or eliminated in the arrangement of *group clusters* because the participants were allowed to discuss the matter first before writing a correct answer. This finding is consistent with that of Johnson and Johnson (1985) cited in Gabel (1994:79) who found that when students work together they could resolve controversies during their interaction.

In the second pre-test (phase 2) the *individuals* scored the highest average achievement mark of all the groups. (See Table 4.7; Fig. 4.7). The average achievement mark (5.10) for the *individuals* was not exceptionally high, but the average achievement marks for the *student pairs* (4.93), and for the *group clusters* (5.04) were low. Many *individuals* scored full marks for this section. The most common error among the *student pairs* was the confusion between the negative and positive pole (16%) and many of the *student pairs (14%)* and the *group clusters (12%)* did not identify the cathode and the anode correctly.

The likely effectiveness of the supplementary programme of re-teaching was indicated when there were a significant increases between the pre-test and post-test scores for the *student pairs* (see Table 4.20; Fig. 4.20).

Qualitative analysis

10% of the students confused the functions of the two different metals; i.e. the copper and zinc. They also interchanged the polarity of the two metals. They may have had a misconception about the anode and the cathode, e.g. wrongly claiming that the anode is the positive electrode and it is the site where reduction takes place; and saying that the cathode is the negative electrode and it is the site where oxidation takes place. There were also students who still confused the anode and the cathode when they had to apply the reversals between the electrolytic cells and the galvanic cells. This finding agrees with that of Ogude (1991:110) and Garnett and Treagust (1992b:1079). This may be due to students not being taught properly the differences between the electrolytic and galvanic cells.

4 % of students expressed confusion with the scientific understanding of terms like *reduction*. A student asked the following question: " Does reduction not mean to become less?". Many students wrongly perceived reduction as loss of electrons, then automatically deduced that oxidation is the gaining of electrons. This was clearly observed in question no.5 when students reversed the incorrect answers. This misconception was also found by Ogude (1991:26).

From the high achievement averages in both pre-tests of phase 1 and phase 2, it seemed that students had a good understanding of the anode and the cathode but, after analyzing the answers, it was observed that many students knew the differences by means of rote application or by means of a pneumonic taught to them by their respective teachers. A handwritten pneumonic like " REDOX AND CAT" was found on some students' answer sheets. 'RED' - reduction linked to 'C'- cathode and 'OX' - oxidation linked to 'A' - anode.

5.4 Oxidation-reduction equations

Quantitative analysis:

In the first formative pre-test (phase 1) there was a highly significant difference in achievement between the *individuals* and the *group clusters*, but a significant difference in achievement between the *student pairs* and the *group clusters* (see Table 4.3; Fig. 4.3). It was found that eleven of the 99 *individuals* appeared to have no idea of the redox reactions and left their answers blank. Of the *individuals*, 30 interchanged the answers of the reduction half reaction and the oxidation half reaction, although they gave the correct answer for the redox reaction. Many of these students, who appeared confused with the two half reactions, also did not clearly understand the terms reduction and oxidation, because they wrongly stated that oxidation takes place at the cathode and reduction takes place at the anode in questions 5.1 and 5.2. The *group clusters* had 59 groups who scoring full marks which was a high percentage. This may have occurred because many students within the groups had the opportunity to elaborate among themselves on which of the half reactions were correct. This is consistent with the finding of Johnson and Johnson (1985 b) cited in Gabel (1994:79) who found that when students worked together they were able to find a solution to the problem.

The *student pairs* had the lowest average mean mark in the second formative pre-test (phase 2) because many of them wrote the half reactions correctly but gave the wrong answers for the redox reaction (see Table 4.8; Fig. 4.8).

In the summative post-test (phase 2) there were no significant differences in achievement between any of the three groups. Many students scored full marks after the intervention of the supplementary programme of re-teaching. The effectiveness of the supplementary re-teaching programme was borne out by the highly significant increase for the *individuals* (see Table 4.22; Fig. 4.22) as well as for *the student pairs* (see Table 4.23; Fig.4.23) , and a significant difference also occured for the *group clusters* (see Table 4.24; Fig. 4.24) in the pre-test to post-test achievement. After the students were re-taught the differences between reduction and oxidation, they were able to give the correct reduction and oxidation half reactions as well as the correct redox reaction.

Qualitative analysis

17% of the 584 students (who completed two formative pre-tests) wrote the oxidation half-reaction incorrectly. They copied directly from the supplied table, e.g. $Zn^{2+} + 2e^- \longrightarrow Zn$, although they wrote it at question 10.2. These students did not know that a loss of electrons is written on the right side instead of the left side of the equation. Many of the students claimed that the substance which is oxidised is the oxidising agent whereas in fact it is the reducing agent. Many of these students also expressed a misconcept of oxidation numbers and this finding agrees with that of Garnett and Treagust (1992 a: 137).

7% of the 584 students (two formative pre-test) who confused the oxidation and reduction gave the following answers:

" The reduction half reaction......... $Zn \longrightarrow Zn^{2+} + 2e^-$ "

" The oxidation half reaction......... $Cu^{2+} + 2e^- \longrightarrow Cu$."

The redox reaction $Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$

It is possible that some teachers do not teach their students the correct understanding of the terms *reduction and oxidation* but instead they might teach their students that the substance which is oxidised is on 'top' of the redox table and the substance that is reduced is at the 'bottom' of the redox table. A problem may arise when students do not know if they are working with the American standard electrode potential table or the British electrode potential table. In the British standard electrode potential table, Li is at the 'top' of the table and $2F^-$ is at the 'bottom' of the table. The American standard electrode potential table is the opposite to the British one in that $2F^-$ is at the 'top' of the table and Li is at the 'bottom' of the table. Such a confusion of the oxidation and reduction terms was also found by Garnett and Treagust (1992 a: 140).

Many students wrote the redox reaction as "$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$" indicating the spectator ions while, others wrote it as "$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu$" in ionic form. Both can be accepted as correct.

5.5 The salt bridge

Quantitative analysis

The scores for the salt bridge questions in the first and second formative pre-tests for all the groups were not as high as the scores for the previous questions. The reason could be that the questions were open ended and, being based on reasoning and analysis, there was less room for guess work.

In the summative post-test with 147 students the *individuals* marginally had the best overall achievement mark of all the groups. (See Table 4.14; Fig.4.14). This is consistent with the finding of Gibbs (1995:6) who said that when individuals work alone they undertake every aspect of an assignment themselves and they learn about every possible angle.

There was a highly significant increase for the *individuals* (see Table 4.25; Fig.4.25), for the *student pairs* (see Table 4.26; Fig. 4.26) as well as for the *group clusters* (see Table 4.27; Fig.4.27) in the pre-test to post-test achievement scores. This is an indication of the positive effect that the supplementary re-teaching programme may have had on many of the students.

Qualitative analysis

Students were required to answer two separate questions on the salt bridge. Question 9 concerned the function of the salt bridge. 18% of the 584 students had the misconception that the salt bridge is a connector of electrons between the two electrolytes. Students gave the following different answers:

> "...it serves as a pathway for the electrons..."
> " electrons flow from the positive pole to the negative pole through it"

etc. as recorded in chapter 4

These findings agree with those of Sanger and Greenbowe (1997:386) who found that many students held the misconception that electrons enter the solution from the cathode, travel through the solutions and the salt bridge and emerge at the anode to complete the circuit.

12% of the 584 students gave illogical and unfounded answers when asked in question 11 what will happen if the salt bridge is removed. Some of the answers were:

> " An explosion will occur"
> " ...many of the positive and negative electrons will be unbalanced..."
> " ... nothing will take place..."
> "Erosion will not occur"

etc. as recorded in chapter 4

These findings agrees with those of Garnett and Treagust (1992), cited in Sanger and Bowe (1997:820) that some students apply information too generally and they over-generalize scientific statements.

There were 10% of 584 students who were not sure of the function of the KCl in the salt bridge. In response to question 9 one student answered that "The salt bridge transfers KCl" and, in response to question no.11, a student wrote 'KCl will not be formed".

The investigation found that there were 10% of the 584 students who did not appear to know what the salt bridge is nor its function in the electrochemical cell. For example, in spite of having the voltmeter in the sketch as well as in the practical demonstration a student wrote that the function of the salt bridge is " To measure the amount in the different solutions", while other students wrote "It does not take part in the action".

5.6 The open-ended question

This question was very poorly answered by all the three groups in both formative pre-tests. In the second formative pre-test with 147 students, 62% of the *individuals* had zero score; 72% of the *student pairs* scored zero and among the *group clusters*, 52% had a zero score.

62% of the 584 students did not even attempt to answer one of the questions. Possibly many students had not been taught the content of the open ended question but the idea was to see how students can use their general knowledge on electrochemistry in the South African industry.

For the open-ended question there was a highly significant increase in the pre-test to post-test achievement results for the *individuals, the student pairs and the group clusters*. After the supplementary re-teaching programme 48% students recorded an improved understanding of the use of electrochemistry in the industry.

5.7 Other types of errors

5.7.1 Cognitive difficulties: item 7

10% of the 584 students did not understand the conversion of the different forms of energy in spite of being given the possible answers. 2% of the students left blank spaces, and some guessed the answer. In 8% of the wrong answers there was the claim that "heat potential energy is converted to chemical energy".

5.7.2 Perceptual difficulties: item 8

12% of the 584 students were not sure in which direction the current would flow; therefore they could not determine which metal increased in mass. These students wrongly claimed that current flows from the copper plate to the zinc plate.

5.8 Achievement gains by participant students

The high gains in phase 2 of the 147 participant students in their pre-test to post-test achievement scores is an indication that the supplementary re-teaching programme motivated various students and it developed content mastery among many students. According to Hunter (1982:51), cited in Demirtas (2000: 89), students' concerns, feelings and interests towards instructional programmes can have an impact on students' motivation. The characteristics of instructional programmes are described by Bruner (1986), cited in Demirtas (2000 : 1989), and the effects of various science teaching instructions on achievement might be related to pre-test and post-test improvement in achievement scores (Wise and Orkney ,1983 : 43, cited in Demirtas, 2000 : 89)

5.9 Suggestions for further research

For larger studies it is suggested that the study might be extended by giving more attention is given to gender issues.

It is suggested that students' characteristics such as home language, age and socio-economic background might also be investigated when an instructional programme takes place.

This study was based on a relatively small-scale research confined to high schools in the Western Cape of South Africa only. It is suggested that the study might also be carried out on a tertiary level as well as in other regions of South Africa.

The study encountered some students who had a problem receiving instruction in English as it was used as the language of instruction in most of the physical science classes, although many of them receive instruction through their first language, e.g. Xhosa or Afrikaans, in other subjects. It is suggested that students might be taught where desired through the medium of their first language with which they feel comfortable, and that this possibility be researched.

It is suggested that research to be conducted into science teachers acquiring the recommended equipment for their chemistry lessons, as the study has found that many students still do chemistry based on their imagination. Adams (1993:116) recommends that teachers improve their laboratory techniques and this variable could be researched in follow-up studies.

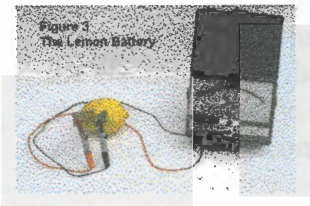
It is suggested that future research into teaching electrochemistry might include microcomputer based learning diagnostic systems, like those designed by Nachmias, Stavey and Avrams (1990), to identify South African students' conceptions of heat and temperature, which could be developed for learning electrochemistry (Garnett and Treagust: 1097: 1992b).

According to McDonald, Gilmore and Moodie (1985), cited in Adams (1993:114), many educational innovations rely on teacher education, either pre-service or in-service for their successful implementation. They identified four roles for the teacher if the innovation and its demands are to be introduced successfully and they are the teacher as an *employee*, as a *subject specialist*, as a *classroom director* and as a *professional*.

Many students in physical science are usually motivated, and are willing to learn and develop. It is suggested that teachers could use and research different types of methods to teach the subject, e.g. group work as well as individual work, as it was pointed out by the study. This might help students feel good, and they may expand their will and energy to make a success in the learning of chemistry.

Additional suggestions for programmes that can be researched and taught in electrochemistry are offered by Carboni 1998: 6 in Figures 5.1 to 5.3

Figure 5.1
BATTERIES
THE LEMON BATTERY
"Materials:



- a lemon
- a strip of copper
- a strip of zinc
- a voltmeter
- two cables with alligator clips
- a thermometer or clock with an LCD display

Roll the lemon firmly with the palm of your hand on a tabletop or other hard surface in order to break up some of the small sacks of juice within the lemon. Insert the two metal strips deeply into the lemon, being careful that the strips not touch each other. Using the voltmeter, measure the voltage produced between the two strips (figure 3). It should show to be about one volt.
It would be nice to be able to illuminate a light bulb using your new lemon powered battery, but unfortunately it is not strong enough. If you were to try to light a bulb using this setup, the voltage across the strips would fall immediately to zero. Given this, if you want to demonstrate that the current produced by this battery is capable of powering something, try with a small device that uses an LCD display. A clock or a thermometer usually works well. An LCD display consumes an extremely small amount of current and your lemon battery is able to adequately drive this type of device. Remove any conventional battery that is in your clock or thermometer and power it with your lemon battery. You should see the device recommence functioning normally. If not, try swapping the polarity of the electricity from your lemon battery. This system allows you to demonstrate that the battery is producing energy even if you don't have a voltmeter.

How does this battery work? The Copper (Cu) atoms attract electrons more than do the Zinc (Zn) atoms. If you place a piece of copper and a piece of zinc in contact with each other, many electrons will pass from the zinc to the copper. As they concentrate on the copper, the electrons repel each other. When the force of repulsion between electrons and the force of attraction of electrons to the copper become equalized, the flow of electrons stops. Unfortunately there is no way to take advantage of this behavior to produce electricity because the flow of charges stops almost immediately. On the other hand, if you bathe the two strips in a conductive solution, and connect them externally with a wire, the reactions between the electrodes and the solution furnish the circuit with charges continually. In this way, the process that produces the electrical energy continues and becomes useful.

As a conductive solution, you can use any electrolyte, whether it be an acid, base or salt solution. The lemon battery works well because the lemon juice is acidic. Try the same setup with other types of solutions. As you may know, other fruits and vegetables also contain juices rich in ions and are therefore good electrical conductors. You are not then, limited to using lemons in this type of battery, but can make batteries out of every type of fruit or vegetable that you wish.

Like any battery, this type of battery has a limited life. The electrodes undergo chemical reactions that block the flow of electricity. The electromotive force diminishes and the battery stops working. Usually, what happens is the production of hydrogen at the copper electrode and the zinc electrode acquires deposits of oxides that act as a barrier between the metal and the electrolyte. This is referred to as the electrodes being polarized. To achieve a longer life and higher voltages and current flows, it is necessary to use electrolytes better suited for the purpose. Commercial batteries, apart from their normal electrolyte, contain chemicals with an affinity for hydrogen which combine with the hydrogen before it can polarize the electrodes.

Figure 5.2
Another example using fruit: (Carboni : 1998:17)

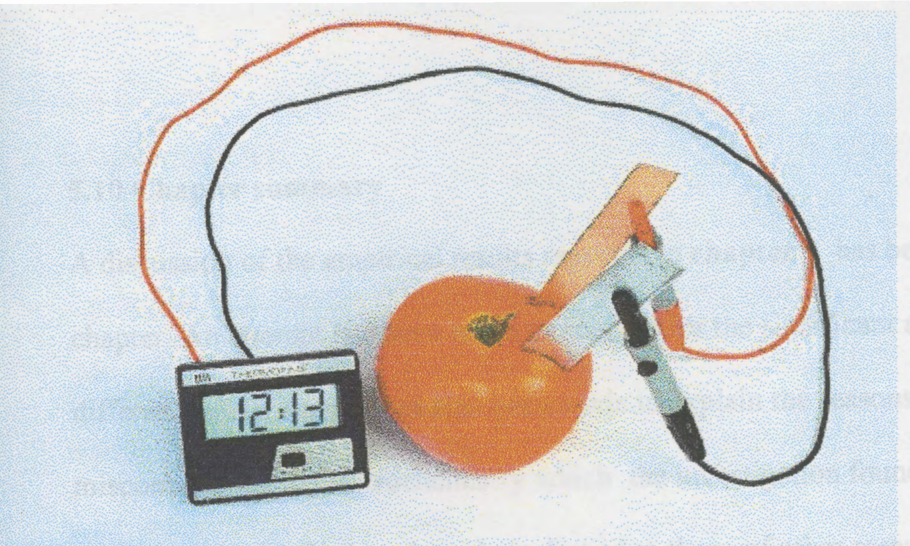


Figure 15 - LCD-Clock powered by a tomato battery.

To be able to get higher voltages one can connect multiple Daniel cells in a series. The connection between one cell and another is metallic wire rather than a saline bridge. (Carboni:1998:10)

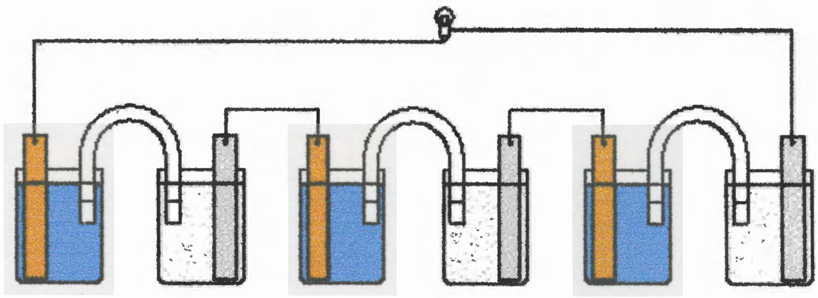


Figure 8 - Battery of three Daniell's Cells

Figure 5.3

5.10 Chapter summary

A discussion of the empirical results reported in **chapter 4** has been elucidated in this chapter. An attempt has been made to account for the significant achievement differences. An attempt has also been made to explain the reasons for certain misconceptions in electrochemistry which the investigation found among some students; and the findings have been linked to those of other researchers on the topic. Suggestions for further research has been given as well as additional basic experiments in electrochemistry.

Chapter 6 will draw conclusions and recommendations for further research.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The aim of this study has been to investigate and compare academic performance in chemistry achieved by students working either in groups, or in pairs or as individuals, randomly assigned to one of these three modes of grouping. The study found that there was a diversity of results among the various groups. Sometimes the group clusters had the significantly best average achievement mark; sometimes the student pairs had the best average achievement mark; and sometimes the individuals had the best average achievement mark. Teachers, lecturers and curriculum planners could take note of this finding when they implement group-based instructional methods in the outcomes-based education system (OBE) in South Africa.

The study found that initially there were many misconceptions and misunderstandings about electrochemistry among the sampled students all of whom had already been taught the electrochemistry section from their textbooks by their respective science teachers. The study addressed these problems and also gave solutions as to how these problems could be overcome through a carefully designed additional intervention programme of instruction.

After the supplementary programme of re-teaching many of these misconceptions, misunderstandings and confusion were corrected in terms of students' knowledge of the difference between the anode and cathode, their understanding of the oxidation-reduction equations, as well as their understanding of the functions of the salt bridge as the results of the post-tests have shown.

6.2 Conclusions

The investigation set out to answer the following questions:

1. When students work on and answer the graded evaluation materials on electrochemistry either in randomly formed groups, or in pairs, or as individuals, will their achievement scores be, on average, equal?

2. Following further instructional intervention assistance, will significant mean test score increases occur for the three types of instructional grouping arrangement (individuals; pairs; clusters)?

The main findings were:

1. The cluster groups did not always score the highest average achievement marks followed by the student pairs and the individuals as it was expected. Instead the research has found that on some items the individuals scored the highest average achievement marks on others the group clusters scored the highest achievement mark, and there were instances in which the student pairs scored the highest achievement marks.

2. After the instructional supplementary intervention programme there were significant increases in the overall scores of the three grouping arrangements, i.e. the individuals, the student pairs and the group clusters.

6.3 Recommendations

The evidence recorded in this investigation suggests a variety of steps that science teachers, curriculum developers as well as policy makers might take to remedy the difficulties identified in the teaching of electrochemistry at high school level in South Africa, as well as the teaching of this topic to individuals or groups.

Recommendation 1

It is recommended that high school chemistry teachers do not use the term *electrode potential* but that they use the terms *oxidation* and *reduction potential.* This will reinforce the concept that the overall reaction is the sum of the oxidation half reaction and the reduction half reaction which eventually results in the redox reaction.

Recommendation 2

It is recommended that teachers, lecturers and curriculum developers select explanatory language in chemistry with care, and that they should be particularly cautious in selecting words that has everyday meanings that differ from meanings in a scientific context. The meanings which scientists attribute to certain terms are sometimes different from everyday meanings of those terms, because students use these everyday meanings to help construct their understanding of science concepts. For example in electrochemistry the conceptual meaning of *reduction* – gain of electrons - is different from its everyday use which implies loss rather than gain.

Recommendation 3

It is recommended that the content of several chemistry text books in South Africa be reviewed. Some textbooks statements were found by the study which can lead to misinterpretation by students. For example the statement 'the salt bridge completes the circuit' can lead to the misunderstanding that electrons move through the salt bridge. Another phrase 'continuity of current' can wrongly imply that current is uniform throughout the cell.

Recommendation 4

It is recommended that students be taught more carefully the difference between a galvanic and an electrolytic cell. This study found that students mistakenly tended to apply the same principles to both the galvanic and the electrolytic cells when they had to identify the anode and the cathode.

Recommendation 5

It is recommended that teachers emphasise that the purpose of the salt bridge is to allow positive and negative ions to drift to the cathode and the anode respectively, and therefore maintain electrical neutrality. To say that "the salt bridge completes the circuit" leaves too much to the imagination for some students.

Recommendation 6

It is recommended that teachers should consider letting students work together sometimes in groups, sometimes in pairs and sometimes as individuals, when they work on experiments in electrochemistry. The working of groups has been recommended also by Adams (1993:116) who said that teachers should use more co-operate activities to promote student-to-student interaction. Wallace (1986) also encouraged the working together of pairs in experiments. The working of individuals has been promoted by Gibbs (1995:6).

Recommendation 7

It is suggested that classroom science teachers seek to acquire the relevant equipment or apparatus for their electrochemistry lessons. The study found that many students improved their overall marks when a practical demonstration of the electrochemical cell was included in the intervention programme of supplementary instruction. For example students were encouraged to point out the observed increase in mass of the electrode at the anode, and they could then deduce the direction of the flow of the current.

Recommendation 8

It is suggested that chemistry teachers ask students to write out the half reactions in front of their peers; as well as individually. Students should use the redox table to write the half reactions.

Recommendation 9

It is suggested that the teacher give each student a copy of the flash cards as they were used in the supplementary re-teaching programme, and that the students be invited to sequence the cards correctly.

6.4 Chapter summary

This chapter has given recommendations and conclusions which have presented a successful outcome to the intended goal of the study.

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APPENDICES

APPENDIX 1 Pilot study no. 1

ELECTROCHEMICAL CELL (GALVANIC) ANSWER SHEET

Write all YOUR answers on the question paper in the spaces provided.

Good Luck!

Answer the following questions about the cell experiment when it is operating under normal circumstances:

1. Using the six labels provided in the diagram, say which metal is the cathode?

....(1)

2. Is this metal, cathode, the negative or positive pole of the cell?

....(1)

3. Of the six labels provided in the diagram, say which metal is the anode?

....(1)

4. Is this metal, anode the negative or positive pole of the cell?

....(1)

5. Choose the correct word in brackets by writing your selected answer in the space provided: -

5.1 The anode is the electrode at which (oxidation / reduction) takes place.

....(1)

5.2 The cathode is the electrode at which (oxidation/reduction) takes place.

....(1)

6.Complete the empty spaces in this statement: -

Current flows from the........... ....electrode to the ....electrode (2)

7. Read the following list of different forms of energy: <u>kinetic</u>: <u>heat</u>: <u>light</u>: <u>chemical</u>: <u>potential</u>: <u>total mechanical</u>: <u>electrical</u>: <u>nuclear</u>.

Now select two of these forms of energy and write them down in the missing spaces in the following sentences:

In this electrochemical cell ....potential energy is converted

into ....potential energy. (2)

8. Which of the two metals undergoes an observable increase in mass while the cell functions after a few minutes at room temperature?

....(1)

9. Suggest as many different functions of the salt bridge as you can.

....

....

....

....(4)

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction...(1)

10.2 The Oxidation half reaction..(1)

10.3 The balanced cell (or redox) reaction

....(4)

List several careers in science / technology in which you will be interested in to pursue your future:
e.g. food technician: Antarctic meteorologist; rust proofing expert: paint technologist: etc.

Name/Nickname:	Gender:	Career:
1	....	....
		....
2	....	....
		....
3	....	....
		....
4	....	....
		....
5	....	....
		....
6	....	....
		....

APPENDIX 2 Pilot study no. 2

ELECTROCHEMICAL CELL (GALVANIC) ANSWER SHEET

Write all YOUR answers on the question paper in the spaces provided.

Good Luck!

Answer the following questions about the cell experiment when it is operating under normal circumstances:

1. Using the six labels provided in the diagram, say which metal is the cathode?

....(1)

2. Is this metal, cathode, the negative or positive pole of the cell?

....(1)

3. Of the six labels provided in the diagram, say which metal is the anode?

....(1)

4. Is this metal, anode the negative or positive pole of the cell?

....(1)

5. Choose the correct word in brackets by writing your selected answer in the space provided: -

5.1 The anode is the electrode at which (oxidation / reduction) takes place.

....(1)

5.2 The cathode is the electrode at which (oxidation/reduction) takes place.

....(1)

6.Complete the empty spaces in this statement by writing down the ***names of the metals***: -

Current flows from the............ ....electrode to the ....electrode (2)

7. Read the following list of different forms of energy: kinetic: heat: light: chemical: potential: total mechanical: electrical: nuclear.

Now select two of these forms of energy and write them down in the missing spaces in the following sentences:

In this electrochemical cell ....potential energy is converted

into ....potential energy. (2)

8. Which of the two metals undergoes an observable increase in mass while the cell

functions after a few minutes at room temperature?

....(1)

9. Suggest as many different functions of the salt bridge as you can.

....

....

....

....(4)

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction...(1)

10.2 The Oxidation half reaction..(1)

10.3 The balanced cell (or redox) reaction

....(4)

List several careers in science / technology in which you will be interested in to pursue your future:
e.g. food technician: Antarctic meteorologist; rust proofing expert: paint technologist: etc.

Name/Nickname:	Gender:	Career:
1	....	....
		....
2.....................	....	....
		....
3.....................	....	....
		....
4.....................	....	....
		....
5.....................	....	....
		....
6.....................	....	....
		....

APPENDIX 3 Pilot study no. 3

ELECTROCHEMICAL CELL (GALVANIC) ANSWER SHEET

Write all YOUR answers on the question paper in the spaces provided.

Good Luck!

Answer the following questions about the cell experiment when it is operating under normal circumstances:

1. Using the six labels provided in the diagram, say which metal is the cathode?

....(1)

2. Is this metal, cathode, the negative or positive pole of the cell?

....(1)

3. Of the six labels provided in the diagram, say which metal is the anode?

....(1)

4. Is this metal, anode the negative or positive pole of the cell?

....(1)

5. Choose the correct word in brackets by writing your selected answer in the space provided: -

5.1 The anode is the electrode at which (oxidation / reduction) takes place.

....(1)

5.2 The cathode is the electrode at which (oxidation/reduction) takes place.

....(1)

6. Complete the empty spaces in this statement by writing down the *names of the metals*: -

Current flows from the............ ....electrode to the ....electrode (2)

7. Read the following list of different forms of energy: kinetic: heat: light: chemical: potential: total mechanical: electrical: nuclear.

Now select two of these forms of energy and write them down in the missing spaces in the following sentences:

In this electrochemical cell ....potential energy is converted

into ....potential energy. (2)

8. Which of the two metals undergoes an observable increase in mass while the cell functions after a few minutes at room temperature?

....(1)

9. Suggest as many different functions of the salt bridge as you can.

....

....

....

....

....

....

....

....

....

....(4)

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction...(1)

10.2 The Oxidation half reaction...(1)

10.3 The balanced cell (or redox) reaction

....(4)

List several careers in science / technology in which you will be interested in to pursue your future:
e.g. food technician: Antarctic meteorologist; rust proofing expert: paint technologist: etc.

Name/Nickname:	Gender:	Career:
1	....	....
		....
2....................	....	....
		....
3....................	....	....
		....
4....................	....	....
		....
5....................	....	....
		....
6....................	....	....
		....

APPENDIX 4

Photocopies of students' work

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Zn^{2+} + 2e \rightleftharpoons Zn$ ....(1)

10.2 The Oxidation half reaction $Cu^{2+} + 2e \rightleftharpoons Cu$ ....(1)

10.3 The balanced cell (or redox) reaction

$Zn + Cu^{2} \rightleftharpoons Cu + Zn^{2}$ ....(4)

1

11. What will happen if the salt bridge is removed?

Die elektrisiteit sal stop

KCl sal nie gevloei word nie

....(2)

1

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

[illegible]

....(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction........ $Cu^{+} + e^{-} \rightleftharpoons Cu$ ....(1)

10.2 The Oxidation half reaction........ $Zn^{2+} + 2e^{-} \rightleftharpoons Zn$ ....(1)

10.3 The balanced cell (or redox) reaction

$Cu + Zn^{2+} \rightleftharpoons Cu^{+} + Zn$ ....(4)

11. What will happen if the salt bridge is removed?

....

....

....

....(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

.... to generate energy ....

.... to conserve electricity & ....

....

....

....

....

....

....(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ (1)

10.2 The Oxidation half reaction $Cu(s) \rightarrow Cu^{2+} + 2e^-$ (1)

10.3 The balanced cell (or redox) reaction

$Zn^{2+}(aq) + Cu(s) \rightarrow Zn(s) + Cu^{2+}(aq)$ (4)

11. What will happen if the <u>salt bridge is removed</u>?

The e⁻'s won't be transferred

There will be no connection between the Zinc and Copper

(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

To conduct electricity

To build cells or batteries

(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Zn \rightleftharpoons Zn^{2+} + 2e^-$ ....(1)

10.2 The Oxidation half reaction $Cu^{2+} + 2e^- \rightleftharpoons Cu$ ....(1)

10.3 The balanced cell (or redox) reaction

[illegible] ....(4)

11. What will happen if the salt bridge is removed?

[illegible]

[illegible]

....(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

[illegible]

[illegible]

....(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Cu^{2+} + 2e^- \rightleftharpoons Cu$ ....(1)

10.2 The Oxidation half reaction $Zn \rightleftharpoons Zn^{2+} + 2e^-$ ....(1)

10.3 The balanced cell (or redox) reaction

ZnCu ....(4)

11. What will happen if the <u>salt bridge is removed</u>?

Many of the positive and negative elections will be unbalanced

The cycle of elections gets completed through it. ....(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

....

....

....

....

....

....

....

..........(7)

Total:30

7. Read the following list of different forms of energy: kinetic; heat; light; chemical; potential; total mechanical; electrical; nuclear.

Now select two of these forms of energy and write them down in the missing spaces in the following sentences:

In this electrochemical cell ..CHEMICAL...potential energy

is converted into ELECTRIC.........potential energy. (2)

8. Which of the two metals undergoes an observable increase in mass while the cell functions after a few minutes at room temperature

....(1)

9. Suggest as many different functions of the salt bridge as you can.

....

....

....

....

....

....

....

....

....(4)

10. Pick up the redox table and use it to write down the following reactions occuring in the diagram:

10.1 The Reduction half reaction ....(1)

10.2 The Oxidation half reaction ....(1)

10.3 The balanced cell (or redox) reaction

....(4)

11. What will happen if the salt bridge is removed?

..............An Explain..

....(2)

7. Read the following list of different forms of energy: <u>kinetic</u>: <u>heat</u>: <u>light</u>: <u>chemical</u>: <u>potential</u>: <u>total mechanical</u>: <u>electrical</u>: <u>nuclear</u>.

Now select two of these forms of energy and write them down in the missing spaces in the following sentences:

In this electrochemical cell ....potential energy is converted

into ....potential energy. (2)

8. Which of the two metals undergoes an observable increase in mass while the cell functions after a few minutes at room temperature?

....(1)

9. Suggest as many different functions of the salt bridge as you can.

It serves as a pathway for electrons.
Electrons flow from the positive pole to the negative pole through it.

....(4)

REDOX Mus Cat

23

ELECTROCHEMICAL CELL (GALVANIC) ANSWER SHEET

Write all YOUR answers on the question paper in the spaces provided.

Good Luck!

Answer the following questions about the cell experiment when it is operating under normal circumstances:

1. Using the six labels provided in the diagram, say which metal is the cathode?

...Copper..(1)

2. Is this metal, cathode, the negative or positive pole of the cell?

...~~negative~~ positive..(1)

3. Of the six labels provided in the diagram, say which metal is the anode?

...Zinc..(1)

4. Is this metal, anode the negative or positive pole of the cell?

...negative..(1)

5. Choose the correct word in brackets by writing your selected answer in the space provided: -

5.1 The anode is the electrode at which (oxidation / reduction) takes place.

...oxidation..(1)

5.2 The cathode is the electrode at which (oxidation/reduction) takes place.

...reduction..(1)

6.Complete the empty spaces in this statement by writing down the *names of the metals*: -

Current flows from the..Zinc.... ...electrode to the ..Copper....electrode (2)

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Cu^{2+} + 2e^{-} \rightleftharpoons Cu^{+}$ (1)

10.2 The Oxidation half reaction $Zn \rightleftharpoons Zn^{2+} + 2e^{-}$ (1)

2

10.3 The balanced cell (or redox) reaction

$Cu^{2+} + Zn \rightleftharpoons Cu^{+} + Zn^{2+}$ (4)

4

11. What will happen if the salt bridge is removed?

There won't be a flow of KCl into both containers, containing the two different metals keeping them balanced. (2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

(7)

Total: 30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction. $Cu^{2+} + 2e^- \rightleftharpoons Cu$ ....(1)

10.2 The Oxidation half reaction. $Zn \rightleftharpoons Zn^{2+} + 2e^-$ ....(1)

10.3 The balanced cell (or redox) reaction

$Zn + Cu^{2+} \rightleftharpoons Zn^{2+} + Cu$ ....(4)

4

11. What will happen if the <u>salt bridge is removed</u>?

....

....

....

....(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

....

....

....

....

....

....

....

....(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Cu^{+2} + 2e^{-} \rightleftharpoons Cu$ (1)

2

10.2 The Oxidation half reaction $Zn \rightleftharpoons Zn^{2+} + 2e^{-}$ (1)

10.3 The balanced cell (or redox) reaction

$Cu^{2+} + Zn \rightleftharpoons Cu + Zn^{2+}$ (4)

4

11. What will happen if the salt bridge is removed?

$CuSO_4$ will turn colourless

(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Zn^{2+} + 2e^- \rightleftharpoons Zn$ (1)

10.2 The Oxidation half reaction $Cu^{2+} + 2e^- \rightleftharpoons Cu$ (1)

10.3 The balanced cell (or redox) reaction

.... (4)

11. What will happen if the salt bridge is removed?

if the salt bridge is removed their would be an overflow of negative or positive electrons and it would not be balanced (2)

1

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

Electrochemicals can be use ~~in~~ for Solar energy, electric vehicles It can be used to build nuclear weapons. It can be used for computer in the world of technology

.... (7)

2

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction.... $Cu^{2+} + 2e^- \rightleftharpoons Cu$ ....(1)

2

10.2 The Oxidation half reaction.... $Zn^{2} + 2e^- \rightleftharpoons Zn$ ....(1)

10.3 The balanced cell (or redox) reaction

$Cu^{2} + 2e \rightleftharpoons Cu$

$Zn \rightleftharpoons Zn^{2+} + 2e$ $= Cu^{2} + Zn \rightleftharpoons Zn^{2} + Cu$ ....(4)

4

11. What will happen if the salt bridge is removed?

you'll have too much pos or neg

electrons being unbalanced

Erosion will not take place

....(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

....(7)

Total:30

10. Pick up the redox table and use it to write down the following reactions occurring in the diagram:

10.1 The reduction half reaction $Cu^{2+} + 2e^- \rightarrow Cu$ ....(1)

10.2 The Oxidation half reaction $Zn \rightarrow Zn^{2+} + 2e^-$ ....(1)

10.3 The balanced cell (or redox) reaction

........(4)

11. What will happen if the salt bridge is removed?

nothing

....

....

........(2)

12. List as many possibilities how the electrochemical cell can be used in the industries / the technological world.

electroplating

car batteries

....

....

....

....

....

........(7)

Total:30

SHANNON Du-Plooy.
NAZEREEN BASADIEN.

20

ELECTROCHEM AL CELL (GALVANIC) ANSWER SHEET.

Write all YOU answers on the question paper in the spaces provided. Good Luc

REDOX AND CAT

Answer the following questions about the cell experiment when it is operating under normal circumstances:

1. Using the six labels provided in the diagram, say which metal is the cathode ?

....(1)

2. Is this metal, cathode, the negative or positive pole of the cell ?

....(1)

3. Of the six labels provided in the diagram say which metal is the anode ?

....(1)

4. Is this metal anode, the negative or positive pole of cell ?

....

5. Choose the correct word in brackets writing your selected answer in the space provided.

5.1 The anode is the electrode at which (oxidation : reduction) takes place

....(1)

5.2 The cathode is the electrode at which (oxidation:reduction) takes place

....(1)

6. Complete the empty spaces in this statement by writing down the *names of the metals* -

Current flows from the .... electrode to the

.... electrode (2)

APPENDIX 5

Patt International Conference paper

PROCEEDINGS

of the

INTERNATIONAL

CONFERENCE

ON TECHNOLOGY EDUCATION:

Optimal Use of Resources

HELD IN CAPE TOWN

4 – 6 OCTOBER 2001

Published by

Cape Technikon, Cape Town, South Africa

ISBN 0-9584246-6-7

GALVANIC ELECTROCHEMICAL CELLS: A STUDY OF THE UNDERSTANDING AND KNOWLEDGE RESPONSES GENERATED BY MALE AND FEMALE STUDENTS TESTED AS INDIVIDUALS, IN PAIRS, AND IN GROUPS IN THEIR UNDERSTANDING OF TECHNICAL TERMS.

Moegamad Riedwaan Gallant
University of Cape Town
South Africa

ABSTRACT

As a sequel to the work of Meyer and Woodruff (1997) and Swain (1999) on the productivity of responses of groups in science lessons, this achievement study investigated summative technical knowledge responses of 437 physical science students after they had been taught and completed studying the topic *Galvanic Electrochemical Cells.*

The students were presented with a self-evaluation programme comprising 13 sections. They were placed randomly in one of three different types of grouping arrangement for the purpose of gathering the technical knowledge response data, namely: (1) individuals whose written responses were silent and solitary; (2) pairs of individuals who responded in writing after verbal discussions in twos; and (3) clusters of three to six students who responded collectively in writing after inter-group discussion of each achievement evaluation question. The findings were: (a) The mean electrochemistry achievement scores obtained under the three different grouping arrangements were: M_1 = 62.50% (N = 99 individuals); M_2 = 68.00% (N = 43 student pairs); and M_3 = 71.01% (N = 66 clusters of between three and six students each). (b) The differences in achievement scores were highly significant between grouping arrangements (1) and (3), i.e. between the students tested as individuals and the students tested as groups ($t = 3.51$; $p < 0.001$).

In their understanding of the anode and the cathode there was a significant difference in achievement between grouping mode 1 and grouping mode 3 ($t = 3.10$; $p < 0.01$). In their understanding of the oxidation-reduction equations there was a highly significant difference in achievement between grouping mode 1 and grouping mode 3 ($t = 4.64$; $p < 0.001$) as well as a significant difference between grouping mode 2 and grouping mode 3 ($t = 2.82$; $p < 0.01$). In their understanding of the functions of the salt bridge there was also a significant difference between grouping mode 1 and grouping mode 3. ($t = 2.16$; $p < 0.01$)

1. INTRODUCTION

The following is an explanation of the basic function of a galvanic electrochemical cell.

Electrochemistry can be described as that branch of chemistry which concentrates on the relation between electricity and chemical reactions. It also explains how chemical changes can produce electricity and how electrical energy can produce chemical change. (Ogude:1991:5). The kind of cell which converts chemical energy into electrical energy is known as a *galvanic cell.*

1.1 *Oxidation and Reduction*

Oxidation and reduction always work together into a redox reaction or a net reaction. The number of electrons generated in an oxidation half-reaction is equal to the number accepted in the reduction half-reaction. Electrons are neither created nor destroyed but are transferred directly on atomic contact (Ogude:1991:6;).

<u>We use a Cu-Zn cell as an example:</u>

At the Zn electrode the following takes place:

It loses electrons.
Oxidation occurs.
It becomes the anode.
It is known as the negative pole.
The mass of the Zn electrode decreases.
The oxidation half-reaction is: $Zn \longrightarrow Zn^{2+} + 2e^-$

Electrons flow through the external conductor to the copper electrode where they are accepted by the copper ions in solution.

At the Cu electrode the following takes place:

Electrons are taken up by Cu^{2+} -ions.
Reduction takes place.
It becomes the cathode.
It is known as the positive pole.
The mass of the Cu increases.
The reduction half-reaction is: $Cu^{2+} + 2e^- \longrightarrow Cu$
The total net reaction that takes place can be illustrated as follows:

$$\begin{array}{l} Zn \longrightarrow Zn^{2+} + 2e^- \\ Cu^{2+} + 2e^- \longrightarrow Cu \\ \hline Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu \end{array}$$

1.2 *The salt bridge*

The salt bridge consist of an ionic solution that is an electrolyte such as KNO_3 or KCl.

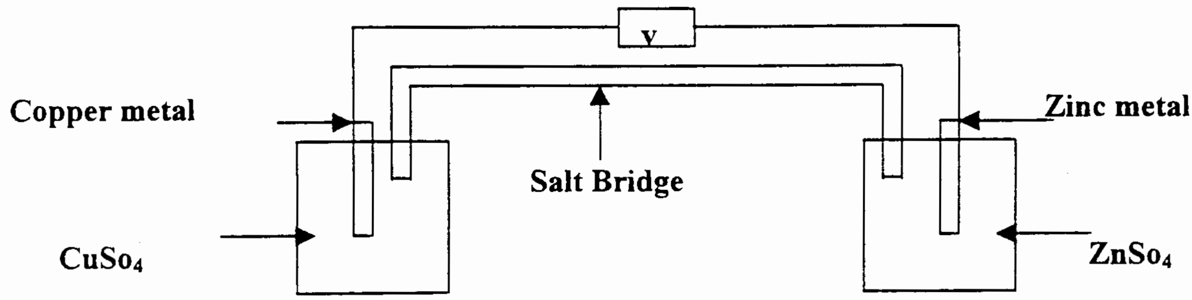
The functions of the salt bridge are:

It provides an electrical connection between the two half cells of a voltaic cell.

It keeps the two electrolytes separate so that they do not mix.

It ensures that the positive and negative charges are equal at all times during the operations of a galvanic cell.

It acts as a pathway in which ions can move to ensure electrical neutrality in the electrolytes in both half cells, i.e. it acts as an ion exchanger.



1.3 Electrical changes

The electrical wire and the voltmeter serve as paths for the electrons but they do not undergo any physical or chemical changes due to conduction. The electrical current in the operational cell takes place due to a movement of electrons in the electrode and a movement of ions in the electrolyte.

2. ORIGIN AND BACKGROUND OF THE PROBLEM

During the last few years there has been a substantial amount of research into students' understanding and interpretation of scientific concepts and phenomena. Research has been conducted because cognitive scientists and educational researchers found that many students gave unexpected explanations when they tried to interpret basic scientific phenomena (Ogude: 1991:1).

Chemistry is a difficult subject for many high school students and some university students (Bojczu, 1982) cited in Ogude (1991:8).

One of the reasons why students find difficulty in chemistry is because of the information overload (Kellet and Johnson, 1980) cited in Ogude (1991:8) and their inappropriate pre-requisite knowledge (McDermott, 1980) cited in Ogude (1991:8). Ben-Zvi, Eylon and Silberstein (1988), cited in Ogude (1991:9), says that the rapid transition between microscopic and macroscopic levels by experienced chemists poses a great problem for students during their early studies in chemistry. They argue that a major contributory factor in making chemistry difficult to comprehend is students' inadequate understanding of the atomic model together with the following three aspects:

(a) The abstract and non-intuitive nature of the concepts involved.

(b) The need to co-ordinate the levels of description in using the atomic model

(c) Communication; that is, the language for chemistry can be very difficult for a novice. For example, similar symbols can have different meanings according to the description being used. The symbol Cu for instance, can be used to refer to both an atom of copper and a piece of copper.

The topic electrochemistry is difficult for many students (Alsopp and George, 1982; Ainly, 1986; Chambers, 1983; Hillman, Hudson and McLean, 1982) cited in Ogude (1991:10)

Garnett and Treagust (1992a: 121) found that many students still experience problems in identifying oxidation-reduction equations Many students were reported to experience confusion when trying to identify the anode and the cathode in an electrochemical cell or diagram or experiment (Garnett and Treagust, 1992b: 1079).

Many students have been reported to lack an understanding of the underlying concepts of electrochemistry (Sanger, 1997:377). Garnett and Treagust (1990:147) also found that there were many factors which contributed to students' lack of understanding in electrochemistry. This lack also included students' inadequate prerequisite knowledge of the subject.

Ogude and Bradley (1994), cited in Sanger and Greenbowe (1997: 820), claimed that student misconceptions concerning current flow in electrolyte solutions and the salt bridge can be attributed to two factors :

(ii) reference by textbooks or by the instructor to continuity of current; and established belief in the electronic nature of current electricity; (for example phrases like "continuity of current" imply that current is uniform throughout the cell); and

(ii) careless discussion of the electrode process; (for example, textbooks with obvious mistakes or misleading statements can result in student misconceptions).

3. METHODOLOGY

3.1 Sample

The investigation used of 437 grade 12 students, 16-to 18-year-old boys and girls drawn from 15 high schools in the Western Cape, South Africa. Matriculation results of the past three years were used to see that all the schools were on par with each other.

3.2 The graded measures

Pupils, who had already completed the chapter on electrochemistry with their respective teachers, were invited to progress through a self-teaching and evaluation programme comprising a succession of graded diagnostic, evaluative tasks and questions. These were designed to evaluate the pupils' understanding of the operational details of a large picture of a Galvanic electrochemical zinc-copper cell; and a redox table with the EMF values of 48 chemical elements.

3.3 Procedure

The experimental procedure was as follows:

3.3.1 Instructions to the teacher

Each class was divided randomly into a system of three groups. As the students come into the classroom they were divided into their groups as they sat in their benches.

The students were divided into the following groups:

1. working individuals 10 X 1 = 10 students
2. working pairs 5 X 2 = 10 students
3. working clusters 2 X 5 = 10 students

3.4 Evaluation

The evaluation materials were administered by the researchers and / or the normal physical science teacher.

3.5 Hypothesis

Ho1 When 437 students are grouped to study and answer graded materials in electrochemistry for half an hour there will be no significant differences in achievement scores between the three types of grouping arrangement (individuals; pairs; clusters) on: -

One the total achievement test (scored out of 30);

Two the minor test of understanding of anode and cathode functions (scored out of 6);

Three the minor test of understanding of oxidation-reduction equations (scored out of 6);

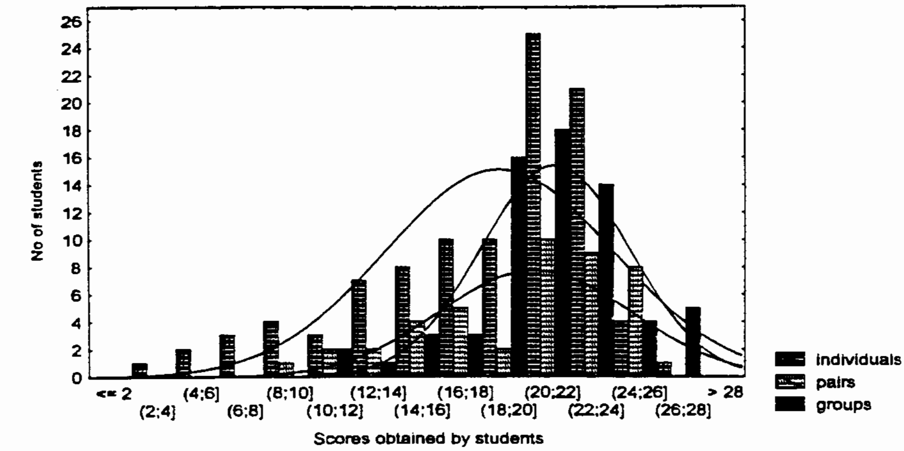
Four the minor test of the understanding of the functions of the salt bridge (scored out of 6)

4 RESULTS: QUANTITATIVE

Table 4.1 Achievement scores in the full electrochemistry test (out of 30) obtained by 437 physical science students with size of grouping as an independent variable.**(see p.6)**

Grouping Mode Arrangement		
Mode 1 99 individuals (N = 99)	Mode 2 43 student Pairs (N = 86)	Mode 3 66 clusters of 3-6 students (N = 252)
Mean + SD 18.75 $\pm$ 5.22	Mean + SD 20.40 $\pm$ 4.42	Mean + SD 21.30 $\pm$ 3.41
$t_{12} = 1.81$; $p = 0.073$; non-significant difference $t_{13} = 3.51$; $p < 0.001$; highly significant difference $t_{23} = 1.21$; $p = 0.23$; non-significant difference		

Fig.4.1 Simplified plot showing the different scores obtained by the individuals, pairs and groups in their full electrochemistry test scored out of 30



The null hypothesis Ho1 a is partially tenable. Table 4.1 presents the results of the achievement scores obtained by the cohort of 437 physical science students according to grouping mode. *It is found that there is no significant difference in achievement between grouping mode 1 and grouping mode 2 as well as grouping mode 2 and grouping mode 3. However there is a highly significant difference in achievement between grouping mode 1 and grouping mode 3.*

Table 4.2 Achievement scores in student understanding of the anode and cathode functions (out of 6) obtained by 437 physical science students with size of grouping as an independent variable.(see overhead projector)
Fig 4.2 Simplified plot showing the different scores obtained by the individuals, pairs and groups in their understanding of anode and cathode functions scored out of 6.(see overhead projector)

The null hypothesis Ho1 b is partially tenable. Table 4.2 presents the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of the anode and cathode functions according to grouping mode.

It is found that there is no significant difference in achievement between grouping mode 1 and grouping mode 2 as well as grouping mode 2 and grouping mode 3. However there *is a significant difference in achievement between grouping mode 1 and grouping mode 3.*

Table 4.3 Achievement scores in student understanding of oxidation-reduction equations (out of 6) obtained by 437 physical science students with size of grouping as an independent variable.(see overhead projector)
Fig 4.3 Simplified plot showing the different scores obtained by the individuals, pairs and groups in their understanding of the oxidation-reduction equations scored out of 6.(see overhead projector)

The null hypothesis Ho1 c is partly tenable. Table 4.3 presents the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of oxidation-reduction equations according to grouping mode. It is found that there is no significant difference in achievement between grouping mode 1 and grouping mode 2. *However there is a high significant difference in achievement between grouping mode 1 and grouping mode 3 and a significant difference between grouping mode 2 and grouping mode 3.*

Table 4.4 Achievement scores in student understanding of the functions of the salt bridge (out of 6) obtained by 437 physical science students with size of grouping as an independent variable.(see overhead projector)
Fig 4.4 Simplified plot showing the different scores obtained by the individuals, pairs and groups in their understanding of the functions of the salt bridge scored out of 6.(see overhead projector)

The null hypothesis Ho1 d is partly tenable. Table 4.4 presents the results of the achievement scores obtained by the cohort of 437 physical science students in their understanding of the function of the salt bridge according to grouping mode. It is found that there is no significant difference in achievement between grouping mode 1 and grouping mode 2 as well as grouping mode 2 and grouping mode 3. However there is *a significant difference in achievement between grouping mode 1 and grouping mode*

5. QUALITATIVE FINDINGS : ERROR-ANALYSIS

The various combinations of students produced 208 completed worksheets in total.
A comprehensive, detailed analysis of the students' responses is being prepared separately for publication elsewhere.

The main types of errors may be briefly summarised as follows:

(1) Conceptual difficulties occurred in the students' responses to questions 1, 2, 3, 4 and 5.
16 % of the students confused the functions of the

two different metals; i.e. the copper and zinc. They interchanged the polarity of the two metals. They had a misconception about the anode and the cathode; e.g. wrongly claiming that the anode is the positive electrode and it is where reduction takes place; the cathode is the is the negative electrode and it is where oxidation takes place

Cognitive difficulties: items 7,10

Q.7 Students did not understand the conversion of the different forms of energy in spite of being given the answers. Many students left blank spaces, and some guessed the answer. Many of the wrong answers claimed that heat potential energy is converted to chemical energy.

Q.10 Students did not understand oxidation-reduction equations. This resulted in the incorrect analyses of the redox reaction. Students wrote the oxidation half-reaction wrong. They copied directly from table e.g.

$Zn^{2+} + 2e^{-} \longrightarrow Zn$

(2) Perceptual difficulties: items 8,9

Q.8 Students were not sure in which direction the current flows, therefore they could not determine which metal increased in mass. E.g. students wrongly claimed that current flows from the copper plate to the zinc plate.

Q. 9 Students could not observe that the salt bridge served as a connector. E.g. students wrongly claimed that the $CuSO_4$ and $ZnSO_4$ solutions mix in the saltbridge.

6. DISCUSSION

The highly significant difference in achievement between the cluster groups and the individuals is consistant with the difference in achievement gains between groups and individuals recorded by previous researchers such as Swain (1999); Gayford (1989,1992,1993,1995); Gilbert and Pope(1986) and Wallace(1986).

7. RECOMMENDATIONS

The writer recommends that teachers and lecturers encourage the use of group discussion-based learning as a method of teaching electrochemistry. It is further suggested that teachers and lecturers might implement, after their lessons a pre-test followed by a remediation programme and a post-test to reinforce the subject matter.

8. CONCLUSION

In the investigation with 437 physical science students who were studying the topic *Galvanic Electrochemical Cells* it was concluded that the most productive grouping arrangement for accurate answeres was the *cluster grouping* method followed by the student *pair* arrangement followed by the arrangement in which students were required to respond as private *individuals*.

Statistically the *cluster grouping* arrangement was significantly better than the arrangement in which *individual* students were tested alone.

9. ACKNOWLEDGEMENTS

The author acknowledges with thanks the financial contributions of the National Research Foundation and the University Research Committee of The University of Cape Town to the development and dissemination of this research.

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BIOGRAPHY

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