

**THE USE OF STRUCTURED PROBLEM-SOLVING STRATEGIES TO IMPROVE
THE TEACHING AND LEARNING OF CHEMISTRY**

By

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**SUBMITTED IN ACCORDANCE WITH THE REQUIREMENTS FOR THE
DEGREE OF
DOCTOR OF PHILOSOPHY IN MATHEMATICS, SCIENCE AND TECHNOLOGY
EDUCATION**

IN THE SUBJECT

CHEMISTRY EDUCATION

AT THE

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: PROFESSOR C. E. OCHONOGOR

DECEMBER 2018

DECLARATION

I declare that the thesis “*Comparative effect of Selvaratnam-Fraser and Ashmore et al problem-solving models on Advanced Level students achievement in Stoichiometry and Ionic equilibria*” is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

.....SM.....
MR S MANDINA

10/12/2018...
DATE

DEDICATION

I dedicate this thesis to my wife Sandra and our three sons Rodney, Ryan and Reynold.

ACKNOWLEDGEMENTS

The completion of this thesis would not have been possible without the support of the people around me, to only some of whom it is possible to give particular mention here. I would like to express my sincere gratitude and appreciation to the following:

◆ Professor Ochonogor, Chukunoye Enunuwe and Dr Helen Letseka my research supervisors for their patient guidance and constructive critique on this research work. Your knowledge and academic experience have been invaluable to me.

◆ The Ministry of Primary and Secondary education, Provincial Education director (Midlands Province), the school heads, chemistry teachers, parents and learners for their permission to take part in the study and cooperation throughout the data-collection phase of the study.

◆ Special thanks to my wife, Sandra, my sons, father, mother, brothers and sisters. Without you it would not be possible for me to complete this qualification. You gave me the strength to carry on when times were tough.

◆ To the members of staff of the Institute for Science and Technology Education (ISTE), UNISA, I thank you for being such a great leaders and a scholars of note.

◆ I also thank all my colleagues at ISTE have always been comrades in the struggle.

◆ I am extremely grateful to my workmates Dr S.S Mashingaidze and Dr E. Nyoni for your encouragement. You have played a key role in the success of this research. My mere expression of thanks likewise does not suffice.

ABSTRACT

The study aimed to investigate effect of structured problem -solving instructional strategies on Advanced Level chemistry learners' achievement in stoichiometry and ionic equilibria. The population of the study consisted of Advanced Level Chemistry learners from 15 high schools in Gweru urban District of the Midlands province in Zimbabwe. Using convenience sampling techniques 8 high schools with n=525 Advanced level Chemistry learners and 8 teachers participated in the study. Four schools formed the experimental group (n=250) and the other four school formed the control group (n=275).

The study employed a quasi-experimental design with a non-equivalent control group approach consisting of pre-and post-test measures. Intact classes participated in the study as it was not possible to randomly select participants for the study. The qualitative part of the study involved conducting semi structured interviews with teachers, focus group discussions with learners as well as classroom observations. The quantitative data were collected using standardized achievement tests in stoichiometry and ionic equilibria.

The problem-solving instruction was implemented in four experimental schools by the respective chemistry teachers who had been trained as research assistants on the use of the problem-solving strategies in chemistry teaching. The four control schools were also taught by their teachers using the conventional lecture method. The constructivist theory framed the study. Analysis of Covariance (ANCOVA) was used to analyze data. The results of this study indicated that the participants in experimental schools performed significantly better than participants in control schools on certain aspects of problem solving performance. Furthermore semi-structured interviews, focus group discussions and classroom observations revealed that participants rated problem-solving instruction highly as an effective teaching strategy to enhance the problem solving skills of learners in A' level chemistry. The Scheffe's post hoc test indicated that students taught using the Ashmore et al problem-solving

instructional strategy performed better than those taught with the Selvaratnam-Fraser problem-solving strategy. The study also revealed that student had difficulties with the mole concept, Avogadro's number, limiting reagents as well as determining theoretical and percentage yields. Students were also found to have difficulties with acid-base theory, buffer solutions, and application of Le Chatelier's principle in solving buffer equilibria problems and solubility equilibria. Furthermore the study revealed that students rely on algorithmic strategies when solving stoichiometry and ionic equilibria problems and do not demonstrate adequate understanding of the concepts involved. It is therefore strongly recommended that chemistry teachers use problem-solving instructional strategies in their classes to facilitate students' problem solving performance. In addition pre-service chemistry teachers should be properly trained in instruction that promotes problem solving and how to implement effective problem-solving instruction. Furthermore, in-service training for practicing chemistry teachers is recommended so that they can embrace the skills of the problem-solving strategies for effective implementation of the strategies in teaching chemistry.

KEY TERMS

Problem-Solving Instructional Strategies

Problem-Solving Skills

Stoichiometry

Ionic Equilibria

Constructivist Theory

Advanced Level learners

Academic achievement

Conceptual understanding

Traditional or Conventional method

Algorithmic strategies

ABBREVIATIONS

ANCOVA	Analysis Of Covariance
H_0	Null Hypothesis
H_1	Alternate Hypothesis
IEAT	Ionic Equilibria Achievement Test
PSI	Problem Solving Instruction
SAT	Stoichiometry Achievement Test
SPSS	Statistical Package For Social Scientists
ZIMSEC	Zimbabwe Schools Examinations Council

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CHAPTER ONE

ORIENTATION AND OVERVIEW OF THE STUDY

1.1 Background to the study

Chemistry is one of the school subjects upon which technological scientific development of a nation is hinged. It is relevant for the metallurgical, medical, and agricultural as well as petroleum and petrochemical industries. Through the teaching of chemistry, learners should be able to acquire knowledge and requisite skills for them to be able to fully and effectively participate in the technological and industrial development of their nation. However, the majority of secondary school students find chemistry to be a difficult subject to learn due to its complex, abstract and conceptually demanding nature (Childs and Sheehan, 2009; Kamisah and Nur, 2013 ; Agogo and Onda, 2014 ; Adesoji, Omilani and Dada, 2017). Because the subject is conceptually difficult and complex in nature (Childs and Sheehan, 2009) it becomes critical that chemistry educators identify chemistry topics that students find difficult that serve as barriers to in-depth learning of concepts in chemistry so as to improve their teaching as well as student achievement in chemistry.

According to Novak (2002) meaningful learning is built around what the learner already knows hence there is need for learners to grasp the underpinning abstract chemistry concepts that are central for further learning in chemistry. These abstract concepts are critical because further chemistry concepts and theories cannot be understood if these underpinning concepts are not effectively grasped by students (Coll and Treagust, 2001). On the same note, Kazembe and Musarandega (2012) note that a high degree of quality skills are required in the chemistry class for students to be able to deal with the abstract concepts as well as the

learning difficulties in the discipline. Furthermore the study of chemistry is characterized by a constant interplay between macroscopic and microscopic levels of thoughts (Sirhan, 2007), and it is this aspect of chemistry learning that present a significant challenge to the novice.

Studies conducted by Childs and Sheehan (2009), in Ireland, Ratcliffe (2002), and Bojezuk (1982) in the UK, Johnstone (2006), in Scotland as well as Jimoh (2005), Nigeria looked at the perception of difficult topics in the chemistry curriculum by students in secondary schools. In these studies learners identified a number of topics in chemistry that are difficult to handle. The topics identified include the mole concept, the Avogadro's number, stoichiometric calculations in volumetric analysis, titration analysis, redox reactions, chemical equilibrium calculations, synthesis in organic chemistry, reaction mechanisms in organic chemistry and the reactions of organic compounds.

Students find many concepts in chemistry difficult to learn (Naah and Sanger, 2012; Barke, Hazari and Yitbarek, 2009), and several chemical education researchers have focused their efforts on identifying common student difficulties in chemistry (Cokelez and Dumon, 2005; Drechsler and Schmidt, 2005; Kelly and Jones, 2007; Costu, 2008; Papaphotis and Tsaparlis, 2008; Schmidt, Kaufmann, and Treagust, 2009; Cartrette and Mayo, 2011; Smith and Nakhleh, 2011). Stoichiometry and ionic equilibria are among the important topics in chemistry that students find difficult (Okanlawon, 2008a; Hawkes, 1998; Tan, Treagust, Chandrasegaran and Mocerino, 2010; Yıldırım, Kurt, and Ayas, 2011; Horton, 2007; Kind, 2004; Chiu, 2005; Sirhan, 2007). There is a relationship amongst many concepts in chemistry. One of the most important tools in the chemistry toolbox' is stoichiometry (Okanlawon, 2010) since knowledge of its fundamental concepts is required for chemical and ionic equilibrium problem-solving (Evans, Yaron and Leinhardt, 2008). This is because a learner who has not developed proficiency in stoichiometry will have difficulties in solving

chemical and ionic equilibria problems. In light of the above discussion an examination of the problems encountered by students in learning the two abstract topics of stoichiometry and ionic equilibrium will be done. Stoichiometry is a difficult topic to understand, and students have been shown to have difficulty solving conceptual problems that require understanding of the concepts at the macroscopic and sub-microscopic as well as symbolic levels (Tan et al, 2010). As noted by Chong (2016), the macroscopic level deals with the observable chemical phenomena that can include experiences from students' everyday lives such as colour changes, observing new products being formed and others are disappearing. In order to communicate about these macroscopic phenomena, chemists commonly use the symbolic level of representation that includes pictorial, algebraic, physical and computational forms such as chemical equations, graphs, reaction mechanisms, analogies and model kits (Chittleborough and Treagust, 2008). The submicroscopic level of representation is based on the particulate theory of matter and is used to explain the macroscopic phenomena in terms of the movement of particles such as electrons, molecules, and atoms. These submicroscopic entities are real but they are too small to be observed, so chemists describe their characteristics and behavior using symbolic representations to construct mental images. It is important to note that all three levels of representation are integral in developing an understanding of the stoichiometry concepts under investigation. Consequently, the ability of students to understand the role of each level of chemical representation and the ability to transfer from one level to another is an important aspect of understanding stoichiometry concepts (Treagust, Chittleborough and Mamiala, 2003).

The process of solving quantitative problems in stoichiometry involves the application of difficult concepts such as balancing equations, using the balanced chemical equations to calculate the masses of chemical substances involved in the reactions, the subscripts and coefficients in an equation, mole-mass relationship and ratios to be used in calculations,

excess and limiting reagents, conservation of mass/matter and interpretation of a word problem into procedural steps that lead to the correct answer (Okanlawon, 2010 ; Sanger, 2005; Gauchon and Meheut, 2007; Chandrasegaran, Treagust, Waldrip, and Chandrasegaran, 2009). Problematic issues in stoichiometry that students grapple with include identification and distinguishing the limiting reagent (Tóth and Sebestye'n, 2009), the concept that the limiting reagent is a fundamental part of a reaction in preference to the function of the amounts of reagents available for the reaction (Upahi and Olorundare, 2012), frustrations when mole proportions are not one to one (Perera and Wijarante, 2006), as well as lack of conceptual understanding when solving novel problems (Chandrasegaran, Treagust, and Mocerino, 2011).

The other topic that secondary school chemistry students find problematic is ionic equilibrium. Lin and Chiu (2007) have shown that the sub-microscopic and symbolic representations of acids and bases make understanding of acids and bases challenging for students at all levels with students having difficulty with the concepts of weak and strong acids and fail to identify the submicroscopic representations of strong and weak acids. At the symbolic level, the models of acids and bases are also a problem to students as the use of the different models is seldom clarified by teachers or textbooks (Drechsler and Schmidt, 2005) while determining the pH of polyprotic acids such as sulfuric acid, presents problems for students as they have to consider and understand successive dissociations of such acids, and how these impact on pH calculations (Demerouti, Kousathana and Tsaparlis, 2004).

Teachers play a very crucial role in promoting students' learning and understanding since they influence what students are taught and how they are taught, and thus are key to students' achievement (Tobin, 1998). For meaningful learning of stoichiometry and ionic equilibria to take place, teachers have to transform subject matter knowledge into a form that is

comprehensible to the learners and guard against the danger of misrepresenting it (Clermont, Borko and Krajcik, 1994). Research reports that in solving chemistry problems, most chemistry teachers and text books emphasize on the use of algorithmic methods (Okanlawon, 2010; Niaz and Montes, 2012) characterized by use of memorized formula, manipulation of the formula and plugging in numbers until they fit. This emphasis on algorithmic problem-solving results in limited understanding of stoichiometry and ionic equilibrium concepts by students as a result they have difficulties in solving stoichiometry and ionic equilibria problems (Artdej, Ratanaroutai, Coll and Thongpanchang, 2010; Hanson, 2016).

The algorithmic approach to problem solving as noted by Surif, Ibrahim and Mokhtar (2014), is a quantitative mathematical based approach that demands the memorization and manipulation of formulas. Such an approach according to Cardellini (2014), does not ensure that students learn to solve problems and above all to think about the solution process in a consistent manner. Consequently, students are at risk to become more proficient at applying the formulas rather than to reason. The use of algorithms is disadvantageous in that they lose their value when the student encounters a problem for which the algorithm is not appropriate. Robinson (2003), further notes that the algorithmic approach to problem solving hinders the development of chemistry students' conceptual understanding and higher-level thinking skills and as a consequence learners are unable to transfer what is learned in one context or setting to another context or setting. Hence learning is situated in the original learning context thus further preventing students from coming up with a well-reasoned solutions to the quantitative problem at hand.

Furio, Azcona, and Guisasola (2002), further note that students' conceptions of the underlying stoichiometric concepts such as the mole are a consequence of those held by educators and that these views differ from those expressed by the scientific community in the

International System. For example Strömdahl, Tulberg and Lybeck (1994), carried out an interesting study on the concept of mole among educators, and found that only 11% identified the mole as the unit of, 'amount of substance'. Most of them selected the options that identified it with Avogadro's number (61%) and with the mass (25%). Tullberg, Strömdahl, and Lybeck (1994), showed that the concepts that are problematic to students are those which are not presented during instruction but are assumed to be known, for example, the differentiation between molar mass and atomic or molecular mass. These authors indicated that educators are highly conditioned by their own conceptions of the mole, and that it is necessary to know all the implications of the definition of the International System if teachers are to become aware of their own conceptions.

Drechsler and Schmidt (2005), have shown that chemistry teachers have problems in understanding the role of models in general as well as in chemistry to describe acid-base reactions. They tend to use hybrid models in their teaching instead of specific historical models (Justi and Gilbert, 2000). Hybrid models result from merging or combination distinct attributes from several scientific models. Studies by Kousathana, Demerouti, and Tsaparlis (2005), as well as Ekiz, Bektas, Tuysuz, Uzuntiryaki, Kutucu and Tarkin (2011), in the teaching of ionic equilibria suggest that chemistry teachers could not understand difference between ionization and dissolution processes as a result of inappropriate explanations and representations in chemistry textbooks. These authors also found that teachers had difficulties in drawing ionization and dissolution process at the microscopic level. Since they could not distinguish ionization and dissolution concepts, they failed to represent these processes. Such confusion about these concepts in ionic equilibria has unfavorable consequences on student learning.

The problem of learner difficulties in chemistry is prevalent throughout the world and Zimbabwe is no exception. A study by Kazembe and Musarandega (2012), investigated Student Performance in Advanced-level (A-level) chemistry examinations in one district in Zimbabwe. The findings revealed that the performance of students was low because there was too many contents to master and concepts were very difficult to understand. The students felt that examination questions were also difficult to interpret and determine what they required. Students also said the topics were difficult because they involve abstract concepts such as calculations, citing stoichiometry, pH and pK_a in Chemical Equilibria which were bulky and involving complex calculations.

According to Kazembe and Musarandega (2012), learners face difficulties in stoichiometry and ionic equilibria a sentiment also shared by their teachers who also note that stoichiometry and equilibria are difficult to teach. The Zimbabwe Schools Examinations Council (ZIMSEC, 2013), chemistry examiners report indicates that students have difficulties in tackling questions involving numerical calculations and writing of balance equations. The report further noted poor performance of students on questions involving calculations on the mole concept and ionic equilibria. The ZIMSEC (2014), report has it that most chemistry candidates displayed inability to use the mole concept in deducing empirical formula as well as inability to carry out routine calculations involving moles and reacting masses. Furthermore, ZIMSEC (2015), examiner's report also identified student challenges in calculating pH of a buffer solution as well as failure to identify that degree of dissociation of a weak acid increases on dilution.

From the discussions above it is observed that students experience difficulties with quantitative chemistry problems which are a major obstacle in chemistry learning. This situation is however, not peculiar to Zimbabwe alone but other developed and developing

countries have identified similar difficulties in problem-solving. Researches in problem solving consequently have resulted in the development of some models to address students' problem-solving challenges and improve their capabilities in problem-solving (Asieba and Egbugara, 1993; Ogwuche and Kurumeh, 2011). The application of problem solving models largely depends on the ability of the learners to master their heuristics and use a problem-solving model.

Efforts to develop instructional strategies to enhance student's problem-solving abilities in chemistry have led to the development of many problem-solving models and has seen the establishment of these models in teaching and learning basic science (Adigwe, 1998; Nbina and Joseph, 2011). This has resulted in the enhancement of the academic achievement of students. Studies by Wood and Lindsay (2005), have shown that if learners receive special instruction in problem solving procedures their performance can be substantially improved. In the Zimbabwean context no research has attempted to study how structured problem-solving instructional strategies can promote students' learning and understanding in chemistry. This study, therefore, seeks to investigate how selected structured problem-solving strategies (Ashmore, Casey and Frazer, 1979; Selvaratnam and Frazer, 1982) can facilitate Zimbabwean Advanced Level chemistry students' abilities in solving standard quantitative chemistry calculations in stoichiometry and ionic equilibria.

If students are to become proficient in chemistry, they need constant and frequent exposure to opportunities that engage them in problem solving. As highlighted by Kilpatrick, Swafford and Findell (2001), proficiency in chemistry is characterized by learning chemistry successfully in a way that develops understanding of chemistry. If Zimbabwe is to create a generation of chemical educators, scientists, and researchers, there is need to ensure that the teaching and learning of chemistry promotes proficiency in chemistry (National Council of

Teachers of Mathematics, 2009; Stein, Remillard, and Smith, 2007). A student who is proficient in chemistry has the ability to demonstrate problem-solving characteristics such as reading and understanding problems as well as coming up with appropriate strategies and solutions (Kilpatrick et al., 2001). On the other hand students who are not proficient in the subject attempt to solve problems without making sense of the context of the problem and are less likely to use their knowledge of subject content while solving problems (Council of Chief State School Officers, 2010). This study aimed to investigate the effects of an instructional intervention (i.e., teaching chemistry through structured problem-solving strategies) as a means of promoting learning and understanding in chemistry among Advanced Level learners.

1.2 Statement of the problem

Students in all countries find chemistry a difficult subject (Sirhan, 2007) and results are generally low, in Zimbabwe the A-level chemistry pass rate has become a major source of concern for stakeholders in education. Tertiary institutions are finding it difficult to enroll sufficient numbers of candidates in chemistry departments because of dwindling numbers of students satisfying the entrance requirements (Uchegbu, Oguoma, Elenwoke, and Ogbuagu, 2016). This can have adverse effects on the advancement of science and technology in the country. Analysis of A-level results for the four years (2007-10) reveals that student performance in chemistry is lower than biology, physics or mathematics (Kazembe and Musarandega, 2012). The low pass rate probably contributes to the decline in the numbers of students willing to study chemistry at A-level as the results cause students to regard chemistry as a difficult subject, an observation which at times repels learners from the subject. Research literature indicate that learners have difficulties and misconceptions in stoichiometry and ionic equilibria regardless of their system of education (Adesoji and

Babatunde, 2008; Okanlawon, 2010; Niaz and Montes, 2012; Demerouti et al., 2004; Lin and Chiu, 2007; Drechsler and Schmidt, 2005). Students develop learning difficulties and misconceptions when there is no proper effective teaching. According to Bilgin and Geban, (2006), these misconceptions and learning difficulties hinder effective learning and chemistry educators should therefore find ways of addressing these through the use of effective instruction. Misconceptions and learning difficulties in learners result in poor performance in the national examinations with poor quality passes. ZIMSEC examiners report (ZIMSEC, 2014 and 2015) report students' shallow understanding of the concepts in stoichiometry and ionic equilibria, inability to tackle numerical problems and poor mathematical skills.

In Nigeria the story is not different as the Chief Examiners' Report on the West African Examination Council; WAEC (2010, 2011) has it that, most of the chemistry candidates displayed inability to accurately perform stoichiometric and chemical equilibrium calculations (Upahi and Olorundare, 2012; Ahiakwo, 2016). Reports from USA also indicate that stoichiometry is a difficult topic for students (ACS Examinations Institute, 2015). A review of National Certificate examination reports in South Africa revealed that students have difficulty in solving conceptual questions about chemical equilibrium. The examination reports commented on weak performance of conceptual questions of chemical equilibrium and attributed this to student inability to transfer knowledge to new problem situations (DBE, 2013).

The poor problem solving ability of students points to a likely deficiency in instructional methods, a conclusion also drawn by Gabel (2003). The neglect of students' centered learning strategies has been identified as one of the major reasons for students' poor performance in secondary science education (Gongden, 2016). Chemistry educators in Zimbabwe need to give due consideration to the teaching methods and strategies employed to

teach difficult topics like stoichiometry and ionic equilibria so as to improve academic performance and abilities of the learners to solve standard quantitative chemistry calculations.

Given this background, the researcher observed the need to identify ways and means to redress the problem of poor performance in chemistry by investigating the state of problem solving skills among learners of chemistry, given that this is largely a function of their success. The focus was on improving learners' abilities to solve standard quantitative calculations through the use of structured problem-solving instructional strategies to promote learning and understanding in the teaching of stoichiometry and ionic equilibria. The problem to which this study is addressed is therefore: What is the effect of structured problem solving strategies in the improvement of teaching and learning of chemistry?

1.3 Purpose of the study

The main purpose of this study was to find out the effect using of structured problem solving strategies due to Ashmore, Casey and Frazer (1979), and Selvaratnam and Frazer, (1982), on the achievement of Advanced Level chemistry learners in stoichiometry and ionic equilibria in Gweru district in Zimbabwe. The research study will be a comparison between the use of structured problem solving models and their nonuse to determine which if these two models would be more effective in the teaching of stoichiometry and ionic equilibria to A-Level chemistry students in Zimbabwe.

1.3.1 Objectives of the study

In order to achieve purpose of the study, the following objectives were identified:

- i) To identify the difficulties encountered by students as they solve standard quantitative chemistry problems in stoichiometry and ionic equilibria.

ii) To determine whether the structured problem-solving strategies have any effect on the achievement of Advanced Level chemistry learners in solving standard quantitative calculations in stoichiometry and ionic equilibria.

iii) To evaluate the experiences of learners taught using these problem-solving instructional strategies.

1.4 Research Questions

The following were the research questions to guide the study:

1.4.1 Main research question

What will be the effect of use of structured problem-solving strategies on learners' achievement in solving standard chemistry quantitative calculations in stoichiometry and ionic equilibria?

Hypothesis: There is no significant difference in the mean achievement scores of students taught using structured problem-solving strategies and those taught with the conventional method.

1.4.2 Sub research questions

1. What difficulties do learners encounter as they solve standard chemistry quantitative calculations in stoichiometry and ionic equilibria?
2. What is the effect of structured problem-solving strategies on learners' achievement in solving standard chemistry quantitative calculations in stoichiometry and ionic equilibria?
3. What are the experiences of learners taught stoichiometry and ionic equilibria using structured problem-solving instruction?

1.5 The Significance of the study

The findings and recommendations of the study will benefit Chemistry educators as the effects of using problem-solving models will be documented. When educators refer and implement the recommendations of this study, their effectiveness will be improved. Since stoichiometry and ionic equilibria are problematic to learners, novice chemistry educators will benefit as they will be equipped with strategies on how to effectively teach the two topics leading to an improvement in their teaching and the reduction of students' misconceptions in the topics.

The study is also significant in that it will equip teachers with knowledge of teaching strategies that they implement in their classes to address students' learning difficulties and misconceptions. This will help promote conceptual understanding and minimize the formation of alternative conceptual frameworks among students. When educators use problem – solving methods in teaching and learning, learner performance will improve thereby creating scientific literate citizens. The research findings and recommendations will guide the Ministry of Primary and Secondary Education in instituting professional development programs meant to equip chemistry educators with problem – solving skills that will improve their classroom practice. The study will also help the curriculum development unit to develop materials and computer packages that are in sync with problem-solving teaching strategies.

1.6 Delimitations of the Study

The focus of the study is on investigating the effect of Ashmore, Casey and Frazer (1979) as well as Selvaratnam and Frazer, (1982) problem-solving instructional strategies on the achievement of Zimbabwean A-Level chemistry students in stoichiometry and ionic

equilibrium. The study was confined to Gweru Education district in the Midlands province in Zimbabwe. The study was limited to stoichiometry and ionic equilibria with the following fundamental concepts: the mole, the Avogadro constant, balancing chemical equations, limiting reagents, Bronsted-Lowry theory of acids and bases, buffer solutions, solubility product and the common ion effect.

1.7 Limitations of the study

The non-equivalent control group design employed in the study used intact classes hence it was not possible to assign the participants randomly to the treatment and control groups. The study also made an attempt to ensure that the sample is representative of the target population, however there is need to exercise caution when generalizing the findings of the study beyond participants and the geographical location where the intervention was implemented. Conclusions should, therefore, not be extended beyond the city in which the experiment was conducted. In addition, the study addressed the performance of learners in problem solving focusing on only two sections of the A' Level chemistry syllabus, namely, Stoichiometry and Ionic equilibria.

1.8 Operational Definition of Terms

1.8.1 Problem

Krulik and Rudnick (1988), defined a problem as "a situation . . . that requires resolution and for which the individual sees no apparent or obvious means or path to obtaining the solution" (p. 3). As noted by Kroll and Miller (1993), a problem arises when a task provides some form of blockage for the learners and the problem solver needs to develop a more productive way of dealing with the given situation. Lester (1983), defined a problem as a task for which:

The individual or group confronting it needs to find a solution; there is not a readily accessible procedure that guarantees or readily determines the solution and the individual or group must make an attempt to find a solution (p.231-232).

Based on these definitions, the study defines a problem as a task eliciting some activity on the part of the learner where a learner does not have an immediate known solution, and through which they learn chemistry concepts.

1.8.2 Problem-solving

According to Surif, Ibrahim and Mokthar (2012), problem-solving is defined as what is done by an individual when faced with a question or situation where the solution is not available. In seeking a way out from any obstacle, students should think, make decisions and use specific strategies (Ashmore et al., 1979). According to Ofori-Kusi (2017), problem-solving is an activity requiring a learner to engage in a process of finding a solution to a problem using knowledge and skills. Therefore, to achieve this, the activity of thinking and skills to rationalize a solution plays an important role. It will require the learner to generate and induce systematic and logical thinking. This ability requires learners to follow certain steps and logic because it requires a revision to determine the reasonableness of a settlement. In the context of this study, problem-solving is the process where the learner uses knowledge and thinking skills to solve standard quantitative chemistry calculations.

1.8.3 Problem-solving skills

According to Renkl and Atkinson (2010), problem solving skills are defined as capabilities and abilities of the learners to solve problems from intellectual domains such as mathematics, physics, chemistry and biology. In the context of this study, problem solving skills are manifested when participants succeed in applying previously learnt problem solving knowledge to solving standard quantitative chemistry calculations problems.

1.8.3 Alternative Conceptions

According to Helm (1980), alternative conceptions are conceptions generated which are parallel to the scientific conceptions. They are otherwise known as misconceptions or

alternative frameworks. They are ways of thinking about a particular phenomenon in a less familiar area that lead to novices coming to the wrong conclusion (National Research Council, 2000). In this study, alternative conceptions refers to those ideas that learners have which do not match or are different from science.

1.9 Organization of Thesis

The thesis consists of five chapters with each explaining one essential component of the work or the other. Chapter One contextualizes the research problem and provides a basis and justification of the study. It highlights the problem statement, the research questions and significance of the study as well as the delimitations of the study.

Chapter Two presents the review of relevant literature to gain insight into certain issues critical to the study. It addresses the conceptual framework that guided and informed the study. It also gives an overview of nature of stoichiometry and ionic equilibria concepts and explains the common difficulties the learners encounter as they solve quantitative chemistry calculations. Chapter three describes the methodology that was adopted to assess the effect of the structured problem-solving strategies which followed a mixed method approach. The issues addressed in this chapter include the research paradigm, research design; research population, sample population and sampling techniques; instrumentation, development, validity and reliability of instruments; pilot study, ethical issues, methods of data collection and analysis.

Chapter four presents, the quantitative and qualitative results of the study. The chapter reports on statistical changes in the learners' test scores in stoichiometry and ionic equilibria after their participation or non-participation in the structured problem-solving instructional method. The analyzed samples of answers learners gave in the pre-test and post-test were

used to further support the statistical changes on the effects of the structured problem-solving instructional method on learners' achievement in stoichiometry and ionic equilibria.

Chapter five gives a summary of the findings and also provides conclusions and recommendations. The implications and limitations of the study findings are also presented in this chapter.

1.10 Reflecting on the Chapter

The study has identified the use of structured problem-solving strategies as an instrumental method in promoting learning and understanding of chemistry concepts. It is against this backdrop that the study makes an attempt to prove the efficacy of using structured problem solving strategies in improving achievement of chemistry students in stoichiometry and ionic equilibria. In this chapter, the background to the study, statement of the problem, objectives, research questions, justification of the study, and the structure of the study were briefly discussed.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

The primary focus of this chapter is to review literature on problem solving instructional strategies with reference to the teaching of stoichiometry and ionic equilibria. The literature review addresses the following aspects of the study: conceptual framework, nature of stoichiometry as a topic, student problem solving in stoichiometry, nature of ionic equilibria as a topic, student problem solving in ionic equilibria, conceptual and procedural knowledge in chemistry problem solving, algorithmic versus conceptual approaches in chemistry problem solving, why students use algorithms, student competence in problem solving and improving students' quantitative problem solving skills in stoichiometry and ionic equilibria.

2.2 Theoretical framework

The research study is underpinned by a constructivist perspective in connection with problem-solving regarding the teaching and learning of chemistry. According to Hiebert and Grouws (2007), learners construct their own chemistry knowledge by connecting chemistry facts, procedures and ideas. As a result, understanding or meaningful learning will involve not only internal or mental representations of individual learners, but also social and cultural aspects. As further noted by Lesh and Zawojewski (2007), the development of chemistry concepts and chemistry learners' problem-solving abilities is highly interdependent and socially constructed. Therefore, as suggested by Rigelman (2007), the teaching of chemistry through problem-solving provides opportunities for learners to gain understanding and attain higher levels of achievement.

Bodner and Orgill (2007), note that the theoretical framework of constructivism is grounded in the premise that learners construct new knowledge using their prior knowledge and past

experience as building blocks. Constructivism is a theory based on how people learn. When learners encounter something new, they have to reconcile it with their previous ideas and experience, changing what they believe, or discarding the new information as irrelevant. In any case, they are active creators of their own knowledge. However, as highlighted by Yilmaz (2008), constructivism is not a single or unified theory; rather, it is characterized by plurality and multiple perspectives. This variety of theoretical orientations explicate such different facets of constructivism as cognitive development, social aspects, and the role of context. Yilmaz (2008), further notes that educational literature identifies eighteen different forms of constructivism in terms of methodological, radical, didactic, and dialectical considerations. While there may be various theoretical perspectives about constructivism, many theorists and scholars place all forms of constructivism in three radically distinct categories: social, psychological or cognitive, and radical constructivism (Rolloff, 2010).

In order for teachers to have an effective constructivist classroom, they need to have an understanding of the three forms of constructivism (Powell and Kalina, 2009). Cognitive constructivism pioneered by Piaget is based on the premise that students learn from constructing their own knowledge thus places more emphasis on the role of the individual learner (Sensibaugh et al., 2017). Social constructivism on the other hand, pioneered by Lev Vygotsky is based on students interacting and collaborating with each other. It highlights the role of the group(s) of which the learner is a part (Powell and Kalina, 2009). The main proponent of radical constructivism was Ernst von Glasersfeld. Radical constructivism claims that knowledge is not a commodity which is transported from one mind into another. Rather, it is up to the individual to "link up" specific interpretations of experiences and ideas with their own reference of what is possible and viable. That is, the process of constructing knowledge, of understanding, is dependent on the individual's subjective interpretation of their active experience, not what "actually" occurs (Seyyedrezaie and Barani, 2013)

All three categories share the epistemological assumption that knowledge or meaning is not discovered but constructed by the human mind: students construct knowledge in the process of learning through interaction with phenomenon, as they develop shared-meaning of a phenomenon via interactions within a social context (i.e. culture) (Rolloff, 2010). Though the particulars of constructivist focused learning theory are often contested among Science Educators, it is generally agreed that students learn by making sense of phenomenon as they experience it, evaluate its evidentiary merits, and attempt to make sense of it within a socially acceptable context in light of prior knowledge (Freeman et. al, 2014). Some constructivists stress the role of social interactions in this process, while others do not. Most constructivists agree that learning occurs when individuals assimilate new information into existing mental models of the world, or construct – as a result of discrepant insights – new models that can accommodate both old and new insights gained from experience. All would agree the building of knowledge structures on the part of a student requires she or he be actively engaged in the process of learning.

From the foregoing discussion it is evident that these three forms of constructivism are applicable in the classroom, given the benefits of active learning in both individual and group settings (Freeman et al., 2014). Therefore, in this study the theoretical framework does not focus on any particular form of constructivism. Instead, efforts to promote teaching and learning and the abilities of students to solve standard quantitative chemistry problems is dependent on both group activities and individual efforts. The study emphasizes the broader outcome of gaining knowledge by building upon what students have already learned and experienced.

In the constructivist view of learning (Bodner, 1986), students actively participate in problem solving and critical thinking. Learning is thus an active process in which learners construct new ideas or concepts based upon their current ideas or past knowledge Guest (2004), further

states that in constructivist thinking the learner selects and transforms information, constructs hypotheses, and makes decisions, relying on their own developing cognitive structure to do so. They are constructing their own knowledge by testing ideas and approaches based on their prior knowledge and experience, applying these to a new situation, and integrating the new knowledge gained with pre-existing intellectual constraints. According to Dhindsa and Emran (2006), a constructivist view to learning involves the use of active learning strategies such as group work and discussion that allows the individuals to explore beyond the information given to them. The teacher and students are engaged in active dialogue where the main task of the teacher is to present information to be learnt to match the students' current state of understanding supported by their prior knowledge.

Duggins (2002), notes that in constructivism students take an active role in the learning process as they construct knowledge through integrating their prior knowledge and experience with new knowledge. In accordance with this teaching and learning style, the learning activities must be structured in such a way that they are meaningful, relevant and engage the students. Students create new knowledge through the use of problem-solving and critical thinking skills in applying prior knowledge to new situations (Sutton, 2003). As a learner centric paradigm constructivist pedagogy views education as means to encouraging the life-long process of intellectual character development. As noted by Chaney (2004), effective constructivist teaching thus enhances intellectual character because it facilitates higher order thinking and deeper knowledge as well as exposing learning which exceeds factual knowledge, and promotes problem solving and the discovery of meaning. It encourages students to manipulate ideas by synthesizing, explaining, hypothesizing, drawing conclusions and forming interpretations.

In constructivist perspective the role of the teacher is to act as a mentor and facilitator (Duggins, 2002). Duggins (2002), further opines that the teacher acts as a guide to the student throughout the learning process by stimulating the student's critical thinking skills and providing learning situations, environments, skills, content, and tasks that are relevant and realistic and simulate real-world contexts. The students are thus actively involved in knowledge construction instead of being passive recipients of knowledge. According to Wang (2003), this knowledge is constructed by devising appropriate tasks and questions that explore a student's understanding. This knowledge is not simply constructed by individual learners but is also co-constructed through social interaction (Simpson, 2002). As noted by Duggins (2002), this knowledge construction actively takes place in a social and cultural context and as such the quality of learning is heavily influenced by the quality of these interactions. Duggins (2002), propounds that the role of teacher as facilitator does not preclude the teacher from presenting new material in a formal class lecture; it just emphasizes the need to have the student actively involved in applying the knowledge in a problem-solving situation.

Barhoumi and Kabli (2013), opine that constructivist learning theory promotes problem solving situations. Indeed, the problem solving is viewed as a situation of basic constructivist learning. The primary aim of a problem solving situation is to put learner in a situation of a cognitive conflict in order to allow him to acquire new knowledge. The cognitive conflict triggered by problem solving is able to generate conceptual changes that allow learners to progress in the acquisition of knowledge. O'Shea and Leavy (2013), problem-solving requires learners to test ideas, examine hypotheses and formulate solutions when engaging in learning. Consequently chemistry problem-solving should be seen as the process of making sense of particular phenomena. It is also worth noting that individuals cannot solve chemistry problems in isolation and this necessitates collaborative work which is an

important aspect of learning through a constructivist perspective. Chemistry is about sense making hence problem-solving should play a central role in the teaching of stoichiometry and ionic equilibria.

Chemistry educators are therefore called upon to adopt a constructivist framework in structuring problem-solving activities in stoichiometry and ionic equilibria lessons. Since learning requires mental activity, the learner should be an active contributor to the educational process. Chemistry educators are therefore required to structure problem-solving instruction to increase the cognitive activity of the learner (Okanlawon, 2012b). Okanlawon, (2012b), further notes that learners must be dissatisfied with their present knowledge: therefore chemistry educators should design problem-solving activities in such a way that students will be exposed to challenging questions so as to confront their present problem solving capabilities. Since knowledge is socially constructed, problem solving activities should be designed to involve group and whole class activities through the use of the cooperative learning method of active learning where students are involved in some activity beyond listening to the teacher (Cardellini, 2006). According to Okanlawon (2012), learning needs application: therefore problem solving activities should be designed in such a way that students are required to deal with more stoichiometric and ionic equilibria problems that reveal applications of stoichiometric and ionic equilibria principles in a variety of chemical fields.

Despite the benefits of constructivism there are criticisms levelled against this approach. As constructivism is based on constructing knowledge, the biggest criticism is how this theory applies to novice learners. There is very little empirical evidence that supports that constructivist techniques work well with novice learners. The argument is that novice learners don't have the basic knowledge or the schemas necessary to construct knowledge

and the unstructured learning environments that are often used in constructivist classrooms do not prove to be very effective for these learners (Kirschner, Sweller, and Clark, 2006).

Another criticism of constructivism is that it can lead to “group-thinking”, which results in original or unique ideas being lost in favour of the ideas expressed by the majority. With the emphasis of group work in constructivism, there is the potential that individuals may conform their thinking to those expressed by the group, thereby resulting in the sacrifice of their individual point of view. This could result in students not performing well in things such as standardized testing (Fiore, 2009). Since discovery learning is a key component of the constructivist philosophy, it can be difficult to manage and organize content into a logical flow that would be accessible to learners. The delivery of disorganized content may result in decreased academic performance (Miller, 2002).

There is also the criticism that preparing and moderating a constructivist learning environment makes unreasonable time demands on the teacher or instructor. Developing learning tasks that are both authentic and provide opportunities for discovery learning require a great deal of planning and preparation. Also, there are greater time demands on the students. It may take longer for students to come to a conclusion and construct knowledge in a discovery type lesson than it would if the teacher or instructor just provided the information and then asked them to apply it to a given situation (Holloway, 1999).

In spite of these criticisms however, constructivism still remains a powerful force in the field of education. This is because constructivist-minded teachers help students to construct knowledge and do not place the responsibility for learning solely on students. In this way, students are transformed from being passive recipients of information to active learners in

educational environments (Alanazi, 2016). Furthermore, the constructivist theory is appropriate in this case as it helps learners to be guided by their curiosity when learning instead of being led by a large amount of instruction. In addition, the constructivist teaching approach used in this case – problem-solving represent minimally-guided instruction and uses extensive scaffolding and guidance during activities in learning environment (Kirschner et al., 2006). The scaffolding reduces cognitive load, provides expert guidance, and helps students acquire disciplinary ways of thinking and acting while still allowing room for the creative process (Hmelo-Silver et al. 2007). The problem-solving instruction helps teachers in teaching/learning environments nurture students to better explain their thinking and identify their limitations.

The traditional teaching approach (lecture method) is very common in Gweru district chemistry classrooms. The traditional chemistry classroom in Gweru district resembles a one-person show with a captive but largely uninvolved audience. Classes are usually dominated by lecture or direct instruction; there is a fixed body of knowledge that students must learn. Students are expected to blindly accept the information they are given without questioning the instructor (Stofflett 1998). The teacher seeks to transfer thoughts and meanings to passive students, leaving little room for student-initiated questions, independent thought, or interaction among students (VAST 1998). In this approach the teachers ignore the students consequently the mental level of interest of the students. The teachers focus more on coverage of the context and rote memorization on the part of the students. The students are

2.2.1 Problems and Problem Solving in chemistry

According to Hayes (1989), a problem is a situation where a gap exists between where an individual is now and where they want to be, and they don't know how to find a way to bridge that gap. Krulik and Rudnick (1980), describe a problem as a situation, quantitative or

otherwise, that confronts an individual or group of individuals, that requires resolution, and for which the individual sees no apparent or obvious means or path to obtaining a solution. Kroll and Miller (1993), highlight that a problem arises when a task provides some form of blockage for the learners and the problem solver needs to develop a more productive way of dealing with the given situation. Lester (1983), on the other hand describes a problem as a task for which the individual or group confronting it needs to find a solution for which there is not a readily accessible procedure that guarantees or readily determines the solution and the individual or group must make an attempt to find a solution. Based on these definitions, this theoretical framework defines a problem as a task eliciting some activity on the part of the learner where a learner does not have an immediate known solution, and through which they learn chemistry concepts.

One area of inquiry which has been of profound interest to cognitive psychologists and science educators is the manner in which people solve problems (Sensibaugh et al., 2017) as a result, the nature of the problem determines how problem solving is examined. Sensibaugh et al., (2017), categorise problems as either domain general or domain specific. Funke (2010), describes a domain-general problem, such as one encountered in everyday life, does not require any specialized knowledge while a domain-specific problem necessitates that particular knowledge be brought to bear to successfully solve the problem. Cracolice, Deming, and Ehlert (2008), classified problems as algorithmic and conceptual. Algorithmic problems require learners to execute a routine set of procedures to come up with a solution while conceptual questions require students to map out their own unique solution to a question. Reid and Yang (2002b), have highlighted that algorithmic questions are not problems at all, but exercises since they allow the learner to practice and demonstrate what they already know. However, for Bodner (1987), the categorization of a question as a problem or exercise is dependent on the level of engagement of the individual with the task.

If the method to the solution is readily available, then the question is an exercise but when the individual does not have a readily accessible procedure that guarantees or readily determines the solution, the question becomes a problem for them.

Hollingsworth and McLoughlin (2005), further categorize the nature of a problem based on its characteristic structure, whether it is well defined or ill defined. Problems that are well-defined have a prescribed method for finding the one correct solution. Such problems have been termed algorithmic problems (Cracolice et al., 2008). As further noted by Sensibaugh et al. (2017) problems that are well defined result in a limited number of solutions. In contrast, ill-defined problems are vague, present with relatively little information, and yield a greater number of solutions than well-defined problems. Ill-defined problems are novel problems that learners approach using a variety of methods to produce one of many possible solutions. A comparison of the features of well and ill structured problems is given in table 2.1 below. As it can be seen from the table, well-structured and ill-structured problems are different, based on the nature of the problem, solving processes, and solving components.

Table 2.1 – Comparison of well and ill structured problems

Criteria	Well-Structured problems	Ill-Structured problems
Goals	Present all elements of the problem with well defined, clearly stated goals.	Problem elements are unknown with vaguely defined or unclear goals
Knowledge Domain	well defined	Ill- defined
Constraints	well defined	usually not well defined
Solution process	Comprehensible, familiar and knowable method	Unfamiliar; no explicit means for action.
Solution	Possess one probable correct, convergent solution.	Possess multiple solutions or solution paths, and there is no consensual agreement on the appropriate solution.

Source: Reed, 2016

The development and enhancement of problem-solving abilities of students has long been an important objective of science education (DeHaan, 2009). Gunderson (2011), highlights that the assessment and evaluation of student achievement in problem-solving in mathematics and science is based on tasks with clearly defined goals and methods. Yet, in contrast, problems in the real world are ill-structured and ill-defined (Overton and Potter, 2008). This is a cause for concern among chemistry educators as learners are not acquiring adequate problem solving skills during chemistry courses (Delvecchio, 2011). This need can only be addressed if chemistry educators incorporate more ill-structured problems into the problem solving tasks they present as a way of providing learners with more opportunities to develop the flexible expertise needed to tackle more complex problems.

There are different definitions for problem solving in literature. Surif, Ibrahim and Mokhtar (2012), define problem-solving as what is done by an individual when faced with a question or situation where the solution is not available. In seeking a way out from any obstacle, students should think, make decisions and use specific strategies (Ashmore et al., 1979). According to Ofori-Kusi (2017), problem-solving is an activity requiring a learner to engage in a process of finding a solution to a problem using knowledge and skills. Therefore, to achieve this, the activity of thinking and skills to rationalize a solution play an important role. It will require the learner to generate and induce a systematic and logical thinking. This ability requires learners to follow certain steps and logic because it requires a revision to determine the reasonableness of a settlement.

Schoenfield (2013), emphasizes that for an individual to be successful in problem solving, it requires that individual to use problem solving strategies, known as heuristic strategies. As described by VanLehn et al., (2004), the heuristics will help the individual to transform a non-procedural cognitive skill to a procedural one. From the point of view of Metallidou (2009), problem solving is a goal-directed behavior requiring an appropriate mental representation of the problem and the subsequent application of certain methods or strategies in order to move from an initial, current state to a desired goal state. Reif (1981), stresses that successful problem solvers understand the problem by initially constructing a description of the problem, translating the problem into an easily understandable form thus helping in the search of an appropriate solution. Such a translation of the problem include key concepts required to describe the problem (Mataka et al., 2014). For instance, to solve a stoichiometric problem, a learner may need to include key concepts such as the mole, Avogadro's constant, balanced equations and others in the initial description of the problem.

Moreover, problem solving, as regarded by cognitive psychologists, encompasses self-analysis, observation, and the development of heuristics (Mataka et. al., 2014). The interest of

cognitive psychologists has been in examining the mental processes involved when individuals learn and solve problems. Cognitive psychologists stress a need for knowledge organization in order to improve the efficiency of retrieval of this knowledge from the conceptual schemata during problem solving (De Jong and Ferguson-Hessler, 1986). The hope is to organize and connect knowledge in long-term memory such that it is easily recalled when needed (Johnstone, 1991). This led to the development of cognitive approaches to solving problems.

Attempts have been made to breakdown the complex process of problem solving into manageable steps that are broadly applicable. Polya (1957), proposed a four-step model for solving mathematical problems. According to Delvecchio (2011), first, the learner must understand the problem. This involves identifying what is known and what relevant data are given, creating a representation of the problem that might include a diagram or flow chart, and recognizing the various parts of the problem. Second, the learner devises a plan to find the connection between the given information and the goal of the problem. At this stage, the learner should recall other problems that may be similar to the new task or that may allow the learner to solve a part of the new problem. Third, the learner carries out the plan and checks each step. Lastly, the learner looks back at the solution to check for correctness, to propose alternate approaches, and to note how this solution might be useful to solve a different problem.

This study includes the implementation of structured problem-solving instructional strategies aimed at promoting students' problem solving skills. In this study, the researcher sought to investigate whether or not structured problem solving strategies improve problem solving abilities of Advanced level learners. It is important to note that problem solving is an integral part of chemistry education (Delvecchio, 2011). The problems that learners encounter in chemistry may be qualitative in which students' solutions require an explanation drawn from

their conceptual knowledge base. Other problems are quantitative and require the learners to integrate their conceptual knowledge and numeracy skills. Such problems may be written or hands on investigative problem solving tasks. In chemistry, the mole is a rudimentary concept that forms the basis for many other types of chemistry problems such as stoichiometry and ionic equilibria problems. Stoichiometry and ionic equilibria problems integrate the concepts of the mole, balanced chemical equations and formulae. Therefore, the selection, modification, and application of the appropriate algorithms and heuristics becomes critical. These types of problems provide the ideal tool to investigate students' problem solving processes. For this reason, I selected stoichiometry ionic equilibria type standard problems for all problem solving tasks in my study.

2.3. Nature of Stoichiometry as a topic

Stoichiometry is the branch of chemistry that studies the quantitative relationships between reactants and products in a given chemical reaction based on the laws of definite proportions, conservation of mass and energy (Gauchon and Méheut, 2007). Schmidt and Jignéus (2003), further point out that stoichiometric calculations are also essential in evaluating the results of quantitative analyses like titrations. Chemical formulae can be calculated if it is known how much of each element is present in a compound. Because of the above reasons stoichiometry has become an important topic in curricula and chemistry textbooks, and many investigations have been carried out to understand students' problems in this field. Okanlawon (2008b) posits that stoichiometry, as a topic which is fundamental to all aspects of Chemistry, involves problem solving where problem solvers are required to calculate the masses of other reactants consumed and other products formed with the aid of a balanced chemical equation, given the mass of a reactant or product in a chemical reaction.

Evans, Leinhardt, and Karabinos (2006), view stoichiometry as a fundamental ‘tool’ in the chemical ‘toolbox’ since if one is proficient in solving problems in stoichiometry they will be able to solve problems in chemical and ionic equilibria with ease. As a complex chemistry topic, a series of skills, organized knowledge of chemistry and mathematical ability are required in dealing with stoichiometry (Gulacar, Overton and Bowman, 2013). The authors further note that to be successful in solving stoichiometry problems the solver is expected to calculate molecular weight, understand the mole concept and the particulate nature of matter, balance chemical equations to find the correct stoichiometric ratios, determine the limiting reagent, and more. For solving stoichiometry problems, in addition to demonstrating an understanding of chemical reactions, the student must be able to apply the principles involved in ratio and proportion calculations (Upahi and Olorundare, 2012).

BouJaoude and Barakat (2003), identify stoichiometry as one of the most basic, central, yet abstract topics in chemistry which is essential for understanding quantitative and qualitative aspects of chemical reactions as well as for solving many types of problems in high school chemistry. They further note the importance of conceptual understanding for successful problem solving and qualitative thinking in chemistry and suggest that students’ inadequate and incorrect conceptual knowledge impede successful problem solving in stoichiometry. Since teaching stoichiometric calculations is a difficult task (Schmidt, 1990), new instructional approaches and methodologies should be used in implementing curricula meant to prepare meaningful learners in chemistry; a situation which requires an understanding of students’ problem solving strategies in chemistry in general and more specifically in stoichiometry (BouJaoude and Barakat, 2003).

2.3.1 Students' problem solving in stoichiometry

Research into challenges and problems related to the teaching and learning of stoichiometry and its associated concepts has received considerable attention among chemistry educators due to the significance of stoichiometry as a branch of chemistry (Dahsah and Coll, 2007). These issues have been approached by chemistry education researchers from various perspectives including the difficulties faced by students and their teachers in the teaching and learning of stoichiometry, students and teachers alternative conceptions (Furio, Azcona and Guisasola, 2002), problem-solving skills in stoichiometry (Gabel and Sherwood, 1984; Schmidt, 1994), and studies of alternative teaching and learning strategies used to promote students understanding and problem-solving skills in stoichiometry (Cain, 1986; Dominic, 1996).

Tóth and Sebestyén (2009), noted a mismatch between the problem solving process that students undergo and their conceptual understanding of chemistry. Students can correctly solve quantitative (numerical) stoichiometry problems but still lack understanding of the fundamentals without underlying the problem at a molecular level. Tóth and Sebestyén (2009), further report on a study which showed that there was significant difference in the characteristic knowledge structure of the students who learned the basic physical and chemical quantities (molar mass, molar volume, mass percent etc.) by conceptual understanding and that of the students who learned these concepts by rote learning. It was also shown that rote learning made the finding of the connections between concepts hard and gave separated and non-mobilizable knowledge.

Chandrasegaran, Treagust, Waldrip and Chandrasegaran (2009), further note that chemistry students were found wanting when required to provide explanations as they were solving stoichiometry problems. The students could successfully solve traditional problems using

algorithmic strategies, but lacked conceptual understanding when solving unfamiliar problems. Consequently, this lack of understanding of the chemical concepts was further supported by their inability to solve transfer problems involving situations different from the ones that were used during instruction (Chandrasegaran et al, 2009).

It has also been shown that a number of factors influence the problem-solving strategies a student applies (Tóth and Sebestyén, 2009). Studies by Schmidt (1997), in Germany and by Schmidt and Jignéus (2003), in Sweden have revealed that high school students in the two countries were very successfully in solving simple stoichiometric problems by employing their own strategies, but however when faced with difficult problems they tended to use algorithmic methods taught at school. In contrast to these results Tóth and Kiss (2005), noted that Hungarian secondary school students applied the strategies learned at school even in case of simple stoichiometric problems. In balancing chemical equations Tóth (2004), found that Hungarian high school students created their own balancing strategy (mainly the trial-and-error) before learning the oxidation number method at school, and they stuck to their own strategies of low efficiency even in case of complicated redox equations.

Chandrasegaran, Treagust, Waldrip and Chandrasegaran (2009), echo the importance of mathematical concepts in facilitating stoichiometry problem solving. They further highlight the tendency for students to treat exercises on limiting reagents like any other problem in mathematics (as they often do in all chemistry problem solving exercises) with little display of their knowledge and understanding of the chemical principles involved (Chandrasegaran et al., 2009). Students' limited proficiency in the use of the mathematical concepts of proportions, ratios and percentages in reaction stoichiometry is thus a contributory factor to the difficulties that they experience when solving stoichiometry problems.

The issues pertaining to the role and influence mathematics plays in chemistry education are further highlighted by Furio et al., (2000), who noted the views of chemistry teachers regarding the difficulties that novice students of chemistry face in relation to the use of the mole in stoichiometry computations. In addition to this difficulty Chandrasegaran et al., (2009), acknowledge that chemistry students are not able to translate word related statements in chemistry into mathematical statements. Chandrasegaran et al., (2009), further illustrate how a statement like, “*for a given amount of sodium carbonate, twice the amount of hydrochloric acid is needed*”, is often misrepresented mathematically. Instead of stating $n(\text{HCl}) = 2 \times n(\text{Na}_2\text{CO}_3)$, students incorrectly state $2 \times n(\text{HCl}) = n(\text{Na}_2\text{CO}_3)$. This misrepresentation as noted by Chandrasegaran et al., (2009), is analogous to the ‘reversed equation phenomenon’ in algebra involving the translation of expressions in everyday language to algebraic equations using letters, and vice versa.

One of the most fundamental aspects that students need to be able to perform stoichiometric calculations in chemistry is their ability to understand the mole concept and interpretation of chemical formulae and equations (Chandrasegaran et al., 2009). As suggested by De Jong et al., (2002), and Furió et al., (2002), both teachers and students have been shown to be confused over the meaning of the mole. This confusion arises from the fact that a number of different definitions are used in chemistry textbooks and the chemistry curriculum in several different countries (Chandrasegaran et al., 2009). The inability of students to perform stoichiometry computations is further worsened by the students’ poor and inadequate understanding as well as interpretation of the significance and importance of chemical equations and formulae. Sanger (2005), particularly observes that the students’ understanding about the conservation of mass in relation to chemical formulae as well as the significance of coefficients and subscripts in chemical equations seems to be limited.

From the foregoing discussion it can be concluded that conceptual understanding in stoichiometry is crucial for any student taking chemistry if they are to be successful in solving numerical problems in stoichiometry. However, as shown by Dahsah and Coll (2007), students possess a very low conceptual understanding and they also possess many alternative conceptions related to stoichiometry. Their conceptual understanding seems to be related to the Problem solving strategies they employ therefore students need a proper conceptual understanding in order to develop meaningful thinking ability, use and apply that understanding in meaningful ways, (Roth, 1990). However, students seem to be lacking conceptual understanding and often resort to rote learning whereby they simply memorise certain problem solving methods to answer questions. Furthermore it has also been found that some high achievers tend to solve numerical problems in stoichiometry based on memorization rather than reasoning and out of proper conceptual understanding (Tóth and Sebestyén, 2009). The ability to solve problems successfully does not indicate deep conceptual understanding and these students often have a challenge when they are exposed to problems which are a little bit different from the usual one, as they cannot figure out the solution although it is still based on the same concept. Therefore, it is essential for chemistry educators to teach students for conceptual understanding.

2.4 The concept Ionic Equilibria

Burgot (2012), defines ionic equilibrium as a type of equilibrium observed in substances that undergo ionization easily, or in polar substances in which ionization can be induced. Acids, bases and salts come under this category. Kousathana, Demerout and Tsaparlis (2005), also note that acid-base chemistry is an important component of the ionic equilibria concept.

The subject of acids and bases is an important topic in the chemistry curriculum of secondary schools, high schools and the general chemistry courses at universities (Kala, Yaman and

Ayas, 2013). The concepts are related to many of the other chemistry concepts, such as the nature of matter, chemical equilibrium, chemical reaction, stoichiometry, and solutions (Demircioğlu, Ayas and Demircioğlu, 2005). Research has shown, however, that acids and bases are difficult for students to understand (Demerouti et al., 2004) and also that textbooks are unclear when describing this area (Drechsler and Van Driel, 2008). In teaching and learning, acid-base concepts are usually introduced to students with models. The model emphasized in the Zimbabwean Advanced level chemistry curriculum are the Arrhenius and the Brønsted-Lowry models.

In the Arrhenius model, acids are defined as substances that could produce H^+ ions in a water solution while bases are defined analogously as substances that in water solution would produce hydroxide (OH^-) ions (Verma, Khanna and Kapila, 2010). In a neutralization reaction between an acid and a base, hydrogen ions from the acid react with hydroxide ions from the base forming water. As noted by Drechsler (2007), the Arrhenius model describes strong and weak acids in terms of their dissociation constant as well as the change in conductivity when acids are diluted. However, its limitation is that acids and bases are still considered as substances and the model is limited to water as a solvent.

Paik (2015), observes that according to Brønsted, acids and bases are particles, that is, molecules or ions. Acids are defined as particles that donate protons while bases are defined as particles that accept protons (Drechsler, 2007). When an acid donates a proton it becomes a base. An acid and a base that are connected in this way are said to be a conjugated acid-base pair. If, for example, the acid HA donates a proton, the base A^- remains. If the base B^- accepts a proton, the acid HB is formed. A proton transfer according to Brønsted can be written in general terms like this: $HA + B^- \rightleftharpoons A^- + HB$

A study of chemistry text books by Carr (1984), revealed that there is no clear distinction given in the books between the Arrhenius model and the Brønsted model. The books neither explain why a new model was being introduced nor clearly outline the differences that exist between the new model and the earlier one. Such explanations are vital since they enable learners to move flexibly between appropriate models which is one of the hallmarks of a sophisticated understanding of the scientific enterprise (Cooper, Kouyoumdjian and Underwood, 2016). If the teachers and books do not clearly explain the differences between these models, it has been shown that students often have trouble understanding the nature of models, particularly in chemistry (Gilbert and Boulter, 2012). As a result students tend to understand models as concrete representations of reality rather than tools with which to predict and explain (Cooper, Kouyoumdjian and Underwood, 2016). Similar studies by Oversby (2000), have noted deficiencies that exist in chemistry textbooks where the different acid-base models are explained without clearly outlining and discussing the strengths and weaknesses of each model.

According to De Vos and Pilot (2001), there are disconnections and inconsistencies in contexts of knowledge as presented in many modern chemistry textbooks to such an extent that teachers of chemistry and their students are left to grapple with acid-base models that are incoherent and problematic to teach and to learn. Further studies by Furió-Más, et al. (2005), as well as Gericke and Drechsler (2006), have proved that new models on acids and bases in textbooks are introduced in a non-problematic, linear and cumulative way that seem to suggest the nonexistence of conceptual gaps between the different models. As noted by Drechsler (2007), student fail to see the connections and progression between the models since this scientific knowledge is growing linearly and is independent of the existing context. Instead, the way models are used in textbooks suggests that different models of a

phenomenon constitute a coherent whole; that is, different models are seen as different levels of generalization. In this way, attributes from a simpler or older model would be valid in all later models as well. According to Justi (2000), this idea could lead to learning problems among students.

Chemistry students have difficulties with the acid-base chemistry concepts (Demircioglu, 2005). These difficulties according to Sheppard (2006), have been ascribed to the existence of many alternative conceptions or misconceptions, a poor understanding of the particulate nature of matter, difficulties with the use of different models used in acid–base chemistry and confusion between acid–base terminology and everyday words. Research studies by Cros et al., (1988), which addressed neutralization and pH among other acid-base concepts revealed that chemistry students could only give a descriptive definition of these concepts despite instruction that emphasized its more quantitative aspects. Furthermore, studies by Schmidt (1995), reported that students consider the products of neutralization reactions to always have a pH of 7 and he described neutralization as a ‘hidden persuader’. As a consequence of the issues highlighted above, students are having difficulties with understanding what is happening to the values of pH during a titration.

As noted by Sheppard (2006), students who have challenges with acid-base chemistry, are characterized by their inability to accurately explain and describe the related acid base concepts like acid and base strength, neutralization and pH. Further, Sheppard (2006), showed that most students could not relate the concepts to actual solutions. Student difficulties stemmed from a lack of understanding of some underlying chemistry, such as the nature of chemical change and the particulate nature of matter. Urbansky and Schock (2000), have shown that students have considerable difficulty solving buffer problems without using the Henderson-Hasselbach equation. Undoubtedly, this difficulty (Okanlawon, 2012), may prevent them from successfully calculating the pH at any point between the starting point

(i.e., $V=0$) and the equivalence point of a titration involving a strong acid with a weak base (or a weak acid with a strong base).

Orgill and Sutherland (2008), have noted that the concept of buffers as well as solving corresponding buffer problems is a phenomenon that both upper- and lower-level chemistry students find challenging. Their study revealed that students have a very simple, mostly macroscopic view of buffers. The majority of students seemed to be more aware of what buffers do than of what buffers are or of the dynamic interactions between particles in a buffer solution. Orgill and Sutherland (2008), further showed that students were unfamiliar with particular buffer terms and could not interpret chemical formulas confidently. It is possible that students' difficulties in understanding buffers conceptually are related to their inability to visualize buffers on the microscopic scale (Orgill and Sutherland, 2008). A previous study (Demerouti et al., 2004a), showed that secondary students have difficulty identifying the species and equilibria present in aqueous solutions of salts of weak bases. If students are not able to identify these species and equilibria, visualizing them in solution will be challenging. What is clear is that instructors and their students do not visualize buffers the same way and that students are unable to relate the macroscopic, microscopic and symbolic representations of buffers.

While the sub-microscopic and symbolic representations of acids and bases make understanding of acids and bases challenging for students at all levels, a study by Smith and Metz (1996), found that even undergraduates had difficulty with the concepts of weak and strong acids in that they could not identify the submicroscopic representations of strong and weak acids. On the other hand, Demircioğlu et al., (2005), reported that Grade 10 students believed that acidity increases as the number of hydrogen atoms in the formula of an acid increases a misconception also found by Lin, Chiu and Liang (2004), among Taiwanese learners. According to Barke, Al Hazari, and Yitbarek (2009), for most students, the strength

of acids is based on the pH value of the solution. The students also confuse the difference between acid strength and concentration. Students have also been shown to have difficulties in understanding the difference between 'equivalence point' and 'neutral point' (pH = 7) in acid-base titration. Students assume that acid-base reactions always result in a neutral solution (Schmidt, 2000).

In foundation biochemistry and biological chemistry courses, a major problem area that has been identified is students' lack of understanding of pH, acids, bases, and buffers and their inability to apply their knowledge in solving acid/base problems. A study by Waters and Waters (2006), analyzed student understanding of the concept of pH and the extent to which they could apply fundamental ideas about pH to relevant biological problems. At best, most students attempted to recall previously learnt definitions of what pH and pK_a meant. Their knowledge structures were fragmented with ideas unconnected to other relevant concepts in any convincing fashion, indicating a surface level and atomistic understanding. Mathematical naivete was widespread, confirming previous research on the mathematical literacy of undergraduate students (Weber, 2002). For example, the students did not seem to appreciate the size of the numbers they were dealing with and what concentrations of 10^{-10} and 10^{-7} M actually represent in a physical sense. Many demonstrated very poor background knowledge of high school mathematics, particularly unfamiliarity with logarithms, thus hindering the understanding of the pH scale. A lack of knowledge of pH, pK_a , ionization, and related concepts meant that students had difficulty decoding questions and even attempting relatively simple problems.

Halstead (2009), presented a critical analysis and synthesis of published research into student difficulties in acid-base chemistry carried out in the naturalist nomothetic paradigm using a constructivist framework. Halstead (2009), gives a concise summary of these difficulties as follows: difficulties with acid-base models where they fail to accommodate more than one

operational model, difficulties with general definitions as acid and base definitions are not distinguished, difficulties with everyday acid-base examples since they can figure the relevance of acidic and basic substances in everyday life, difficulties with macroscopic aspects of neutral solutions and salts as well as microscopic aspects of neutral solutions; students think that salts are not a class of compounds and that neutral solutions have neither H^+ (or H_3O^+) nor OH^- ions. Halstead (2009), further notes students' difficulties with chemical characteristics of acid and bases' thinking that pH applies only to acidity and that salt solutions do not have a pH. Difficulties with macroscopic aspects of neutralization reactions as well as interpreting observations of neutralization reactions, and difficulties with the nature of reactions in acid-base chemistry were also noted among students. Students were further shown to have misconceptions with other acid base reactions where conjugate acid-base pairs are viewed as being both strong or both weak while the Arrhenius model is thought to be for strong acids and the Brønsted model is for weak acids. Difficulties with symbolic and mathematical representations in pH calculations, difficulties with chemical formulae and equations in which formulae with hydrogen are thought to indicate acids while bases have formulae with no hydrogen and that all formulae with an OH group indicate bases were noted among chemistry students (Halstead, 2009).

2.4.1 Students' problem solving in ionic equilibria

Cardellini, (2000), notes that chemistry students exhibit considerable difficulties in solving ionic equilibrium calculations. Proficiency in solving ionic equilibrium calculations and problems is not only important in chemistry alone but in other fields as well including geology, biology, environmental engineering and biochemistry. Therefore chemistry students need strong grounding in ionic equilibrium concepts if they are to be able to apply the knowledge in other related fields. Ionic equilibrium calculations are part of quantitative problem solving in chemistry constituting a challenging aspect of any physical science course

(Cohen et al., 2000). Generally, students have been encouraged to pursue traditional techniques in an effort to provide structure to this task. While these techniques may help to generate numerical answers, they can become exercises in symbol manipulation that leave the student without a clear picture of the physical situation associated with the problem.

In solving ionic equilibrium problems, problem solvers are required to perform mathematical calculations based on formulas and equations. As noted by Cardellini (2000), the formulas used in solving ionic equilibrium problems in general chemistry textbooks are derived from the Butler 5% approximation rule (Butler, 1961). The drawback of using memorized formulas to solve problems is that they are shortcuts and avoid a systematic reasoning. In practice, this approach leads the student to solve ionic equilibrium problems using some rote-learned formulas or an algorithm; they can solve problems without processing the information and referring to a correct chemical representation. According to Robinson (2003), such a scenario lead many students to develop algorithmic techniques to solve such problems yet never develop an understanding of the scientific concepts behind those techniques. Consequently, there is a need for chemistry educators to stress approaches that emphasize qualitative understanding and better equation writing on the part of students.

Robinson (2003), further observes that the reliance on rote and algorithmic teaching and learning acts as a barrier to the development of students' high level cognitive skills as well as conceptual understanding. The inability of many chemistry students to derive and draw relationships between and among the various fundamental chemistry concepts and their quantitative representations is as a result of poor mathematical skills and conceptual understanding of chemistry. The students are thus not able to come up with well thought out and reasoned solutions to the given quantitative problems (Okanlawon, 2008). To obtain the "correct solution" these students memorize a variety of algorithmic techniques rather than attacking the problem using the basic concepts. A lack of understanding of introductory

concepts acts as an obstacle to teaching and learning as well as understanding of subsequent related topics.

Cardellini (2000), discovered that the didactic approach is not the most suitable way to teach students how to solve ionic equilibrium problems as it mainly relies on rote memorization of formulae. The student has to ask himself or herself questions in order to decide what formula to use: *Is this a buffer solution? Are we at the equivalence point? Is the hydrolysis appreciable? Can the dissociation of this weak acid be considered negligible?* and so on. Such questions according to Cardellini bewilder the student (but not the expert chemist) who has to evaluate terms such as "negligible", "perceptible" or "significant". This approach sometimes (Cardellini, 2000), leads to the application of a procedure that leads to imprecise results, because the student does not remember the hypothesis that makes the approximate formula work. This method fails because the student cannot estimate the result with the necessary precision. Often, this method leads to correct results, but the logical abilities and the critical thinking of the student are used at a very low level.

Cardellini (1996a), asked students to find the hydrogen ion concentration of a water solution of acetic acid ($K_a = 1.753 \times 10^{-5}$ M) 1.00×10^{-7} M. The researcher noted that some students solved the problem in this way: $[H^+] = (K_a C_a)^{1/2} = 1.32 \times 10^{-6}$ M where C_a is the total acid concentration. How is it possible that $[H^+] = 13.2 \times C_a$? Cardellini (1996b) then observed that textbooks always work examples where $[H^+] = C_a$ or $[H^+] = (K_a C_a)^{1/2}$ and where C_a is the total acid concentration, without ever considering the water dissociation. In this way, students memorize a generalization of the hypothesis in the form "All p's are q"; this is a logical implication: p implies q. In this case p is "acid solution" and q is "there is no need to consider the water dissociation". The same can be said about the Henderson-Hasselbach equation (Cardellini, 1997): all these approximate equations fail under some circumstances. As suggested by Freiser, (1970), the didactic approach of acid-base calculation must, avoid the

scylla of oversimplification to achieve "clarity" and the Charybdis of "cumbersome" rigorous equations.

The characterization of students' reasoning strategies is of central importance in the development of instructional strategies that foster meaningful learning. In particular, the identification of shortcut reasoning procedures (heuristics) used by students to reduce cognitive load can help us devise strategies to facilitate the development of more analytical ways of thinking (McClary and Talanquer, 2011). A qualitative study conducted by McClary and Talanquer (2011), investigated the reasoning strategies used by organic chemistry students to predict the acid strength of a number of compounds based on their composition and structural formulas. McClary and Talanquer (2011), found that many chemistry students heavily relied on a number of heuristics such as *reduction*, *representativeness*, and *lexicographic* in making decisions. Despite having visual access to rich structural information about the substances included in each ranking task, many students relied on isolated composition features to make their decisions. However, the specific characteristics of the tasks seemed to trigger heuristic reasoning in different ways. Although the use of heuristics allowed students to simplify some components of the ranking tasks and generate correct responses, it often led them astray. Very few study participants predicted the correct trends based on scientifically acceptable arguments. The results suggest the need for instructional interventions that explicitly develop college chemistry students' abilities to monitor their thinking and evaluate the effectiveness of analytical versus heuristic reasoning strategies in different contexts.

As noted earlier, quantitative chemical problems are a major obstacle to students in secondary and tertiary level courses (Asieba and Egbugara, 1993). Cook and Cook (2005), suggest that quantitative chemical problems must be solved from a concept-based approach rather than an algorithm approach. The major thrust being that students must first understand and appreciate

the problem they are trying to solve rather than simply arrive at the correct answer by a currently accepted “plug and chug” algorithm. For these algorithmic methods to be useful in the context of learning an understanding of the concepts are mandatory and, in fact, the algorithms are derived based on a thorough understanding of the problem. However, once an algorithm has been formulated, its application by others does not ensure an understanding of the problem being solved by it. Generally, it can be concluded that it is obvious that there is an overwhelming emphasis on using learned algorithms, as equations and other memorized techniques, to solve ionic equilibria problems, sometimes without understanding the chemistry concepts involved in solving the problems. It seems that because students over rely on memorized equations they are successful when an equation can be applied directly to solve a problem but are less successful when they need qualitative chemical thinking to solve a problem.

2.5 Conceptual and Procedural Knowledge in problem solving in Chemistry

The goal of chemistry education is to help students develop problem solving competence (Taasobshirazi and Glyn, 2009), gain conceptual chemical understanding (Nakhleh, 1993), and equip students with science-process skills (Heeren, 1990), among other competences that will enable them to live and function as informed citizens who can make decisions about important contemporary scientific issues, or as professionals in scientific fields (Price and McNeill, 2013; Nyachwaya et al., 2014). However, according to Gotwals and Songer (2013), scientific literacy can only be attained through instruction that does not facilitate and encourage memorization of facts. Adadan et al. (2010), further note that meaningful learning in science requires conceptual understanding as opposed to rote memorization and application of algorithms to solve simple problems. Research in chemistry education has unfortunately shown that students leave chemistry courses lacking in problem solving skills

and adequate conceptual understanding of requisite chemistry content (Nyachwaya et al., 2014).

Nieswandt (2007), defines conceptual understanding in chemistry as comprising of three ‘types of knowledge’: declarative knowledge (knowledge of facts), procedural knowledge (encompassing rules, algorithms, and concepts) and conditional knowledge—when to use particular information, and why a piece of information is appropriate in a given situation (Paris et al., 1984). The ability of students’ to recognize and organize pieces of information constitutes conceptual understanding (Nieswandt, 2007). Surif, Ibrahim and Mokthar (2012), on the other hand highlight the importance of both conceptual and procedural knowledge in solving any chemistry problem. Students need to apply both conceptual and procedural knowledge in order to solve any problem correctly (Cracolice et al. (2008). Learners thus have to understand conceptual ideas in chemistry and then apply these in any problem-solving situation (Wolfer, 2000).

Nyachwaya et al. (2014), point out that for better understanding of chemical concepts, there is need for consideration of the different levels of representation necessary for complete, conceptual understanding. According to Johnstone, (1991), chemistry is commonly represented at three levels: macroscopic, symbolic and submicroscopic or particulate levels. Treagust et al. (2003). Also notes the need for students to understand chemistry at the three levels, recognize the level they are operating in, navigate between and within the levels fluently, and understand how the three levels contribute to understanding of chemical phenomena. The authors further highlight the importance of the use of the particulate and symbolic levels in explaining chemical phenomena. This implies therefore that unless students understand the particulate nature of matter, they will not be able to make sense of and explain chemical phenomena (Dori and Hameiri, 2003). It is unfortunate to note that a number of research studies (Treagust et al., 2003; Nyachwaya et al., 2011; Naah and Sanger,

2012; Nyachwaya et al., 2014) acknowledge that students experience challenges with representing chemistry at all three levels of representation, explaining chemistry at the three levels and the relationship between the levels.

Chemistry problem solving strategies are characterized in a variety of ways. Two types of learners have been identified, based on their learning approaches and success with different types of questions: algorithmic learners and conceptual learners (Nyachwaya et al., 2014). Pushkin (1998), describes algorithmic learners as those who can master assessment items requiring mimicking, regurgitation and short-term memorization, while conceptual learners can master assessment items requiring evaluation, comparison, and attribution skills. Grove and Bretz (2012), have recently categorized chemistry problem solvers into four categories namely indifferent learners, unaware learners, transitional learners and meaningful learners. According to Nyachwaya et al. (2014), new scheme challenges the notion of a dichotomy that previously existed, instead placing learners on a continuum from rote memorization to meaningful learning. According to Grove and Bretz (2012), while indifferent learners resort to rote memorization; meaningful learners recognize a need to develop sound understanding of concepts and meaningful approaches to problem solving.

2.5.1 Algorithmic versus Conceptual Approaches to problem solving in Chemistry

While it is believed that understanding chemistry requires conceptual understanding, a number of research studies (Nakhleh, 1993; Bodner, 2003; Pappa and Tsaparlis, 2011) have shown that students resort to memorizing formulas and algorithms for solving problems. According to Cracolice et al. (2008), most students continue to rely on algorithm problem solving techniques since their lack in conceptual understanding results in the lack of conceptual usage in solving problems. It can therefore be said that many students can successfully solve problems (by using an algorithm) as compared to answering interview

questions based on the concepts involved. It shows that students are only able to memorize and remember the formula and the processes involved without understanding the concepts. According to Okanlawon (2008b), the algorithmic approach (i.e. quantitative mathematical-based approach) is simply described as mechanized habits of response to a problem. Meija and Bisenieks (2004), and Suits (2001), referred to it as a problem solving process which requires substitution of numbers in a prescribed scheme (i.e. formula or equation).

Okanlawon (2008b), further states that the algorithmic approach is based on the use of memorized formula as well as manipulation of the formula in line with the main objective of the problem at hand, therefore one cannot rule out its susceptibility to mathematical errors. These errors occur when a formula or equation is used as the algorithm to solve a problem requiring the correct rearrangement for the calculation of the unknown. For example, a problem solver wishing to determine the amount (in mole) of a solute, given the molar concentration and volume of solution, may end up computing the amount (in mole) = C/V or V/C . While algorithms are useful and necessary for solving several important parts of a problem, they are however not sufficient for solving a problem completely. Meija and Bisenieks (2004), clearly highlight the limitation of this approach by stating that the problem-solving stages requiring mathematical skills are: (i) implementing the proposed strategy and (ii) evaluating the result obtained while it is irrelevant in understanding the problem and in developing the solution strategy.

According to Robinson (2003), as well as Dori and Hameiri (2003), the use of algorithmic teaching and learning does not foster the development of conceptual understanding and higher order thinking skills among chemistry learners. Consequently, during the learning process, information is stored in a compartmentalized manner making it difficult for transfer learning to take place. The learners are thus unable to apply what is learned in one setting to another new and novel setting. As noted by Okanlawon (2008), such a scenario prevents

learners from making well-reasoned solutions to quantitative chemistry problems. Bodner (2003), further opines that the use of algorithms by students to solve problems without understanding the concepts underlying the problem can be traced to some classroom practices and the way textbooks are written, where students are required to apply formulas without explaining what they are doing. Lack of conceptual understanding by students leads them to carry out manipulations of mathematical equations which they have not thought about (Gabel, 2003).

Okanlawon (2008b), considers quantitative chemical problem solving by the conceptual approach as a more effective technique than the algorithmic one since learners are able to integrate concepts and procedures in solving chemical problems. Advocates of the conceptual approach regard it as fundamental to both teachers and their students in the identification of alternative conceptions and difficulties in the underlying conceptual base (Ardac, 2002). By using the conceptual approach to chemistry problem solving, students are able to connect and link the algorithmic problem solving strategies to the underlying chemical principles (Okanlawon, 2008). Okanlawon (2008), further notes that students who solve chemical problems conceptually do rely on the deep structures of the problem together with the use of reasoning in combination with an understanding of the fundamental concepts underlying the problem, while on the other hand those who solve chemical problems algorithmically, tend to focus on surface features of the problem. Studies by Papaphotis and Tsaparlis (2008), found that student performance on questions requiring a combination of knowledge and critical thinking to be very low compared to those that required the application of algorithms.

From the above discussion, it can be noted that the dependence on algorithmic problem solving strategies is prevalent among students. As a result are able to solve algorithmic problems but lack the understanding of chemistry necessary for solving conceptual questions. (Cracolice et al., 2008). Lack of conceptual understanding leads to rote memorization which

does not contribute meaningfully to the learner's knowledge structure as a result does not foster critical reflective thinking. Rote memorization does not foster deeper learning, instead it leads to knowledge compartmentalization and students are not able to make connections between the learned concepts. Thus, rote learning impedes learners' understanding and their reasoning abilities (Reid and Yang, 2002; Novak, 2002).

2.5.2 Why students use algorithms

Beall and Prescott in Nyachwaya et al. (2014), suggest that the reason why students prefer algorithmic learning is that they conceive and perceive chemistry to be a collection of facts and formulas that they can memorize and use in examinations. Hammer (1994), cited in Nyachwaya et al. (2014), further say that students believe that memorization of facts, formulas and algorithms demonstrates understanding of the material and as a result there is no motivation to seek deeper understanding of the subject. Pushkin (1998), in Nyachwaya et al. (2014), reports that the conceptions students have about the nature of chemistry may be a result of the fact that instructors put more value on algorithmic learning than on conceptual learning giving students the false impression that they can succeed in science by relying on the algorithms. Dahsah and Coll (2008), note that teachers may accept a correct numerical answer without examining students' conceptual understanding dealing with the related concepts. If this occurs, then students who produce the correct numerical answer may be presumed to have an understanding of the underlying concepts (Sawrey, 1990). Teachers, thus, find it easier to teach algorithms and formulas, neglecting the conceptual knowledge.

As further noted by Stefani and Tsaparlis, (2009), the fact that some concepts and processes in chemistry are abstract and complex makes the subject challenging for many students. When students cannot understand these concepts and processes at a conceptual level, they resort to rote memorization. Students revert to rote memorization when they cannot keep up

with the pace of a course, and earn a good grade. Nyachwaya et al. (2014), further argues that students who memorize to get by on tests do not end up learning the intended material, or being able to use the memorized material to solve problems. This scenario as noted by Bennett (2008), as well as Pappa and Tsaparlis (2011), is further worsened by the fact that traditional forms of assessment in chemistry tend to be algorithmic and focus on students' ability to solve problems and get the correct answer, with teachers equating success at solving quantitative problems to conceptual understanding. Most of the traditional forms of assessment in chemistry tend to focus more on students' ability to recall definitions and facts, and apply known formulas and algorithms to solve problems, and less on conceptual understanding (Nyachwaya et al., 2014). Quantitative problems in particular often have steps that students can memorize and blindly apply. However, memorized algorithms interfere with students' ability to understand chemistry at the conceptual level, as well as developing higher order thinking skills (Zoller, 2002).

The designing of effective assessments by the chemistry educator is therefore critical in enhancing conceptual understanding of chemistry concepts. However the biggest challenge that a chemistry educators face in relation to rote learning is that their students have experienced many years of instruction and evaluation where rote learning has been encouraged. This experience makes it difficult for students to change their learning practices (Novak, 2002). This is especially true if the rote memorization has worked for them in the past. Assessments should therefore require higher order cognitive skills (Nyachwaya et al., 2014) and provide evidence for meaningful learning, which according to Novak (2002), occurs when tests do not exactly mirror what students saw during instruction. Teaching that only emphasizes solving problems without requiring demonstration of understanding of underlying concepts is not helpful especially in enabling students apply knowledge to novel situations (Dahsah and Coll, 2007).

According to Cracolice (2005), the development of cognitive skills is an essential component of a student's education, yet memorization of algorithms has no effect on these skills. The development of cognitive skills—particularly those used in scientific reasoning—should be a central goal for any high school or college chemistry course since students who exhibit poor reasoning skills cannot solve conceptual problems. This lack of skill leaves a student with no choice except to memorize algorithms if they want to survive a chemistry course (Cracolice et al., 2008). Nakhleh (1993), further highlights that a significant fraction of our students have no choice other than to be algorithmic problem solvers because their reasoning skills are not sufficiently developed to allow them to successfully solve conceptual problems. Other studies have shown that there is a relation between operational level and problem solving ability with students at a formal stage being more likely to choose a conceptual approach than students at the transitional or concrete operational levels (Bird, 2010). Chemistry educators should therefore facilitate student development of logical reasoning skills through cognitive enrichment experiences in chemistry courses.

2.5.3 Students' competence in problem solving

A study of South African students by Selvaratnam and Mavuso (2010), on their competence in strategies for problem solving revealed that the students had poor competence on the use of intellectual strategies for problem solving. Their study also pointed out that the lack of competence would result in lack of self-confidence that could seriously impede their learning throughout their courses. This lack of competence would lead to many students memorizing standard principles and procedures and trying to use them for problem solving. They are then found wanting when confronted with unfamiliar problems and do not seem to know where to start and how to proceed with obtaining the solutions. Thus, they then manipulate the given data and the equations with which they are familiar, without much understanding (Selvaratnam and Mavuso, 2010).

Teachers' competence in cognitive skills and strategies is very critical in developing problem solving skills among learners (Selvaratnam, 2011). A study by Selvaratnam (2011), to test the competence of high school Physical Sciences teachers in some important cognitive skills and to identify possible reasons for their difficulties and make suggestions for rectifying them. The study method used was the analysis of teachers' answers to questions that were carefully designed to test competence in explanation skills, mathematical skills, graphical skills, three-dimensional visualization skills, information-processing skills and reasoning skills. Teachers' competence was found to be poor in most of the skills tested. It would not be reasonable to expect teachers who are not very competent in cognitive skills and strategies to have a positive influence on the development of students' cognitive abilities. Furthermore, this lack of competence will foster negative attitudes and decrease self-confidence which will also impact negatively on the teaching and training of students. There is therefore a need for ensuring that teachers become more competent in cognitive skills and strategies.

Drumond and Selvaratnam (2008), studied the competence of first year university chemistry students in four intellectual strategies (clarification and clear presentation of the problem; focusing on the goal and identifying a strategy for moving towards the goal; identification of the principles needed for solution; proceeding step by step) that are particularly important for successful problem solving. The findings suggest that about 80 % of the students were unable to use the required strategies, and also that many students who have the competence to use the strategies did not recognize the necessity for doing so. The results also suggest negative attitudes and lack of self-confidence in problem solving. Selvaratnam (2011), further suggests that difficulties with the use of cognitive strategies are often not due to students' inability to understand and use them but to insufficient emphasis being placed on them in their courses. Since an increase in competence in cognitive strategies and cognitive skills can be expected to result more effective learning as well as competence in problem

solving, not only in education courses but also throughout their lives, there is a need for training students in them until they become automatic and spontaneous mental operations. Such training as opined by Selvaratnam (2011), should be integrated, throughout any course, with the teaching of content knowledge.

Chemistry educators also need to reorient the teaching of chemistry at the high school level placing more emphasis on understanding associated chemical concepts and relationships among them. This necessitates the use of analogies and graphic organizers like concept maps and schematic diagrams (Gayon, 2007). However, the teaching of chemistry problem solving should not only focus on quantitative problem solving. Equal attention should be given to conceptual problem solving as this will provide a more holistic approach to teaching problem solving in chemistry.

2.6 Improving students' problem solving skills in stoichiometry and ionic equilibria

Solaz-Portolés and Lopez (2008), highlight the important and significant role played by problem-solving in science teaching and learning though many students find it a very difficult thing to do. Chemistry is no exception. According to Lorenzo (2005), most of the problems that chemistry students are required to solve at high school are quantitative in nature and require a sound grounding in chemical formulae and mathematical applications. Lorenzo (2005), further notes that inspite of the efforts made by chemistry educators to improve and increase the problem-solving capabilities of students, the majority of students still experience difficulties in solving problems even when they require the application of simple algorithms to obtain the correct solutions. Therefore, the main goal of science education and chemistry education should be to continue to seek strategies to enhance and improve the problem-solving skills of learners. According to Zoller (1993), problem solving is a higher-order cognitive skill which demands many abilities, sometimes requiring much effort from the

solver. Cardellini (2006) notes that the process of problem solving requires that the learner combines, refines, extends and invents a number of reasoning patterns. Furthermore, the problem-solving process is not only about substituting numbers in known formulas but also requires lateral thinking, formal knowledge as well as creativity. As highlighted by Lorenzo (2005), to be successful in problem-solving one requires a combination of conceptual understanding of subject matter (Phelps, 1996), strong domain knowledge, knowledge of problem-solving strategies, and confidence (Lorenzo, 2005); teacher assessment methods (Chittleborough, Treagust and Mocerino, 2005), reasoning ability (Bird, 2010), cognitive development (Huitt and Hummel, 2003), and working memory capacity (Overton and Potter, 2011). Hence, instructional methods should take into account the general strategies and methods of problem solving, thus providing a tool to increase reasoning skills in the problem solver (Cardellini, 2006).

In order to increase conceptual understanding of students, it is necessary for students to be taught a more organized approach to problem-solving that clearly shows all the steps involved in problem-solving so as to help students deal with novel problems in a systematic manner (Yu, Fan and Lin, 2014). This in turn increases the problem-solving abilities of students, improves their attitude and confidence towards problem solving and problem solving proficiency. Gabel (2003), acknowledges the importance of conceptual understanding in solving quantitative chemistry problems. Hence, the interest by chemical educators to enhance students' deep understanding of chemical concepts.

According to Mataka, Cobern, Grunert, Mutambuki and Akom (2014), students who are successful in problem-solving initially construct a description of the problem in order to understand it, this in turn helps them to come up with an appropriate solution to the problem since the problem will have been translated into a form that is easy to understand. According to Hardin (2002), the process of problem solving comprises of self-analysis, observation, and

the development of heuristics. As noted by Mataka et al. (2014), the interest of cognitive psychologists is in investigating the mental processes involved when individuals learn and solve problems placing much emphasis on the organization of knowledge that leads to an improvement in the efficiency of retrieval of this knowledge from the conceptual schemata during problem solving. The hope is to organize and connect knowledge in long-term memory such that it is easily recalled when needed (Johnstone, 1991). This led to the development problem solving instructional strategies. Research has shown that the use of problem-solving instructional strategies and techniques to teach science influences the problem-solving skills of students (Biglin, 2005).

Mataka et al. (2014), highlight that for students to learn the problem-solving skills, teachers need to be well equipped with necessary pedagogical strategies to effectively teach these skills. A pre-service teachers' college education that emphasizes the acquisition of problem solving skills can effectively provide necessary tools that these future teachers can later utilize. This is important for elementary and middle school teachers because they are responsible for developing problem-solving skills in young children that are a necessary prerequisite for complex problem-solving in the future. Bello and Bajah in Adigwe (1998), note that the teaching of problem-solving through the traditional approaches involving use of worked examples in text books does not effectively teach the process of chemistry problem solving. Nfon (2013), further states that the traditional approach has inadequacies when it comes to teaching the basic procedural knowledge/strategies and skills of solving quantitative problems. The implication is that the students do not acquire the problem-solving procedures and skills required for successful performance.

Science educators have therefore developed various instructional strategies to assist learners in improving their problem-solving skills. Such efforts at developing instructional strategies to enhance students' problem-solving skills in chemistry led to the development of problem –

solving instructional models. Pizzini et al. (1989), notes that the use of problem-solving instructional strategies and techniques to teach science has an influence on the problem-solving skills and achievement of students. George Polya's work on problem solving has been of great importance in the field of science education. For science education and the world of problem solving, his work marked a line of demarcation between two eras, problem solving before and after Polya (Schoenfeld, 1987).

2.7 Structured problem-solving

Adegoke (2017), highlights that problem solving involves defining a problem, collecting information related to the solution process, reasoning through the problem state to the solution checking and evaluating the solution. It is important to note that problem-solving skills cannot be inherited but can be learned and improved upon (Dale and Balloti, 1997). Chemistry educators therefore need to avail opportunities for students to participate in the arranged activities directly so that they succeed in solving the presented problems. Hence, chemistry educators must address the crucially important task of teaching students to become more proficient in problem solving.

According to Çalışkan, Selçuk and Erol (2010), interventions directed towards teaching of problem solving in a systematic way are often referred to as structured strategies. The structured strategies entail facilitating students' problem solving through exposing them to a series of steps to simplify, understand and solve the problem (Adegoke, 2017). Polya is cited by Cruz (2014) as the pioneer in the field of structured problem solving. Polya (1957) systematized the problem-solving process as composed of four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. This strategy helps student think systematically, employs implicit planning, and reflects explicitly on their problem-solving behaviors.

The first step of the strategy by Polya, requires the learner to list all the given and desired information, drawing a diagram to illustrate the situation. In the second step, the learner is expected to select the basic relations and come up with a plan for solving the problem. The third step requires the learner to implement the plan by doing all the necessary calculations. The last step tells the student to check whether the final answer makes sense (Cruz, 2014). While it seems that the steps in this strategy follow a linear path, it has been found by researchers such as Carlson and Bloom (2005), that the steps are actually cyclic in nature. In their study on how mathematicians approach problem solving, Carlson and Bloom (2005), revealed that mathematics problem solvers normally pass through one step, remember something, go back and check before proceeding. Carlson and Bloom (2005), further state that when the solution was not acceptable during checking, the mathematicians usually returned to the planning phase.

As noted by Çalışkan, Selçuk and Erol (2010), the problem solving process is a linear and hierarchic process. Each stage feeds into the next stage and is as a result of the previous stage. The stages in Polya's model are seen as separate skills and each stage has its own sub-skills. These skills constitute the analytical parts of the problem solving process which requires problem definition, problem examination, revising and employing the problem. Selçuk et al. (2007), further highlights that these sub-skills are expressed as problem solving strategies in the related field.

Since the work by Polya on problem solving, a number of problem-solving models or strategies have been developed to try and describe the generic processes that problem solvers go through as they attempt to solve problems (Bodner and Heron, 2002). One such model that can be used to analyze student's difficulties in chemistry is the framework of Ashmore, Casey and Frazer (1979) model for solving problems in chemistry (Adesoji and Babatunde, 2008). The generic stages in the model are: defining the problem goal, selecting information

from problem statement, selecting information from memory and evaluation of the solution to the problem. The model is based on the premise that if students are to be successful in solving chemical problems then they must possess strong knowledge in chemistry, knowledge of problem solving strategies and tactics as well as confidence.

The first step of the strategy by Ashmore, Fraser and Cassey (1979), requires the learner to demonstrate an understanding of the overall goal and objective of the problem. The learner should keep this goal in mind as they are engaged in solving the problem. During the first step the learner is also expected to formulate and write a plan of action as well as rephrasing and subdividing the problem into a number of smaller problems (Upahi and Olorundare, 2012),

In the second phase of the strategy, the learner is expected to select appropriate information from memory, class notes, textbooks or information provided in the problem statement. To be able to do this, the learner should possess adequate mastery of the content area and must have an idea of the relationships that are involved. The third step asks the learner to combine the separate pieces of chemical information being guided by the goal of the problem. More so the learner is also expected to execute the formulated plan by carrying out all calculations. The last step tells the student to check if their answer is in line with the goal of the problem, in line with the information given in the problem statement and if the problem is solved (Asieba and Egbugara, 1993).

The choice of this model by Ashmore, Casey and Frazer (1979), is based on its emphasis on problem solving networks which entail breaking down the problem into unitary pieces of information and then reassembling them to show how the various pieces of information have to be connected to arrive at a solution to the problem. Furthermore, the use of networks emphasises and reinforces the notions that there are alternate routes to problem solving and

that if a student fails to make progress on a particular route they can be motivated and encouraged to seek other alternative paths to the solution. In addition the networks give an opportunity for chemistry educators to analyse chemistry problems into networks thus enabling them to fully perceive the anticipated difficulties students are likely to face when solving problems. This will enhance teaching strategies teachers employ in teaching problem solving the students as well as assessing the progress and capabilities of students in problem solving.

Another problem solving model in the area of Chemistry education is the Systematic Approach to Problem Solving (SAP) model devised by Selvaratnam and Frazer (1982). According to Udo (2011), the model has five steps which are: clarifying and defining the problem, selecting the key equation or relationship, deriving the relationship for the solution of the problem or calculation, collecting data, checking the units and calculating or solving the problem and finally reviewing, checking through steps 1-4, confirming the units and learning from the situation. Each of the steps consists of a number of sub-tasks which the learners must perform. For example, during clarifying and defining the problem, the learner is required to quickly reading through the problem statement, identifying the known and the unknown, sorting out and arrange the data in convenient manner; and focus on the problem that is to be solved (Udo, 2011).

The second stage of strategy by Selvaratnam and Fraser (1982), expects the learner to have adequate knowledge of the relationships necessary to solve the problem. This will enable the learner to convert the problem to a standard problem by linking the unknown and the data with given relations between quantities. The third step asks the learner to break the problem into sub problems as well as to interrelate unknown and data by applying the relationships to the problem situation through linking those using appropriate equations. The fourth step

entails the execution of routine operations. In this case the learner works out the solution to the problem using equations and relations that have been identified in the preceding phase. The last step is the evaluation where the learner is required to check if the problem has been solved correctly and completely. This done by looking at the answer, retracing the way the problem has been solved, identifying and correct possible mistakes (Udo, 2011).

The Selvaratnam and Frazer (1982) model incorporates a general progression from problem definition to alternatives testing, solution development, implementation, and checking. The model is advantageous in that it follows a stepwise approach thus encouraging broader information search, resulting in more careful solution planning and consideration of alternatives (instead of simply embracing the first solution considered), and it leads to more complete consideration of the possible implications of actions taken (or not taken) (Adigwe, 1998). Furthermore, the model requires learner's ability to recall underlying concepts, relationships or equations, rules and principles relevant to the problem. The model also put emphasis on the review, interpretation and evaluation of solution as the final stage of the problem – solving process.

The problem-solving model devised by Ashmore et al. (1979) suggest that effective problem solvers go through four stages of problem solving while that of Selvaratnam and Fraser (1982), has five stages. These two chosen strategies are compared and contrasted in table 2.1. An analysis of the table seem to indicate a similarity in the first step of both models. Here the learner is required to define the problem. Reading carefully and understating the problem becomes of paramount importance, for without understanding the goal of the problem, the learner cannot be able to formulate an appropriate plan to solve the problem. The assumption of the first step in both models is that problem solving begins with understanding the problem.

Table 2.2: Problem-Solving Strategies

Salvaratnam and Frazer (1982)	Ashmore, Cassey and Fraser (1979)
1. Clarify and define the problem	1. Define the problem
2. Select the key equation or formula	2. Select appropriate information
3. Derive the key equation for the calculation	3. Combine the separate pieces of information
4. Collect the data, check the units and calculate	4. Evaluation of solution to the problem
5. Review and learn from the solution	

The initial stages in both models require the learner to define the problem by reading it so that he or she may understand it. Through understanding the goal of the problem the learner can be able to formulate a relevant plan to solve the problem. The assumption in both models is that problem solving begins by understanding the problem. An analysis of the two strategies seems to indicate a similarity in the second step of each strategy. The selection of appropriate information or key equations and formulas require the learner to have adequate content knowledge of the relationships pertinent to the solution of the problem. The learner has to retrieve important information from memory.

In the third step of the Ashmore et al. (1979) strategy the retrieved pieces of information are combined and applied in formulating a plan and execution of calculations to solve the problem. There is similarity with the Selvaratnam and Fraser (1982), strategy where application and linking of relationships is prominent in solving the problem with the difference being that in the Selvaratnam and Fraser strategy calculations are performed in the fourth stage where solutions to the problem are worked out. The last steps of the strategies look similar and involve evaluating and checking the solution to determine if it is a reasonable and correct computationally. Besides checking their answers this step allows the

learner to reflect on how they arrived at the solution. There is no much difference in the two strategies except that Ashmore et.al. (1979) strategy is more applicable to simpler problems although it is more accurate and gives direction to the problem solver.

The chosen models are advantageous in that they equip learners with the analytical capacity and a capacity to analyze a problem and to solve it. Furthermore, the learner must have a knowledge and understanding of the principles of chemistry and then develop a strategy for applying these principles to new situations in which chemistry can be helpful. As noted by Fast (1985), the models facilitate and enhance problem solving skills of learners through the step-by-step format and the recall and comprehension of principles and concepts necessary for solving a given problem. In addition the models require the student to analyze and evaluate the problem then design a solution using the data stated in the given problem before the student actually formulates a solution for the problem. Thus, the models emphasize the use of pathways to guide the learners through the problem and a logic approach to examining what is needed to solve the problem.

While efforts to develop instructional strategies to enhance student's problem solving abilities in chemistry have led to the development of the above mentioned problem solving models and has been established that the use of these models in teaching and learning basic science (Nbina and Joseph, 2011; Adigwe, 1998), enhances the problem solving ability of learners. However, literature on problem solving instructional strategies in chemistry seems to be scanty in the Zimbabwean context. This study therefore will utilize two structured problem solving instructional strategies by Ashmore, Casey and Frazer (1979), as well as Selvaratnam and Frazer, (1982), in a bid to determine the effects of these strategies on improving the teaching of stoichiometry and ionic equilibria at Advanced Level.

An investigation of literature on the extent to which these two structured strategies have been used in the teaching of chemistry to students at various education levels was done. Asieba and Egbugara (1993), evaluated secondary pupils' chemical problem-solving skills using the Ashmore, Casey and Frazer (1979), problem-solving model. The findings revealed that the strategy contributed significantly to the development of the problem-solving skills as well as mastery of chemical content. Adesoji (2008), corroborated the findings of Asieba and Egbugara (1993), in a study 'Managing Students' Attitude towards Science through Problem – Solving Instructional Strategy'. In addition to enhancing achievement in chemistry, Adesoji (2008), demonstrated that the Ashmore, Casey and Frazer (1979), problem-solving model was also effective in improving students' attitudes in chemistry.

Raimi (2002), looked at the Selvaratnam and Fraser (1982), problem solving technique and laboratory skills as supplements to laboratory teaching in senior secondary school students' learning of volumetric analysis. The model was found useful in the teaching of concepts in volumetric chemistry. Adesoji and Raimi (2004) further examined the effect of supplementing laboratory instruction with Selvaratnam and Fraser (1982) problem solving strategy and or practical skills teaching on students' attitude toward chemistry. The results revealed that the use of enhanced laboratory instructional strategy significantly improved the attitudes of students toward chemistry. Raimi and Babayemi (2013) investigated the effects of the use of Selvarathnam and Frazer (1982) model and the Ashmore, Frazer and Casey (1979) on college students' achievement in volumetric analysis and attitude towards learning of Chemistry. The study revealed that students who were taught with problem-solving strategies performed significantly better than their counterparts in the control group.

The studies thus reviewed attest to the efficacy of each of these models on learning of Chemistry. However, very few of these researches have compared the effects of the use of two or more of these models on learning of Chemistry especially when it involves solving

problems in stoichiometry and ionic equilibria. The present study intends to fill this gap. With this background in view, it is necessary in this study to determine which of the two models would promote better learning and understanding of Chemistry especially solving standard quantitative calculations/ problems in stoichiometry and ionic equilibria.

2.7 Chapter Summary

The chapter has provided a discussion on a number of pertinent issues such as nature of stoichiometry as a topic, students' problem solving in stoichiometry, nature of Ionic Equilibria as a topic and students' problem solving in ionic equilibria. In addition, the chapter has also reviewed studies on Conceptual and Procedural Knowledge in problem solving in Chemistry, algorithmic versus Conceptual Approaches to problem solving in Chemistry, why students use algorithms as well as students' competence in problem solving. The chapter closes with a discussion on how to improve students' problem solving skills in stoichiometry and ionic equilibria. The following chapter will look at the methodology adopted in this study.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The researcher's choice of a research design is influenced by nature of the research problem and aims of the research which in turn determines the choice of methods, techniques and instruments that are to be used for the data collection process. This chapter gives a detailed description of the design that the researcher utilized in this study. Other aspects to be covered in greater detail in this chapter include the population of study, research sample, the sampling techniques, data collection instruments and their validation, reliability of instruments, methods of data analysis and ethical considerations.

3.2 Research Hypotheses

The aim of this study was to investigate the comparative effects of Ashmore, Casey and Frazer (1979), and Selvaratnam and Frazer (1982), problem solving strategies on the performance of Advanced Level chemistry students' in solving stoichiometry and ionic equilibrium problems. The null hypothesis and an alternative hypothesis for the study are expressed below.

Null Hypothesis (H₀): The implementation of problem solving instruction does not enhance the problem solving skills of learners in stoichiometry and ionic equilibrium, and hence their performance.

H₀: μ problem solving instruction = μ conventional instruction.

Alternative Hypothesis (H₁): The implementation of problem solving instruction enhances the problem solving skills of learners in stoichiometry and ionic equilibrium, and hence their performance.

H₁: μ problem solving instruction \neq μ conventional instruction.

3.3 Research Paradigm

According to Guba (1990), a research paradigm refers to a belief system (or theory) that guides the actions of the researcher in the conduct of research. As further noted by Jonker and Pennink (2010), a research paradigm is an established system of fundamental assumptions and beliefs reflecting the researcher's perceptions of the world thus serves as a thinking framework that guides the behaviour of the researcher. A research paradigm is described as a lens through which to view the world, a bundle of assumptions about the nature of reality, which influences the kinds of methods adopted by the researcher (Dobson, 2002). Research paradigms are characterised through their: **ontology** (the nature of reality), **epistemology** (how we know what we know, how do we know reality?) and **methodology** (how to go about finding out, what procedure can we use to acquire knowledge) (Guba, 1990). These characteristics create a holistic view of how we view knowledge: how we see ourselves in relation to this knowledge and the methodological strategies we use to un/discover it.

If a researcher can find a paradigm that best suits his or her study, then the study can be effectively executed (Kusi, 2017). This study is underpinned by the pragmatic philosophical paradigm. As noted by Cherryholmes (1992), pragmatism arose out of the work of William James, John Dewey, and Charles Sanders Peirce. The focus of pragmatism is on the outcome of the research and what counts is the 'research problem' and all approaches can be applied to understanding the problem (Creswell, 2003, p.11), as well as on consequences of the research. The pragmatic research philosophy recognises that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture and that there may be multiple realities (Saunders, Lewis and Thornhill, 2012).

A pragmatic viewpoint offers epistemological justification for bringing together pluralistic approaches to derive knowledge about the problem thus providing a better understanding of the research problem (Tashakkori and Teddlie, 2010).

In choosing this research paradigm, the researcher was motivated by the fact that pragmatism is not committed to any one system of philosophy and reality thus it enabled the researcher to draw liberally from both quantitative and qualitative assumptions in an attempt to fully explain the effects of using structured problem – solving strategies on Advanced level learners' achievement in stoichiometry and ionic equilibria. As suggested by Creswell (2009), individual researchers who opt for the pragmatic philosophical orientation have a freedom of choice, in this way, it enabled the researcher to freely choose the methods, techniques, and procedures of research that best meet the needs and purposes of the study. Furthermore, pragmatists do not see the world as an absolute unity (Morgan, 2007). In adopting this approach the study hoped to use many approaches for collecting and analysing data rather than subscribing to only one way (e.g., quantitative or qualitative). The pragmatic researcher is thus able to maintain both subjectivity in his or her own reflections on research and objectivity in data collection and analysis. The pragmatic paradigm implies that the overall approach to research is that of mixing data collection methods and data analysis procedures within the research process (Creswell, 2003). Creswell (2003), further highlights that pragmatism applies the mixed methods approach and strategies that involve collecting data in a simultaneous or sequential manner using methods that are drawn from both quantitative and qualitative traditions in a fashion that best addresses the research question/s.

3.3.1 Research Design

For this study a mixed methods approach was used. It employed both quantitative and qualitative approaches. Ponce and Pagán-Maldonado (2015), note that mixed methods studies

are based on the belief that there are existing problems whose complexity cannot be fully researched when the combination or integration of quantitative and qualitative approaches are not undertaken as components of the study. In a way, the complexity of the problem cannot be deciphered or fully understood from a single quantitative or qualitative approach. Simply put, the limitations inherent in either of the methods can be neutralized by combining the effects of both methods (Creswell, 2003). Mixed studies address research problems in which clear objective and subjective aspects are manifested that require the use of quantitative and qualitative approaches. A mixed method approach was chosen since the use of multiple approaches gave deeper insight into the effects of the structured problem-solving instructional strategies. This in a way enabled the researcher to determine the effect, if any, of the structured problem-solving instructional strategies on Advanced level learners' achievements in chemistry as well as explaining how the instruction was implemented. The use of both the qualitative and quantitative methodologies facilitated the corroboration of the findings and the possibility of triangulation through addressing the research problem or phenomenon more accurately by approaching it from different vantage points using different methods and techniques. Integration of research findings from quantitative and qualitative inquiries in the same study or across studies maximizes the affordances of each approach and can provide better understanding of chemistry teaching and learning than either approach alone (Warfa, 2016). In this study, the mixed methods approach was used as a triangulation to confirm and to verify quantitative results (from achievement tests) with qualitative findings (from observations and interviews). It was hoped that by using this approach the multi-faceted nature of human experiences in using structured problem-solving strategies in chemistry teaching could be revealed comprehensively.

The researcher adopted the sequential explanatory design. As noted by Subedi (2016), the design comprises of collecting quantitative data first and then collecting qualitative data to help explain or elaborate on the quantitative results. The rationale being that the general overview of the research problem stems from the quantitative data and results while the collection of qualitative data helps in refining, extending and explaining this general overview (Creswell, 2011). With this design, as noted by Creswell and Plano-Clark (2011), the researcher collects and analyzes the quantitative (numeric) data first then qualitative data are collected and analyzed second to help explain or elaborate on the quantitative results obtained in the first phase. According to Subedi (2016), the qualitative results are used to explain and interpret the quantitative findings of the study. The rationale for this approach is that the quantitative data and their qualitative data and their analysis refine and explain those statistical results by exploring participants view in more depth. In this study, the quantitative part comprised of a quasi-experimental pre-test, post-test non- equivalent control group design to test the Effects of the Ashmore, Casey and Frazer (1979), and the Selvaratnam and Frazer (1982), problem-solving strategies on the achievement of students in stoichiometry and ionic equilibria. The qualitative part of the study (*the descriptive survey design*) employed the use of semi structured interviews with teachers, classroom observations, and focus group discussions with learners regarding the teaching and learning of stoichiometry and ionic equilibria.

3.3.1 Quasi-Experimental Design

Gall, Gall and Borg (2007), state that quasi-experimental studies are research experiments where the study participants are not assigned randomly to groups. As noted by McMillan and Schumacher (2010), in a quasi-experimental design, random assignment is not feasible therefore it is not feasible for the researcher to randomly assign participants to comparison groups. Gribbons and Herman (1997), further note that quasi experiments are designed to

study cause and effect relationships among variables. The implementation of a quasi-experimental research to determine the effect of teaching methods requires that intact groups or classes of participants be used (McMillan and Schumacher, 2010). This makes it possible for the researcher in this case to administer a treatment or intervention to some of the classes while the other classes act as the control. The views of Arzi and White (2005), seem to suggest that random selection is not possible in educational research while Cook (2002), observes that in researches involving the effectiveness of teaching strategies to improve student achievement random assignment is rare. Since it was not possible for the researcher to conduct a true experiment, non-equivalent control group design was utilized in the study (Johnson and Christenson, 2012).

Nfon (2013) highlights that when a researcher uses the non-equivalent control group design, the comparison of the experimental group and the control group is based on the pretest and posttest scores. As a result, the researcher can confidently claim that the treatment had an effect when the pretest score in all the groups are similar before the intervention and the groups have different posttest scores after the intervention. Furthermore, Nfon (2013), propounds that the researcher has to eliminate all the threats to internal validity that may arise due to factors such as maturation, testing, history, instrumentation, and regression.

In order to minimize threats to internal validity due to lack of randomness in the study, Dhlamini (2012), suggests that schools with similar socioeconomic and academic backgrounds should participate in the study. The researcher would then ascertain whether the groups are equivalent before introducing the treatment by making a comparison of the pretest scores by comparing the pretest scores of the participating schools. As highlighted by Gweshe (2014), the non-equivalent control group design was found appropriate to use in this study since it allowed the researcher to avoid disrupting the smooth and normal running of the participating schools as well as to minimize threats to the external validity of the study by

maintaining the natural environments. This ensured that school time tables were not disrupted and that learners could learn or participate in other school activities as outlined in the school time table. The non-equivalent control group design as suggested by Gweshe (2014), thus ensured that the study would not disturb any of the schooling activities, by fitting into the schools' term plans.

Educational researchers such as Dhlamini (2012), Gweshe (2014), and Shoemaker (2013), have used this design before. In all these studies, the researchers employed the non-equivalent control group design with intact classes since the researchers were not able to randomly assign participants to the experimental and control groups. For the purposes of this study, the non-equivalent control group design was found appropriate in concordance with Dhlamini (2012), since the random assignment of participants to groups was not possible. The assignment of participants into experimental and control groups as highlighted by Dhlamini (2012), disrupts the smooth, normal and natural set up in the schools taking part in the study hence the need to use and maintain intact classes. In this study, the researcher worked with eight (8) chemistry teachers and their classes. Thus a total of eight (8) intact Advanced level chemistry classes were used.

3.3.2 The descriptive survey design

As noted by Brewer (2009), survey research is important in providing insights into attitudes, thoughts, opinions and behavior of populations. This study examined the views, thoughts and opinions of teachers and learners on the teaching and learning in stoichiometry and ionic equilibria as well as the implementation of problem-solving instructional strategies in chemistry teaching and learning. This was done through the use of semi structured interviews, focus group discussions and classroom observations. The use of these instruments enabled the researcher to gain an insight into the experiences of learners and teachers

regarding the teaching of stoichiometry and ionic equilibria using problem-solving instructional strategies. In the current study, the researcher designed a classroom observation schedule to collect data on the implementation of problem solving instruction in teaching stoichiometry and ionic equilibria. The problem solving behaviours that were observed were followed up and probed through the use of semi structured interviews with teachers and focus group discussions with learners.

3.4 Population of the study

The population for this study consisted of 1100 Advanced Level chemistry learners (Form 5 and Form 6) and Advanced level Chemistry teachers from 15 high schools in Gweru district in the Midlands Province of Zimbabwe.

3.4.1 The Sample

The sample of the study consisted of 525 Advanced level chemistry learners. This constituted 47.7% of the population. The participants were drawn from eight high schools in the district. Two hundred and seventy five (275) of these participant learners (from four schools) formed the control group and while the other 250 learners from four of the remaining schools constituted the experimental group. The learners in the control group (schools) were taught by their teachers using the conventional lecture method. The learners in the experimental group (schools) were also taught by their teachers who served as research assistants after having been trained on the use of problem-solving instructional strategies. These research assistants implemented problem-solving instruction in their classes.

3.4.2 Sampling techniques

In selecting a sample, it is important to ensure that the sample mean is representative of the population mean thus the need to have large samples in order to minimize sampling errors (Johnson and Christensen, 2012). In this case the 525 learners selected ensured that the

sample statistics would be closer to the true population parameters. All the public schools that were involved in the study are governed in accordance with policies, guidelines and regulation stipulated in the Zimbabwean education act.

This study used the purposive sampling technique. According to McMillan and Schumacher (2010), the goal of purposive sampling is for the researcher to select a sample from the population that will be informative about the topic of interest. As suggested by Nwosu (2013), this sampling technique relies on the researcher's personal judgment in drawing a sample whose subjects possess the required characteristic and is most applicable in cases where the researcher has previous knowledge of the population and has a specific purpose for the study. In this case the subjects were Advanced level chemistry learners and their teachers. Merriam (2002), notes that when applying this technique, the researcher has to use an information rich sample so that they can understand insightfully what they are studying. In this study the researcher wanted to gain insight into the effect of Selvaratnam-Fraser and Ashmore et al Problem-solving models on Advanced Level Students Achievement in stoichiometry and ionic equilibria.

While selecting the sample, the researcher ensured that learners in both groups were in lower 6 (form 5). The researcher focused on lower 6 (form 5) chemistry learners because any change (intervention) implemented at lower 6 level has the potential to make an impact on future performance in upper 6 (form 6). Furthermore it was easier to gain access to lower 6 learners than to upper 6, who were preparing for the final national examinations at the time of the study. The participants who were selected had similar characteristics in terms of content coverage of the syllabus, school facilities as well as socioeconomic background. Moreover the participants chosen were proficient and well-informed with a phenomenon of interest. In addition to knowledge and experience the participants were readily available and willing to participate.

Several researchers have employed the purposive sampling technique in their studies. For instance, Nwosu (2008), used purposive sampling while investigating the impact of a cooperative learning instructional strategy on grade 09 learners' performance in science to select two schools that participated in his study. These schools were shown to have characteristics that were comparable in terms of location, learners, teaching and learning facilities. The use of this sampling technique as noted by McMillan and Schumacher (2010), is suitable for quasi experimental studies where it is not possible for the researcher to randomly assign participants to groups and where the researcher uses subjects who happen to be accessible or who may represent certain types of characteristics relevant for the research.

The allocation of the subjects to either the control or experimental groups was based on geographical location. Four schools on the northern and eastern parts of the district constituted the control group while the experimental group was composed of the remaining four schools on the southern and western parts of the district. A distance of about 25km separated the control and experimental schools. Such a separation according to Gaigher (2006), would minimize threats to internal validity of findings due to diffusion, contamination, rivalry and demoralization.

In order to ensure anonymity, schools participating in the study were coded. The codes CS1, CS2, CS3 and CS4 were used to identify schools in the control group. The letters "CS" designated those schools in the control group with the designated numbers 1, 2, 3 and 4 denoting the order and sequence followed by the researcher in visiting the schools for semi-structured interviews and classroom observations respectively (Dhlamini, 2012). Similarly schools in the experimental group were denoted by the codes ES1, ES2, ES3 and ES4 where the numbers 1, 2, 3 and 4 depicted the sequential numeric order in which the researcher conducted his visits in the concerned schools.

3.5 Instrumentation

In this study, the researcher developed stoichiometry and ionic equilibria achievement tests, classroom observations, semi structured interviews and focus group discussions were used for the purposes of collecting data. The researcher also employed problem solving worksheets in stoichiometry and ionic equilibria as data enriching sources for the purposes of triangulation.

3.5.1 Achievement tests

The researcher designed and developed two achievement tests for the purposes of assessing Advanced level chemistry students' problem-solving skills prior to and after treatment. The tests were based on concepts in stoichiometry and ionic equilibria. The selection of these topics was intended to explore the effect of Selvaratnam-Fraser and Ashmore et al Problem-solving models on Advanced Level Students problem solving in stoichiometry and ionic equilibria. The researcher administered the tests to measure the performance of learners in solving stoichiometry and ionic equilibria problems. The tests consisted of both multiple choice and open ended items. The tests were written by both the experimental group and the control groups before and after the intervention. The purpose of the pretest was to identify the weaknesses that learners have in stoichiometry and ionic equilibria problem solving. The post-test also enabled the researcher to determine if these weaknesses had been rectified during the implementation of the intervention.

3.5.2 Classroom observation checklist

Dhlamini (2012), notes that the use of classroom observations as a data collection tool can provide very important and useful information on how problem solving instruction could be implemented in chemistry. Through the use of naturalistic observations, the researcher can have a deep understanding of the behavior of teachers, the students, as well as the interactions

between teacher and student (Dhlamini, 2012). In this study the use of classroom observations was meant to establish what transpired in class during lessons on stoichiometry and ionic equilibria in both the experimental and the control schools. Mulhall (2003), points out that the use of observations enables the researcher to gain a rich picture of the whole social setting in which people function, by recording the context in which they operate.

3.5.3 Semi-structured interview schedule

In this study, the researcher conducted semi structured interviews with chemistry teachers. According to Dhlamini (2012), semi-structured interviews find use in research studies due to their flexibility as well as the researcher to follow up on incomplete and unclear responses. As supported by Harris and Brown (2010), semi structured interviews gives interviewers the chance to ask the participants questions that will generate answers based on the participant's own perspectives and in their own words. The semi-structured interviews were based on data collected from classroom observations. All the gestures, expressions, actions and interactions that the researcher had observed in teachers and learners were thoroughly explored during the face to face semi-structured interviews.

3.5.4 Focus group discussion guide

According to Sherraden (2001), focus groups are an exploratory research tool - a 'structured group process' to explore people's thoughts and feelings and obtain detailed information about a particular topic or issue. In this study focus group discussions were conducted with learners. The primary aim of a focus group is to describe and understand meanings and interpretations of a select group of people to gain an understanding of a specific issue from the perspective of the participants of the group (Liamputtong 2011). The focus group discussion was conducted to probe students' views on stoichiometry and ionic equilibria problem solving as well as the difficulties they encounter as they learn the two topics.

3.6 Development of Instruments

3.6.1 Achievement tests

Two sections of the Advanced level chemistry syllabus were selected for the study. The two sections covered topics on atoms, molecules and stoichiometry as well as ionic equilibria. Two tests namely the Stoichiometry Achievement Test (SAT) and Ionic Equilibrium Achievement Test (IEAT). In developing SAT and IEAT reference was made to the achievement objectives for stoichiometry and ionic equilibria as stated in the Advanced Level chemistry syllabus. The SAT and IEAT covered the concepts of stoichiometry and ionic equilibria as outlined in the Zimbabwe School Examinations Council (ZIMSEC) Advanced Level Syllabus (9189) for 2013 - 2017. SAT and IEAT test items were derived from ZIMSEC past examination question papers and recommended textbooks consisting of both multiple choice and open ended items. The researcher constructed a one and half hour achievement test in each case.

3.6.2 Observation schedule

The researcher constructed an observation checklist in order to study and reveal how lessons were being conducted in both experimental and control groups. The checklist consisted of areas of focus that the researcher would look at when observing teachers and learners in both groups. The researcher wanted to find out if teachers are implementing problem solving strategies in their chemistry lessons and to observe how problem solving strategies could be incorporated into a chemistry lesson as well as how learners were responding to teaching and learning chemistry as a result of the incorporation problem solving strategies.

3.6.3 Semi-structured interview schedule

A semi structured interview schedule was developed by the researcher to address and probe learners' interactions, responses and actions that the researcher had observed in both learners

and teachers during classroom observations. In designing the interview questions the researcher was guided by Dhlamini (2012), who noted the importance of addressing and incorporating the diverse settings and contexts that were observed in the participants during the lessons.

3.6.4 Focus group discussion guide

The focus group discussions were designed and conducted to probe students' views, thoughts and feelings on stoichiometry and ionic equilibria problem solving. The focus group discussions also elicited students' views regarding the difficulties they face when solving stoichiometry and ionic equilibria problems.

3.7 Validation of instruments

According to Kimberlin and Winterstein (2008), validity is the extent to which an instrument measures what it is supposed to measure and performs as it is designed to perform. De Vos et al. (2002), categorize validity into two forms, namely whether the instrument actually measures the concept in question and whether the concept is measured accurately.

3.7.1 Achievement tests

The achievement tests were evaluated for face and content validity. As noted by Kimberlin and Winterstein (2008), content validity relates to how well the test succeeds in covering the field with which the test is concerned. As applied in this study, content validity signifies the extent to which a test succeeds in covering the field and concepts with which the test is concerned. Face validity is a characteristic associated with a test and its individual items. As noted by Holden (2010), face validity is the appropriateness, sensibility, or relevance of the test and its items as they appear to the persons answering the test. It simply refers to the

degree to which test respondents view the content of a test and its items as relevant to the context in which the test is being administered.

The achievement tests in stoichiometry and ionic equilibria were given to reputable and credible chemistry educators, six lecturers from universities in the country who are holders of doctorates in chemistry education, two chemistry heads of department at school level and two experienced Advanced level chemistry teachers. The test was thus validated by ten experts employed at different educational institutions who worked independently. The chemistry educators subjected the test items to face and content validity in terms of language clarity to the target audience, relevance to the aims of the study, coverage of the topics chosen for the study and importance and significance of test content in meeting the intended outcomes of the Advanced level chemistry curriculum. The chemistry educators raised the need to include open-ended questions that test conceptual understanding and require thinking. The tests initially had multiple choice items. The suggestion to incorporate the open-ended items were considered by the researcher in constructing the final test items.

3.7.2 Interviews and observation schedules

The instruments were evaluated for face validity by the supervisor and other experts in chemistry education who critically evaluated the instruments and commented on their content. The experts determined the relevance of the instruments by checking whether the items on the instrument were relevant, reasonable, unambiguous and clear. The validation process ensured the readability and clarity of the content on the instruments.

Furthermore the researcher conducted a pilot study before embarking on the main study. According to Hazzi and Maldaon (2015), conducting a pilot study is meant to identify, reveal and address the deficiencies in the research design of a proposed study, thus improving the quality and efficiency of the main study. In addition, Hazzi and Maldaon (2015), point that a

pilot study can be used to reveal some logistics issues before embarking the main study, which pilot study results can inform feasibility and identify modifications needed in the main study. All the classroom observations were conducted as stipulated in the observation schedule. In order to strengthen consistency in eliciting data from the respondents, all interview questions from the interview schedule were asked. Both the classroom observations and semi structured interviews measured the same constructs. The researcher used the process of convergent validity to cross-validate data that were obtained from observations and interviews. As noted by Guo et al. (2008), convergent validity is agreement between measures of the same construct assessed by different methods. Convergent validity was used to provide evidence that the same concept measured in different ways yields similar results. It examined whether the data from both interviews and observations were related and in agreement (Dhlamini, 2012). In accordance with Waltz, Strickland and Lenz (2010), the use of this method enabled the researcher to counter-balance and overcome the problems, weaknesses and intrinsic biases of one technique with the strengths of the other. The data obtained from the pilot study demonstrated that the two instruments were strongly correlated, hence the strong convergent validity.

3.8 Instrument Reliability

Reliability is defined as the degree of consistency with which an instrument measures the attribute it is designed to measure. It refers in general to the extent to which independent administration of the same instrument (or highly similar instruments) consistently yields the same (or similar) results under comparable conditions (De Vos et al, 2002). , In other words reliability is the repeatability of a measurement.

3.8.1 Achievement tests

In this study the reliability of the tests was determined using the internal consistency method. The estimate of reliability of the achievement tests was determined through Cronbach's alpha. Both multiple-choice and open-ended questions were similarly scored. Students were given 1 point for each correct answer and 0 point for wrong answer. The total score for each test was 50 points. The achievement tests were piloted with 96 students. A higher degree of Cronbach's alpha coefficient demonstrates higher degree of inter item correlation among the constructs. If the value of Cronbach's alpha is more than 0.7, then the instrument is considered to be reliable. The results as shown in the table below indicated the reliability of the tests in measuring the learners' problem solving skills in stoichiometry and ionic equilibria. With a sample of $n = 96$, the values of Cronbach's were computed for reliability of the tests as shown in the table below.

Table 3.8.1 Reliability statistic of pretests

	Cronbach's Alpha ^a	Number of Items
Stoichiometry pretest	.847	25
Stoichiometry posttest	.837	25
Ionic equilibria pretest	.840	20
Ionic Equilibria posttest	.831	20

3.8.2 Classroom observations

The interrater reliability method was used to check the reliability of the observation schedule. Furthermore the reliability of the observations, was determined by repeatedly using the observation schedule as well as checking the internal consistency in the outcomes and in each

case the data from observations was checked against data obtained from the interviews (Dlamini, 2012).

3.8.3 Semi-structured interviews

In line with Donkor (2010), the researcher enhanced the reliability of the semi-structured interviews by conducting the interviews himself so as to ensure reduction in subjectivity and minimization of variability. The researcher also made sure that the participants were interviewed under similar conditions for 30 minutes at school soon after work. Furthermore, in interviewing the participants, the researcher made sure that all the interview questions were asked in the order that was clearly outlined in the observation guide as suggested by Dlamini (2012).

3.9 Data Collection

Data collection was mainly done in two phases: the pilot study and the main study.

3.9.1 The Pilot Study

The researcher conducted a pilot study in high schools that resembled the schools used in the main study in terms of socio-economic conditions and status but located in another district (80km) in an area that was different from where the schools in the main study are located. This ensured that there was no contamination or interaction between participants in the pilot schools and those in the schools involved in the main study. Three Advanced level chemistry classes from three high schools took part in an intervention programme that lasted for about two weeks. The researcher taught these classes using problem-solving instruction. The three schools were code P1, P2 and P3 respectively. School P1 was taught stoichiometry using the Selvaratnam - Frazer Problem –Solving Model while school P2 was taught ionic equilibria using Ashmore, Casey and Frazer model while P3 acted as the control. A convenience sample

of 160 (60 learners (P1), 50 learners (P2) and 50 learners (P3) was used in this study. The three chemistry teachers of these classes were interviewed.

3.9.1.1 Pilot study intervention implementation

The pilot schools allocated 11 periods to Advanced level chemistry teaching. The total amount of time devoted to chemistry teaching was about six and half hours per week. The duration of each period was 35 minutes, which is equivalent to one hour ten minutes for each double period. The schools had four double lessons for theory and a block of three periods reserved for practical lessons. The time tabling arrangement in the three schools enabled the researcher to implement a two week intervention programme as shown in the table below

Table 3.9: Pilot study programme for data collection (P1)

Week	Day	Lesson Activity	Research Activity
1	1	<ol style="list-style-type: none"> 1. Researcher introduces himself 2. Learners write pretest 3. Researcher invigilates pretest 	Pre-test Administration
	2-3	<ol style="list-style-type: none"> 1. Introduction of lesson(Relative masses of atoms and molecules, The mole, the Avogadro's constant). 1.Learners arranged in groups 	Intervention
	4-5	<ol style="list-style-type: none"> 2.Problem solving worksheets given to learners 3. Learners taken through solution steps 4. Problem solving activities by learners 	Observations
2	6-7	<ol style="list-style-type: none"> 1.The determination of relative atomic masses, Ar and relative molecular masses, Mr from mass spectra 2. The calculation of empirical and molecular formulae 3. problem solving activities by learners 	Observations
	8-9	<ol style="list-style-type: none"> 1. Reacting masses and volumes (of solutions and gases) 2. Problem solving activities by learners. 	Observations

	10	3. Revision and remediation. 1. Learners write post test 2. Invigilation by researcher	Posttest Administration
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Table 3.9.2: Pilot study programme for data collection (P2)

Week	Day	Lesson Activity	Research Activity
1	1	1. Researcher introduces himself 2. Learners write pretest 3. Researcher invigilates pretest	Pre-test Administration
	2-3	1. Bronsted-Lowry theory of acids and bases 2. Learners arranged in groups 3. Problem solving worksheets given to learners 4. Learners taken through solution steps 5. Problem solving activities by learners	Intervention
	4-5	1. Acid dissociation constants, K_a and the use of pK_a 2. Base dissociation constants, K_b and the use of pK_b . 3. The ionic product of water, K_w 4. problem solving activities by learners	Observations
		6-7	1. pH: choice of pH indicators 2. Buffer solutions 3. Problem solving activities by learners.
	8-9	1. Solubility product; the common ion effect. 2. Problem solving activities by learners. 3. 3. Revision and remediation.	Observations
2	10	1. Learners write post test 2. Invigilation by researcher	Posttest Administration

3.9.1.2 Pilot study results (quantitative)

The quantitative data that were obtained from the pilot study were analyzed statistically by means of a *t*-test (see section 4.1). The results of the pilot study indicated an improvement in the performance. The mean scores for the pretest and posttest were compared using a *t* test in

order to determine whether the problem solving instruction was effective at the significance level of 0.05. The findings indicated an increase in the mean scores of the treatment group than the control group an indication that the learners in the experimental group had significantly improved in their performance in the stoichiometry and ionic equilibria achievement tests at 0.05 level of significance. The results of the pilot study seemed to suggest that the problem solving intervention was more superior and effective than the conventional lecture method. Since the researcher was to conduct the main study in schools comparable to the pilot schools in terms of socioeconomic status, and given that the schools were run in accordance with rules and regulations of the Ministry of Primary and Secondary Education, it was therefore anticipated that similar findings would be obtained from the main study. Thus the findings from the pilot study provided evidence of the implementability and feasibility of the methodology in the main study.

3.9.2 Main Study

3.9.2.1 Achievement test

The collection of data in this case was conducted in a way as was done during procedure for the pilot study. The commencement of the study was marked by the administration of a pretest to the groups (control and experimental) participating in the study. The researcher ensured anonymity by assigning index codes to learners for use in the achievement tests. In the pretest, the learners were assigned codes such as PRET-001 to represent learner 1 in the pretest. In the post test the same codes were maintained for each participating learner. Thus a learner with code PRET- 150 in the pretest used code POST-150 in the post test. The codes allocated were unique to each learner and continued uninterrupted from school to school (Dlamini, 2012). The duration of test was one and half hours long. The triple period meant for chemistry practical lessons was used for the purposes of writing the test.

The researcher was assisted by the chemistry classroom teacher to administer the test in both the experimental schools and control schools. Prior to the administration of the test, the researcher met with each teacher in order to ensure that both groups that were situated about 25km apart operated under similar conditions. The teachers were strictly admonished to abide by the conditions governing the administration of the test and to invigilate scrupulously. The teachers were requested not to assist the learners in any way while they were writing the test. The strict adherence to these set rules made sure that the tests were written under similar conditions in the participating schools.

The experimental schools were taught by research assistants. Two of them were exposed to a two-week training workshop on the use of Selvaratnam-Frazer (1982), Problem Solving Model while the other two were exposed to two-week training workshop on the use of Ashmore, Casey and Frazer (1979), Problem- Solving Model. They were tutored on how to teach stoichiometry and ionic equilibria using these problem-solving models. The control schools were taught by their teachers using the conventional method and were never trained on the use of these problem-solving instructional models. The problem solving instruction was based on Selvaratnam - Frazer as well as Ashmore, Casey and Frazer problem-solving models.

The implementation of the problem solving intervention was done for over an 8 week period thus in each school the intervention was implemented for a period of two weeks. Each school in the control group was paired with a school in the experimental group during the entire duration of the implementation of the intervention. As suggested by Dlamini (2012), twinning the schools made it easy for the researcher to conduct observations in the control schools for the period that the intervention was being implemented. The researcher also made arrangements with teachers in both experimental and control schools to make classroom observations twice a week. The last day of the intervention period was reserved for writing

the post-test and the triple period designated for practical work was used for the purpose. The duration of the post-test was one and half hours.

3.9.2.2 Teacher Training

In-service training for the four experimental school teachers was provided in order to ensure consistency between schools. Teachers were given verbal instruction in using the structured problem-solving strategies and given worked examples of each type of problem the students would encounter during the study utilizing the problem-solving strategies. Each of the experimental school teachers was given an instructional package consisting of lesson notes for the treatment groups. The lesson notes for the Experimental group 1 featured Ashmore, Cassey and Fraser (1979), problem-solving approach and that of Experimental group 2 featured Selvaratnam and Fraser (1982), problem-solving approach. The training began by explaining the problem-solving strategy to the participants with some examples of problems solved using each strategy. The researcher then explained the main purpose of each step and the process of using the strategy by solving some sample problems following the model.

The teachers were given comprehensive orientation on the principle behind the use of structured problem-solving as an instructional strategy and content areas for the study discussed. They were free to ask questions and offer suggestions on how best the approach could successfully be implemented in the school. The teachers were given comprehensive orientation on the principle of structured problem-solving in order to expose them to the nitty-gritty of the problem-solving instruction so that they could adopt the strategy on their own if found effective after the exit of the researcher.

The Ashmore, Cassey and Fraser (1979) problem - solving method

The Ashmore, et al (1979), model for solving chemistry problems is a heuristics consisting of four steps shown below:

1. Definition of the problem.
2. Selection of appropriate information.
3. Combination of separate pieces of information.
4. Evaluate.

The strategy was presented to the participants in the form of a problem-solving chart shown below.

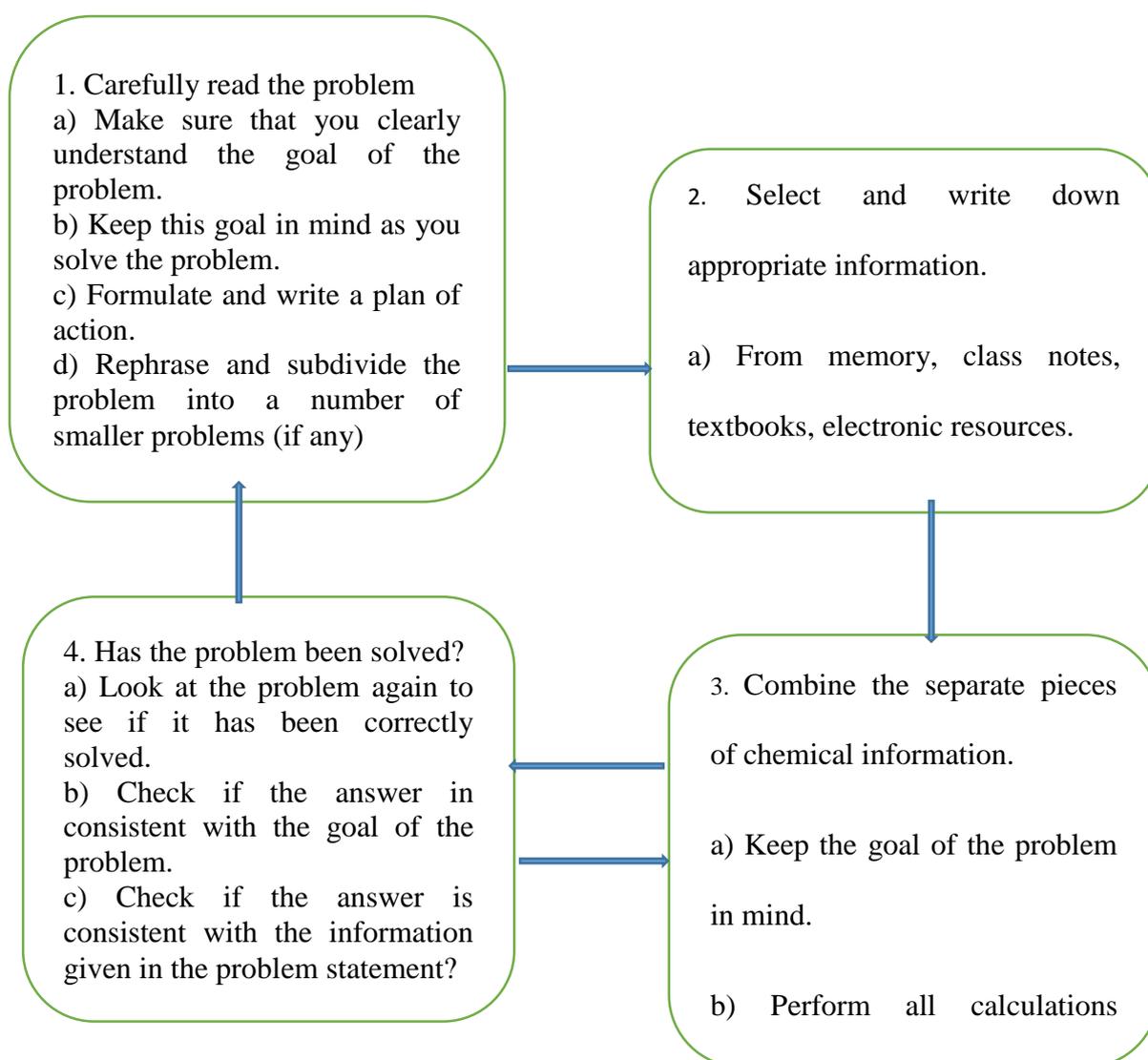


Figure 3.1 Ashmore, Cassey and Fraser (1979) problem-solving Chart

The application of the model in solving stoichiometric problems is illustrated in two examples shown below.

Example 1.

The reaction of powdered aluminum and iron(II)oxide, produces so much heat the iron that forms is molten. Because of this, railroads use the reaction to provide molten steel to weld steel rails together when laying track. Suppose that in one batch of reactants 4.20mol Al was mixed with 1.75mol Fe₂O₃.

- a. Which reactant, if either, was the limiting reactant?
- b. Calculate the mass of iron (in grams) that can be formed from this mixture of reactants.

1. Defining the problem/ information given about the problem

◆ **goal:** determine limiting reagent; determine mass of Fe produced.(unknowns)

◆ **Knowns:** Al reacts with Fe₂O₃
Molten Fe (l) produced used for welding
4.2 mol Al reacting with 1.75 mol Fe₂O₃

2. Selecting relevant pieces of information

mole = wt/MW wt = mole x MW

1 mol Al = 27g; 1 mol Fe = 55.8g; 1 mol O = 16g; 1mole Fe₂O₃ = 160g.

Balanced equation for the reaction: $2\text{Al}_{(s)} + \text{Fe}_2\text{O}_{3(s)} \rightarrow \text{Al}_2\text{O}_{3(s)} + 2\text{Fe}_{(l)}$

3. Combining pieces of information and calculation

2 mol Al require 1 mol Fe₂O₃

1mol Al = $\frac{1}{2}$ Fe₂O₃

→ 4.2mol Al = 2.1 mol Fe₂O₃

Therefore Fe₂O₃ is limiting

1 mol Fe₂O₃ produces 2mol Fe (l)

→ 1.75 mol Fe₂O₃ produces (2x1.75) mol Fe (l) ie 3.5 mol Fe (l)

mole = wt/MW

wt = mole x MW

mass of Fe(l) produced = 3.5 mol x 55.8gmol⁻¹ = 195.3g

4. Evaluate

Is the problem correctly solved? Yes.

Is the answer consistent with the goal of the problem? Yes.

Example 2.

1.20 dm³ of hydrogen chloride gas was dissolved in 100 cm³ of water.

- a.i) How many moles of hydrogen chloride gas are present?
- ii) What was the concentration of the hydrochloric acid formed?
- b) 25.0 cm³ of the acid was then titrated against sodium hydroxide of concentration 0.200 mol dm⁻³ to form NaCl and water:
 - i) How many moles of acid were used?
 - ii) Calculate the volume of sodium hydroxide used.

1. Defining the problem/ information given about the problem

♦ **goal:** determine mol HCl gas; conc HCl solution; mol HCl and vol NaOH used during titration.(unknowns)

♦ **Knowns:** vol HCl gas dissolved (1.20 dm³)
vol H₂O used (100cm³)
vol HCl used during titration (25.0cm³)
conc NaOH used during titration.

2. Selecting relevant pieces of information

1mole gas occupies 24.0 dm³ rtp

conc = mole/volume mole = conc x V

1000cm³ = 1dm³; C₁V₁ = C₂V₂

Balanced equation for the reaction: NaOH + HCl → NaCl + H₂O

3. Combining pieces of information and calculation

1mole gas = 24.0 dm³ → 1.20dm³ = $\frac{1.2}{24}$ = 0.05 mol

C = n/V → C = $\frac{0.05}{0.1}$ = 0.5mol dm⁻³

From equation: moles NaOH = moles HCl produces 2mol Fe (l)

→ mol HCl = 0.5mol dm⁻³ x 0.025dm³ = 0.0125 mol

Vol of NaOH = mol/conc = 0.0125mol/0.2mol dm⁻³ = 0.0625dm³

4. Evaluate

Is the problem correctly solved? Yes.

Is the answer consistent with the goal of the problem? Yes.

Is the answer consistent with the information given in the problem statement?

Yes.

The desired actions during problem solving using the Ashmore, et al (1979) strategy are summarised in figure 3.2 below.

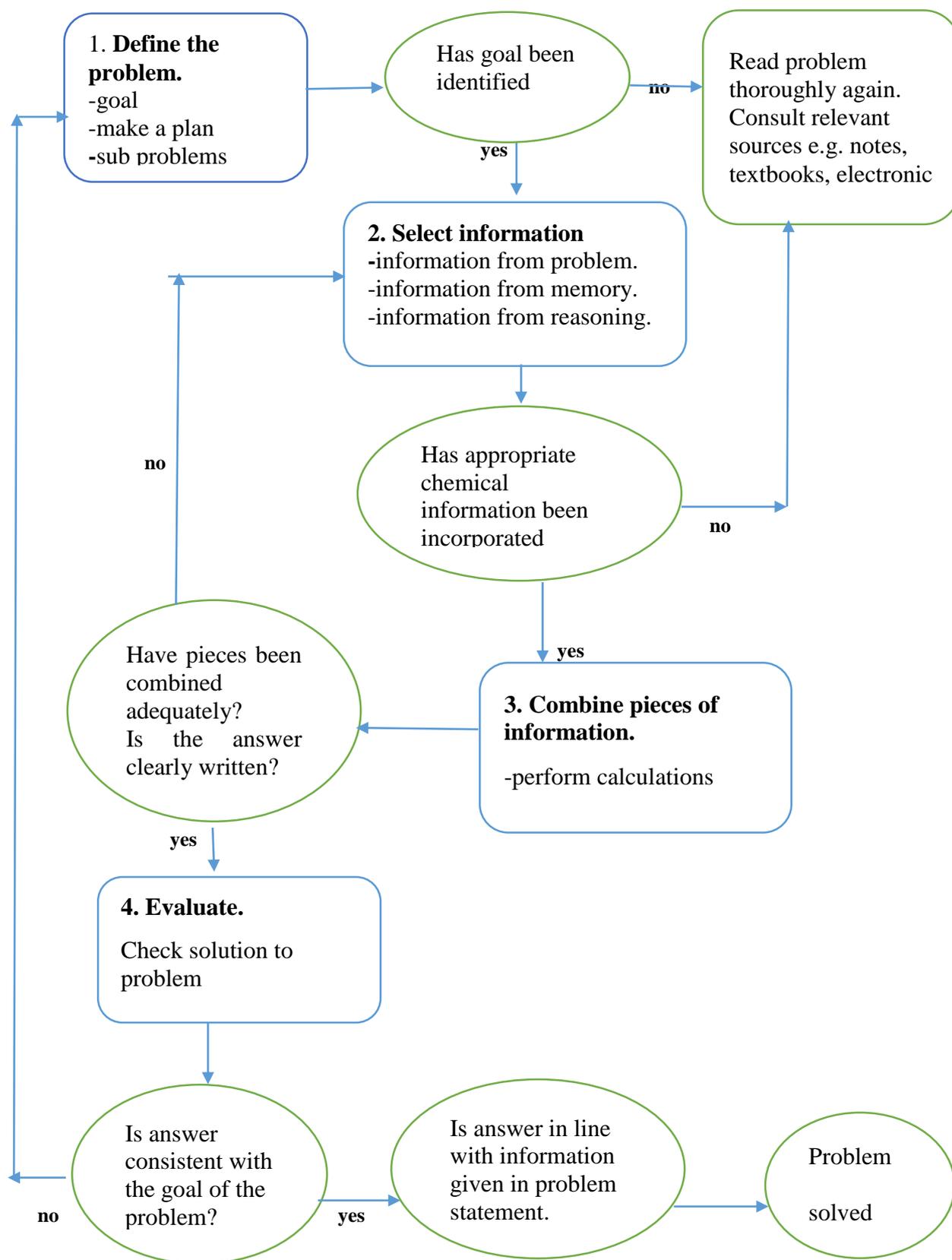


Fig 3.2. Phases of Ashmore, Cassey and Fraser (1979) strategy for problem-solving

The Selvaratnam and Fraser (1982) problem - solving method

The Selvaratnam-Frazer (1982), problem solving approach devised for solving problems in chemistry is a 5 step problem-solving model which involves:

1. clarifying and defining the problem.
2. selecting the key equations.
3. deriving the equation for the calculation.
4. collecting data, checking units and calculating.
5. Review and learning from solution.

The strategy was presented to the participants in the form of a problem-solving chart shown below.

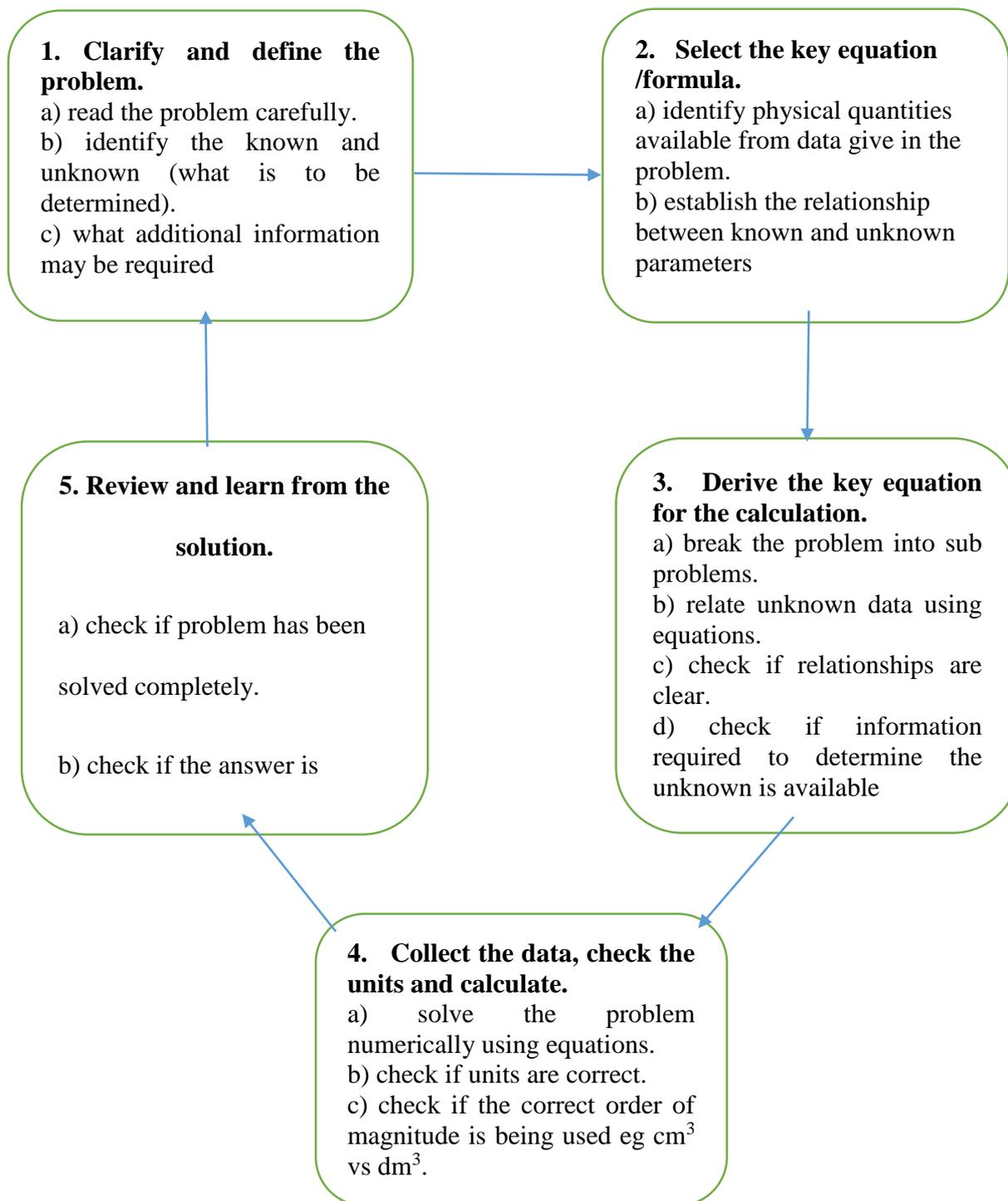


Figure 3.3 Selvaratnam and Fraser (1982) problem-solving Chart

The application of the model in solving stoichiometric problems is illustrated in two examples shown below.

Example 1.

Vehicle air bags protect passengers by allowing a chemical reaction to occur that generates gas rapidly. Such a reaction must be both spontaneous and explosively fast. A common reaction is the decomposition of sodium azide, NaN_3 , to nitrogen gas and sodium metal. Determine the mass of $\text{NaN}_3(\text{s})$ that must be reacted in order to inflate an air bag to 75.0 litres at STP.

1. Clarify and define the problem

◆ **known:** vol N_2 gas produced (75.0 L)

$$1 \text{ mol NaN}_3 = 65 \text{ g.}$$

equation for decomposition of NaN_3 : $2 \text{NaN}_3(\text{s}) \rightarrow 2 \text{Na}(\text{s}) + 3 \text{N}_2(\text{g})$

◆ **unknown:** mass of NaN_3 required

2. Selecting key equations

$$\text{moles} = \frac{m}{M_r}; PV = nRT; n = \frac{PV}{RT}$$

from equation moles of $\text{NaN}_3 = \frac{2}{3}$ moles N_2

3. Derive equation for calculation

◆ **sub problems :** - determine moles of N_2 produced.

- determine moles of NaN_3 .
- determine mass of NaN_3 .

4. Calculations

$$n = \frac{PV}{RT}; n = \frac{1 \text{ (atm)}(75.0 \text{ L})(\text{mol} \cdot \text{K})}{(0.08314 \text{ atm} \cdot \text{L})(273)} = 3.304 \text{ mol N}_2$$

$$\text{moles of NaN}_3 = 3.304 \text{ moles N}_2 \times \left(\frac{2 \text{ mol NaN}_3}{3 \text{ mol N}_2} \right) = 2.203.$$

$$\text{mass of NaN}_3 = 2.203 \text{ mol} \times 65.0 \text{ g/mol NaN}_3 = 143.2 \text{ g.}$$

5. Review and learn from the solution

- ◆ is the answer correct and sensible - **yes**
- ◆ have correct units been used - **yes**

Problem
is solved

Example 2.

Magnesium oxide is not very soluble in water, and is difficult to titrate directly. Its purity can be determined by use of a 'back titration' method. 4.06 g of impure magnesium oxide was completely dissolved in 100 cm³ of excess hydrochloric acid, of concentration 2.00 mol dm⁻³. The excess acid required 19.7 cm³ of sodium hydroxide (0.200 mol dm⁻³) for neutralisation using phenolphthalein indicator and the end-point is the first permanent pink colour. Determine the % purity of the magnesium oxide.

1. Clarify and define the problem

◆ **known:** mass MgO dissolved (4.06g) ; vol of HCl used (100cm³, 2 mol dm⁻³) ; vol NaOH used in titration (19.7cm³, 0.200 mol dm³); Mr (MgO) = 40.3 gmol⁻¹

◆ **unknown:** %purity MgO

2. Selecting key equations

moles = $\frac{m}{M_r}$; $C = \frac{n}{V}$; $CV = n$

Equations for neutralisation : $MgO_{(s)} + 2HCl_{(aq)} \implies MgCl_{2(aq)} + H_2O_{(l)}$
 $NaOH_{(aq)} + HCl_{(aq)} \implies NaCl_{(aq)} + H_2O_{(l)}$

3. Derive equation for calculation

◆ **sub problems:** moles of HCl added to the MgO ; moles of excess HCl titrated ; moles of HCl reacting with the MgO ; mole MgO reacted ; mass of MgO reacting with acid ; % purity MgO.

4. Calculations

moles of HCl added to the MgO = $2 \times 100/1000 = 0.20 \text{ mol HCl}$

moles of excess HCl titrated = $19.7 \div 1000 \times 0.200 = 0.00394 \text{ mol HCl}$

{ mole ratio NaOH : HCl is 1 : 1 from equation }

moles of HCl reacting with the MgO = $0.20 - 0.00394 = 0.196 \text{ mol HCl}$

mole MgO reacted = $0.196 \div 2 = 0.098$ { 1 : 2 in equation }

Mr of MgO = 40.3 therefore mass of MgO reacting with acid = $0.098 \times 40.3 = 3.95 \text{ g}$

% purity = $3.95 \div 4.06 \times 100 = 97.3\% \text{ MgO}$

5. Review and learn from the solution

◆ is the answer correct and sensible - **yes**

◆ have correct units been used - **yes**

Problem solved

The desired actions during problem solving using the Selvaratnam and Fraser (1982), strategy are summarized in figure 3.4 below.

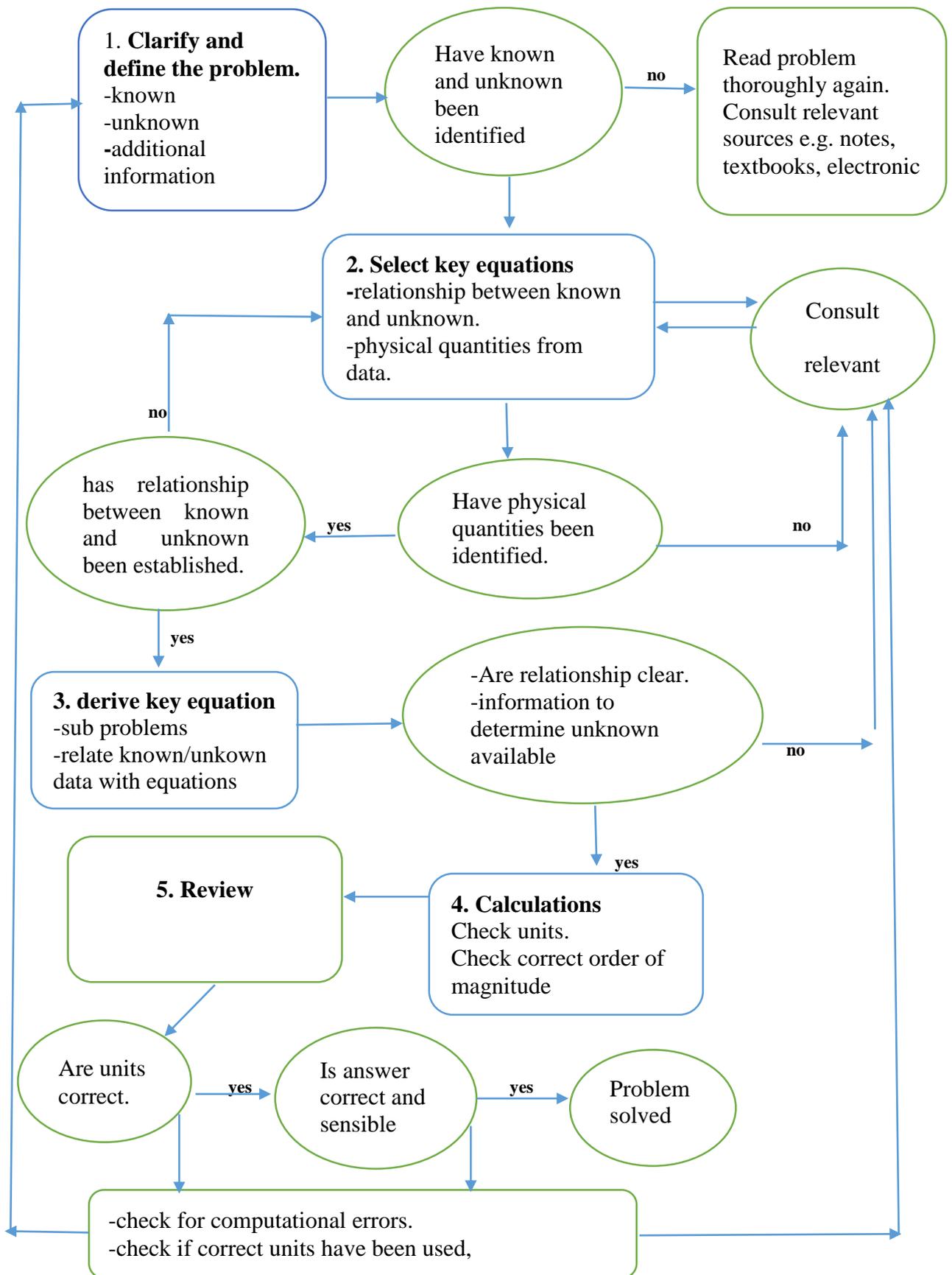


Fig 3.4. Phases of Selvaratnam and Fraser (1982) strategy for problem-solving

3.9.2.2 Classroom observations

To conduct classroom observations with chemistry teachers and learners, the researcher visited each of the experimental and control schools thrice. The numbers of visits were limited in order not to disrupt the smooth running of lessons as well as not to overburden teachers and learners with the researcher's presence. The researcher chose to observe those lessons that offered the learners opportunities that were fertile with problem solving and at the same time allowing the teacher and the learners to think about and seriously reflect on their problem solving actions.

The researchers encouraged the teachers in the control schools to continue teaching in their usual way and were assisted with problem solving worksheets. The teacher observation in control schools was meant to determine the type of instruction the teacher implemented as well as whether the teachers incorporate problem-solving strategies in their lessons. Furthermore the teacher observations were meant to ascertain the quality of teacher-learner interaction during lessons and to determine how the teachers develop learners' problem solving skills.

Observations were also done on learners in both the control and experimental groups. In the control group the observations mainly focused on level of participation, involvement and contribution during instruction, the strategies and approaches used to solve chemistry problems as well as the challenges faced in solving stoichiometry and ionic equilibria problems. On the other hand, observation in the experimental groups focused on testing the effectiveness of the problem-solving intervention. The learners in both groups were engaged in similar activities in problem solving with the exception that those participants in the experimental group were taught using problem-solving strategies by their teachers who had been trained on how to implement these. The learners' reactions and adaptation towards the

problem-solving instruction, challenges posed as a result of exposure to the intervention as well as the influence of the new instruction on learners' problem solving skills were observed by the researcher.

3.9.2.3 Semi structured Interviews

The researcher randomly selected four teachers from the eight to participate in the interviews. The researcher selected two teachers from each group for the interviews. The researcher probed the teachers on difficulties and challenges experienced by learners when solving stoichiometry and ionic equilibria problems. The teachers were further probed on their views regarding how chemistry problem- solving can be taught as well as how they taught problem solving skills in the chemistry classroom.

3.9.2.4 Focus group discussions

Focus group discussions were conducted with learners in both the control and experimental groups. The researcher probed learners in the control group on their views regarding stoichiometry and ionic equilibria problem solving, the challenges and difficulties they face when solving stoichiometry and ionic equilibria problems, and their suggestions on how problem-solving instruction can be incorporated in chemistry teaching.

The experimental group was taught by the research assistants using problem-solving instruction. The researcher probed this group on their experiences as a result of being exposed to new method of teaching, their strategies of solving chemical problems as well as suggestions on how best to incorporate and improve the use of problem-solving instructional strategies in chemistry teaching and learning. Two control schools and two experimental schools randomly chosen participated in the study. There were two focus groups in each school. Each focus group comprised of ten learners.

3.10 Data Analysis

Quantitative data analysis techniques were used to analyze data obtained from achievement tests while qualitative techniques were used to analyze data from observations, interviews and focus group discussions.

3.10.1 Quantitative data Analysis

Quantitative data was analyzed by conducting one way analysis of covariance (ANCOVA) with the dependent variable being learners' post test scores in stoichiometry and ionic equilibria achievement tests with the learners' pretest scores being the covariate. For all statistical data analysis a significance level of 0.05 was used. The researcher had to evaluate the assumptions underlying the ANCOVA test before performing the analysis. Such assumptions as the homogeneity of regression, the linearity of data distribution were evaluated prior to the analysis.

The assumption of homogeneity of regression is used to test if there is an interaction between the covariate and the treatment. The test for regression homogeneity makes the assumption that the independent variable and the covariate do not interact. However there are two possibilities: a significant interaction and a non-significant interaction. According to Dhlamini (2012), a significant interaction ($p < 0.05$) indicates that the ANCOVA assumption of parallel lines is not being met. This implies that the analysis should not be conducted as it violates an assumption of ANCOVA. If the interaction is not significant ($p > 0.05$), then there is not enough evidence to conclude that the assumption of homogeneity of regression has been violated as a result the researcher can go ahead and perform the ANCOVA analysis.

ANCOVA further assumes that the covariate has a linear relationship with the dependent variable. According to Dlamini (2012), if this assumption is violated the results from the ANCOVA will be of little value hence there will be no need for performing the analysis. The

linear relationship between the covariate and independent variable was determined using SPSS by graphically plotting a scatter diagram. A linear relationship exists between the covariate and the dependent variable if the slope of the regression lines is parallel and an ANCOVA can be performed.

3.10.2 Qualitative Data Analysis

Classroom observations, semi structured interviews and focus group discussions were used to collect qualitative data.

3.10.2.1 Classroom observations

Feedback from classroom observations were recorded in the researcher's note book based on the area of focus the researcher had established based on the research questions of the study. The researcher established and used identification codes for teachers as well as learners. Observations for teachers in control schools were coded OBC1, OBC2, OBC3 and OBC4 while teachers in experimental schools were coded OBE1, OBE2, OBE3 and OBE4 with the numbers corresponding to the sequence of observation visits. Similarly observations for learners were coded OLE1, OLE2, OLE3 and OLE4 for learners in the experimental schools while the codes OLC1, OLC2, OLC3 and OLC4 were used for learners in the control schools. The use of this identification system enabled the researcher to trace the source of a noted behavior to a particular school.

The researcher transcribed, sorted and organized data from observations according to common themes. The researcher went on to categorize the data and then analyzed it into emerging themes. The researcher also identified similarities and differences among the data. The data were represented according to emerging patterns and commonalities based the area of focus established earlier on.

3.10.2.2 The interviews

The researcher conducted semi-structured interviews with teachers. The interviews were tape recorded and transcribed verbatim. Four teachers (two from experimental and two from control schools) randomly chosen participated in the interviews. The teachers were identified as CT1, CT2 for control school and ET1, ET2 for experimental schools. Teacher 1 (CT1) was the first to be interviewed while CT2 was interviewed second. Once all the interviews had been transcribed, the researcher reviewed the data in order to identify common, recurrent, or emergent patterns and themes. The data from the interviews were organized into sub-categories related and linked to questions asked the participants in the interviews. Having come up with the sub-categories the researcher then compared the items from these sub-categories noting similarities and differences. The researcher then noted the prominent themes that emerged from each category.

3.10.2.3 Focus group discussions

Focus group discussions with learners from both experimental and control schools were recorded and transcribed verbatim. In this case codes were established and used to identify, label and link the data to the respective schools. The researcher had to categorize the discussions that were conducted in experimental schools as FE1 and FE2 and those from control schools as FC1 and FC2. After transcription the data were then categorized into common themes. Data from each focus group session were classified into sub-categories related to the questions asked during the session. Data from these sub categories were analyzed via constant comparison analysis to assess if the themes that emerged from one group also emerged from other groups.

3.11 Ethical Considerations

In the context of this study, the participation of teachers and learners was based on informed consent. As noted by Christian (2000), subjects in a research study voluntarily agree to participate based on full disclosure, guarantee of protection and safeguard against unwanted exposure and that their identity remains anonymous. It is therefore of paramount importance for the researcher to be open to the research participants and fully disclose the purposes and procedures of the study right from the onset. One of the ethical principles in research is for the researcher to get informed consent and in this case the researcher sought permission to conduct the research from the Ministry of Primary and Secondary Education, the heads of the selected schools, and the advanced level chemistry teachers. The researcher informed the participants about the purpose and procedures to be followed in conducting the study. Furthermore the researcher also explained to the learners that they were not going to be prejudiced in anyway and that they were not going to incur any harm or loss as a result of them participating in the study. The learners were made aware that they are free to withdraw their participation at any time without suffering any consequences.

The researcher wrote letters to the ministry, school heads and teachers seeking for permission to have their schools participate in the research study. Permission was also sought from parents' to have their children participate in the study. Simple, precise and straight forward language was used in writing the consent letters. The researcher also applied for and obtained ethical clearance from the University's Ethics Committee. In line with the code of ethics in research which requires the protection of the identities of participants against exposure, the researcher had to use codes in place of the learners' real names and their schools when reporting the results.

The researcher dealt honestly with all the participants and honored all the agreements made with them. Punctuality to all appointments and lessons was observed by the researcher and

was very sensitive to all the participants regardless of their social and economic backgrounds. The research took extreme care not to abuse his position of authority while he was involved with minors. The researcher adhered to appropriate research procedures as well as using the right instruments in collecting data while at the same time not concealing his identity to the participants.

Since intervention showed positive results, the teachers and learners from the control schools were exposed to the intervention after the completion of the study.

3.12 Chapter summary

This chapter has discussion all the methodological issues related to the study. It described the research approach, the research design, population, sample as well as the sampling techniques that were used in this study. It further explained the techniques that were used to collect and analyze data. In addition the chapter outlined a detailed description of how the intervention was implemented in the experimental schools. Lastly the chapter provided a detailed explanation on how the researcher strictly adhered to ethical principles of research in conducting the study. In the next chapter, the focus is on describing how quantitative and qualitative data was analyzed and presented.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 Introduction

In the previous chapter the methodology adopted for the present study was presented. The purpose of this chapter is to present, analyze and discuss both the quantitative and qualitative findings of the study. One-way analysis of covariance was used to analyze the quantitative data from stoichiometry and ionic equilibria achievement tests. Furthermore, the post hoc pairwise comparison using the Scheffe's test analysis was conducted to determine which of the paired mean differences were significant. In all the cases 0.05 level of confidence was fixed as level of confidence to test the hypotheses. The ANCOVA and other statistical analyses were performed on SPSS version 20.0. Furthermore, the chapter focuses on the presentation and analysis of data obtained from observations, semi structured interviews and focus group discussions. In analyzing qualitative data, the analysis approach drew mainly on the work of Burnard (1991). His stage by stage method of data analysis for semi-structured interviews was used as a base. His method assumes that semi-structured interviews are recorded in full and the whole recording is transcribed. The researcher then reads through the transcripts and categorizes the data according to identified themes.

4.2 Results from the pilot study

The achievement tests in stoichiometry and ionic equilibria were tried and tested during the pilot study. The data were analyzed using a dependent samples *t*-test at the 0.05 level of significance. This test is used to compare means between two related groups on the same dependent variable. As noted by Dhlamini (2016), the paired samples t-test is used to test if the mean difference between two sets of observations is zero. Rejecting or not rejecting the null hypothesis typically involves comparing the p-value to the significance level. If the p-

value is less than the significance level that is $p < 0.05$, the null hypothesis is rejected. However, if the p-value is greater than the significance level that is $p > 0.05$ we cannot reject the null hypothesis. Tables 4.1 and 4.2 below present the results of the t –test from the pilot study.

Table 4.1: Mean and standard deviation for stoichiometry test

<i>Test</i>	<i>group</i>	<i>n</i>	\bar{x}	<i>Std dev</i>	<i>Std Error</i>	<i>t</i>	<i>p</i>
pretest	A' level	60	44.95	8.21414	1.06044	13.626	0.000
Post test	A' level	60	58.0667	6.85162	0.88454		

Table 4.2: Mean and standard deviation for the ionic equilibria test

<i>Test</i>	<i>group</i>	<i>n</i>	\bar{x}	<i>Std dev</i>	<i>Std Error</i>	<i>t</i>	<i>p</i>
pretest	A' level	50	44.08	4.91910	0.69567	20.927	0.03
Post test	A' level	50	61.86	5.27609	0.74615		

Tables 4.1 and 4.2 show that the p-value is less than 0.05. The null hypothesis is therefore rejected in favor of the alternate. We therefore concluded that there is a statistically significant difference between the mean scores of the pre-tests and post-tests. This implies that there was a significant improvement in performance of the experimental group in problem solving achievement tests. These results revealed that the intervention employed would be workable in the main study thus warranting proceeding with the main study.

4.3 The main study (ANCOVA analysis)

Out of the 525 participants, only 485 (92.38%) fully participated in the study. Those who fully participated attended all classes during the duration of the study, undertook all problem solving tasks and wrote both the pretests and posttests in stoichiometry and ionic equilibria. An attendance register of all the participating learners was kept by all the participating teachers in all the schools on a daily basis. The information from the attendance register revealed that 25 learners in the experimental schools did not attend at least two lessons and had not written either one or both achievement tests. It was further revealed that 23 participants from control schools behaved similarly and did not fully participate in the study. It was found that about 48 participants in total did not participate fully in the lessons and achievement tests respectively. The data that were obtained from the 48 participants who did not fully participate in the lessons and achievement tests were not included in the data analysis.

Table 4.3: Information on learner participation in achievement tests

School	Number of learners	Number of absent learners who did not write 1 or both tests	Number of present learners who did not write 1 or both tests	Number of learners who wrote both tests
ES1	62	2	2	58
ES2	63	2	1	60
ES3	62	3	1	58
ES4	63	2	2	59
CS1	68	4	2	62
CS2	69	5	1	63
CS3	68	3	3	62
CS4	70	4	3	63

Total	525(100%)	25 (4.76%)	15 (2.86%)	485 (92.38%)
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The analysis of the data was done in SPSS (Statistical Package for Social Sciences) (Version 20). The one way analysis of covariance was performed on SPSS with the fixed factor as group, the pretest score as covariate and post-test score as the dependent variable.

4.3.1 Rationale for performing the ANCOVA analysis

According to Gall *et al.* (2007), one major potential limitation of the non-equivalent control group design arises from the fact that since assignment to groups was not random, the groups may be different prior to the study and any prior differences between the groups may affect the outcome of the study. Under the worst circumstances, this can lead us to conclude that our program didn't make a difference when in fact it did, or that it did make a difference when in fact it did not. Hence, such data is analyzed using ANCOVA so as to minimize the effects of initial group differences through statistically equating initial group differences between the experimental and control group.

Pallant (2007), notes that ANCOVA is based on inclusion of additional variables (known as covariates) into the model that may be influencing scores on the dependent variable. (Covariance simply means the degree to which two variables vary together – the dependent variable co-varies with other variables). This allows the researcher to account for inter-group variation associated not with the "treatment" itself, but from extraneous factors on the dependent variable, the covariate(s). The purpose of ANCOVA, according to Polit and Beck (2008), then, is the following: to increase the precision of comparison between groups by reducing within-group error variance; and, to “adjust” comparisons between groups for imbalances by eliminating confounding variables.

4.3.2 Levene's test of equality of error variances.

Before performing the ANCOVA test, the researcher had to test the assumption of

homogeneity of variance. In this case the Levene's test for equality of variances was performed. This test is conducted to test the null hypothesis that the variances are equal amongst the two group (Jackson, 2012). The Levene's test was used in this study to assess if there was any difference in the error variance among the two groups involved in the study that is the experimental and control groups. If $p < 0.05$ the Levene's test is positive meaning that the variances are not the same, hence, the groups are significantly different i.e. the homogeneity of variances assumption has been violated (Dhlamini, 2012). In this present study the Levene's test was performed by formulating a Null Hypothesis (H_0), which stated that the variances of the population were equal. On the other hand the alternate Hypothesis (H_1) was stated to indicate that the variances of the population were not equal.

The null hypothesis (H_0) - variances are the same

The alternate hypothesis (H_1) - variances are different

The following results were obtained from the Levene's test

Table 4.4: The results of Levene's test for the Stoichiometry achievement test

F	df1	df2	sig
.787	2	482	.456

Table 4.5: The results of Levene's test for the Ionic equilibria achievement test

F	df1	df2	sig
1.149	2	482	.318

Tables 4.4 and 4.5 respectively show that the results of Levene's test were $p = 0.456 > 0.05$ and $p = 0.318$, respectively. The values from the Levene's test are not significant meaning

that the data in question shows homogeneity of variance. Thus the assumption of homogeneity of variances for ANCOVA has been satisfied. This is an indication that the groups were homogenous. We cannot therefore reject the null hypothesis that the variances are equal. Having satisfied the assumption of homogeneity therefore, the researcher can then proceed with the ANCOVA analysis.

4.3.3 The assumption of homogeneity of regression

Before conducting an ANCOVA – the homogeneity-of-regression (slope) assumption should also be tested. As opined by Dhlamini (2012), the test is used to determine if there is an interaction between the covariate and the independent variable. If there is a significant interaction ($p < 0.05$) between the covariate and the independent variable then the assumption of homogeneity of regression slopes has been violated. The assumption therefore is not tenable. The implication is that ANCOVA analysis should not be performed. In this present study, if $p > 0.05$ the interaction will not be significant suggesting ANCOVA could not be conducted. This study tested if there was an interaction between the independent variable and covariate. The expectation is that the interaction between the covariate and the treatment be not significant. The following hypotheses were tested.

H₀: there is no interaction between the independent variable and the covariate

H₁: there is an interaction between the independent variable and the covariate

The results that were obtained are shown in table 4.6 and table 4.7

Table 4.6: The results for Between-Subjects Effects for the Stoichiometry achievement test

Source	F	Sig	df
groups* pretest	1.623	0.198	2

Error			479
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Table 4.7: The results for Between-Subjects Effects for the Ionic equilibria achievement test

Source	F	Sig	df
groups*pretest	2.114	0.118	2
Error			479

In tables 4.6 and 4.7, the interaction source is labeled **groups*pretest**. The results suggest the interaction is not significant, for the stoichiometry achievement test [$F(2, 479) = 1.623, p = .198 > 0.05$] as well as for the ionic equilibria achievement test [$F(2, 479) = 2.114, p = .118 > 0.05$]. Based on this finding, the interaction between the independent variable and the covariate was not significant so the Null Hypothesis (**H₀**) of no interaction cannot be rejected. Therefore, it can be concluded that the assumption of homogeneity of regression has been satisfied; meaning that the ANCOVA results for this study were reliable. We could therefore proceed with our ANCOVA analysis.

4.4 Research Question 1: What difficulties do learners encounter as they solve standard chemistry quantitative calculations in stoichiometry and ionic equilibria?

To determine the difficulties that exist in stoichiometry and ionic equilibria problem solving, an analysis of the solutions given by learners on open ended questions from the pretest was done. A number of difficulties that characterized participants' responses in the achievement test were identified.

4.4.1 Difficulties in stoichiometry problem solving

Problem 26 (b) required learners to demonstrate an understanding of the mole concept and its relationship to the Avogadro's number and the number of particles. It was found out that 78% of the learners could not apply the relationship involving the amount of substance (the mole) and the Avogadro's number in calculating the number of particles. The solutions provided by the majority of the students indicated that the students have difficulties in reasoning caused by lack of understanding of the problem. See example of use of inconsistent relationship in figure 4.1.

26. The compound NaHCO_3 is commonly known as baking soda. A recipe requires 1,6 g of baking soda, mixed with other ingredients, to bake a cake.

(a) Calculate the number of moles of NaHCO_3 used to bake the cake.

$$n = \frac{m}{Mr} = \frac{1,6\text{g}}{84,91\text{mol}} = 0,019 \quad \checkmark$$
$$= 0,02 \text{ moles} \quad \checkmark \quad (2)$$

(b) How many atoms of oxygen are there in 1,6 g baking soda?

$$\text{oxygen} = 0,02 \times 6,02 \times 10^{23} \quad \checkmark \checkmark \checkmark$$
$$= 1,204 \times 10^{22} \quad \times \quad (2)$$

Figure 4.1: An example of a learner's script showing use of inconsistent relationship

Figure 4.1 shows that the learner used an inconsistent relationships thus leading to the wrong solution. The student failed to note that what was to be converted were 3moles of oxygen atoms not molecules. The learner showed that they lacked understanding of the mole concept. This misconception was found in 60.5% of the learners in the experimental group and 66.2% of the learners in the control group. They could not link the macroscopic (e.g., mole) and

microscopic levels (e.g., molecules and atoms) and thought one mole was the same as one molecule.

Problem 27 required the learners to demonstrate an understanding of limiting reagents through the balancing of a chemical equation and calculating amounts of substances involved. In item 27(a) the learners were required to balance the chemical equation involved, while in 27(b) computational skills were required in calculating the amount of substance of each reactant present. Ninety percent (90%) of the made correct responses to these items.

Item 27 (c) require learners to identify the limiting reactant in a chemical reaction from the given equation. The majority of the students (87.9%) could not identify the limiting reagent neither could they justify their solution. They randomly selected one of the given masses as the limiting reagent without using the stoichiometry of the reaction and also identified the limiting reagent as the one with the smallest mass. Figure 4.2 shows an example of a learner who failed to identify the limiting reagent.

27. The contact process is given by the equation below.

$$\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{SO}_3(\text{g})$$

(a) Balance the chemical equation $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$ (1)

In an investigation 256 g SO_2 reacts with 80 g O_2 in a reaction vessel.

(b) Calculate the number of moles of each reactant present at the start of the reaction.

$n = \frac{m}{M_r}$	S	O
$\frac{256 \text{ g}}{64.1 \text{ g/mol}}$	$\frac{80 \text{ g}}{32 \text{ g/mol}}$	
$= 3.99 \text{ moles}$	$= 2.5 \text{ moles}$	3

(c) Identify the limiting reagent in the reaction and justify your answer.

Limiting reagent is oxygen because it is the one being used to produce the SO_3 in the contact process. (2)

(d) Calculate the mass of SO_3 produced in the reaction

$$\text{Mass} = n \times M_r$$

$$6.5 \times 80.1$$

$$= 520.65 \text{ g}$$

Figure 4.2: An example of a learner's script showing failure to identify limiting reactant

Figure 4.2 shows that the learner failed to identify the limiting reagent and to justify their solution. It shows that the learner failed to use the mole ratio from the chemical equation to convert moles SO_2 to moles O_2 and then compare them to each other.

Problem 29 required learners to calculate the theoretical yield as well as percentage yield. An analysis of the items on this problem indicated that the learners lacked understanding of what theoretical yield was and that theoretical yield was an experimentally determined number. In 29(a) 68% of learners could not come up with a balanced equation to depict the process while in item 29 (b) 84% could not use the given equation to perform the calculations required. The

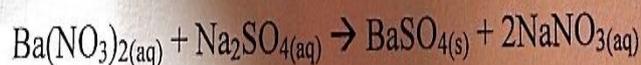
learners could not also calculate the percentage yield. Figure 4.3 below illustrates a learner who failed to calculate the actual as well as the theoretical yield.

29. (a) If 5.00 grams of sodium metal and 18.25 grams of copper (II) sulfate are combined, how many grams of copper metal can theoretically be produced?

$$\begin{array}{r} 18,25 \\ + 5,00 \\ \hline 23,25 \end{array} = 23,25 \text{ g}$$

(3)

- (b) Barium sulfate, BaSO_4 , is made by the following reaction:



An experiment was begun with 75.00g of $\text{Ba}(\text{NO}_3)_2$ and an excess of Na_2SO_4 . After collecting and drying the product, 63.45g BaSO_4 was obtained. Calculate the theoretical yield and percent yield of BaSO_4 .

$$\begin{aligned} \text{Theoretical yield} &= 75\text{g} - 63,45\text{g} \\ &= 11,55\text{g} \end{aligned}$$

(3)

Figure 4.3: Learner's script showing failure to determine theoretical and actual yield

Figure 4.3 indicates that the learner did not demonstrate sufficient understanding of what theoretical yield was and that the given equation was of no use to them. The learner failed to acknowledge the theoretical yield as the amount of product deduced from the quantities of

reactants in the given chemical equation. As result the learner could not determine the percentage yield as a ratio of the actual yield to the theoretical yield multiplied by 100.

Besides the students' inability to determine limiting reagents, theoretical yields, actual yields and percent yields, they also showed failure to identify substances present in excess of the stoichiometric amounts. Analysis of the learners' scripts revealed that 72 % of the respondents could not able to define the goal of the problem before embarking on solving the question. They failed to figure out what the question required. Had the respondents managed to define the goal of the problem, by identifying the mass that was to be found they could have correctly answered the question? Figure 4.4 illustrates this difficulty exhibited by the learners.

30. Silver nitrate, AgNO_3 , reacts with iron(III) chloride, FeCl_3 , to give silver chloride, AgCl , and iron(III) nitrate, $\text{Fe}(\text{NO}_3)_3$. A solution containing 18.0g AgNO_3 was mixed with a solution containing 32.4g FeCl_3 . How many grams of which reactant *remains* after the reaction is over?

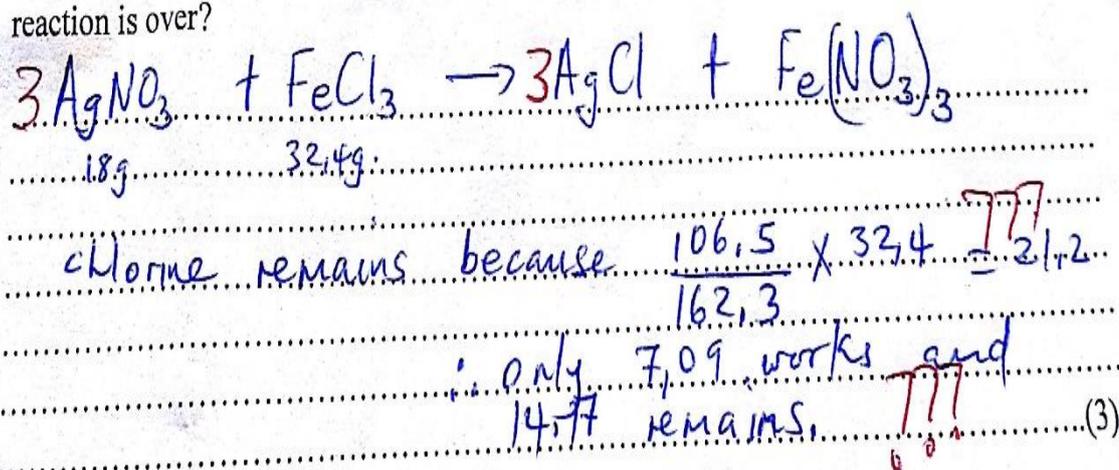


Figure 4.4: Learner's script showing failure to identify substances present in excess

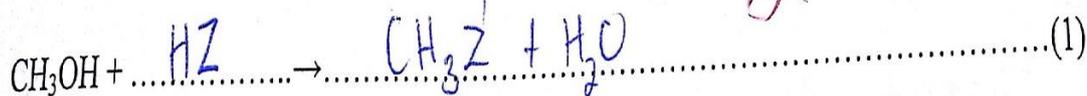
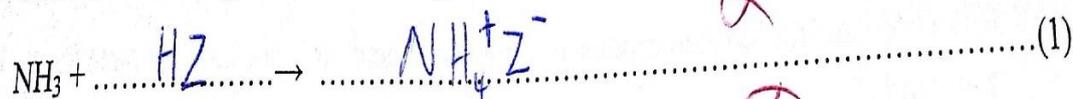
Figure 4.4 shows the learner's inability to write balanced chemical equations which is critical in solving stoichiometric problems. The vignette clearly shows that the learner did not actually understand the goal of the problem in terms of what the question required. The task of the learner was to use the given information to determine the amount in excess. This difficulty was common in 45% of the learners in both groups.

Generally, for most of the students solving stoichiometric problems was difficult. The students also failed to select relevant information from memory and apply it to a novel situation an indication that they had not mastered their content well. Furthermore, the students also showed difficulties in reasoning as well as executing mathematical operations in solving stoichiometric problems. Some solutions had errors in computation showing that students did not evaluate their solutions to check if they were correct. More so the students also showed difficulties in identifying the goal of the problem as a result could not determine limiting reagents, reagents in excess, theoretical yields, actual yields as well as percentage yields. The students lacked understanding of the basic stoichiometric concepts.

4.4.2 Difficulties in ionic equilibria problem solving

In learning ionic equilibria it is important that learners understand key foundational principles such as the acid/base chemistry. A knowledge of the theory of acids and bases becomes critical. One such theory is the Brønsted-Lowry theory. This concept was tested using item 26 (a) where the students were asked to write equation showing how a Brønsted-Lowry acid, HZ and a Brønsted-Lowry base, B⁻ would react with given substances. An analysis of student responses indicated that 30.4 % of the responses were partially correct 69.6% were incorrect. The following figure 4.5 illustrates a learner who had an incorrect response.

26. (a) (i) Using the symbol HZ to represent a Brønsted-Lowry acid, write equations which show the following substances acting as Brønsted-Lowry bases.



- (ii) Using the symbol B⁻ to represent a Brønsted-Lowry base, write equations which show the following substances acting as Brønsted-Lowry acids.

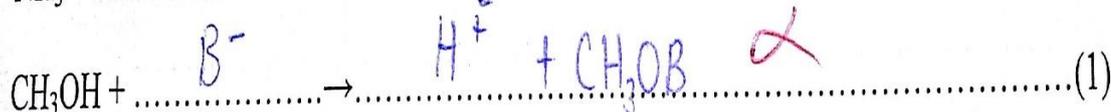
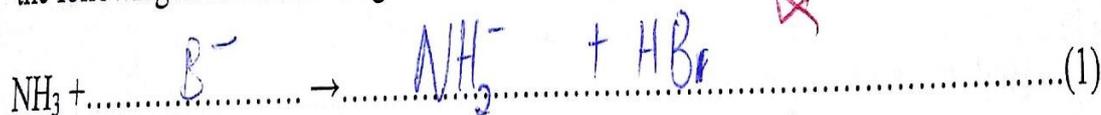


Figure 4.5: Learner's script showing failure to define Brønsted-Lowry acids and bases

Figure 4.5 shows that the learner failed to define a Brønsted-Lowry acid and base. The learner lack of understanding of acid-base model used in chemistry. The learner failed to recognize that as a base NH₃ would accept a proton (hydrogen ion, H⁺) from HZ.

Item 26(b) tested the learners' knowledge about buffer solutions and how a buffer solution would work. An analysis of the responses indicated that 83% of the learners managed to explain what a buffer solution is. They demonstrated understanding of a buffer by managing to define what it is. They defined it as a solution which resists changes in pH when small quantities of an acid or an alkali are added to it. However when it came to explain how a buffer solution works, the majority of students (89%) failed to recognize that buffer solutions

are a dynamic equilibrium between a weak acid and its conjugate base in water (see figure 4.6 below).

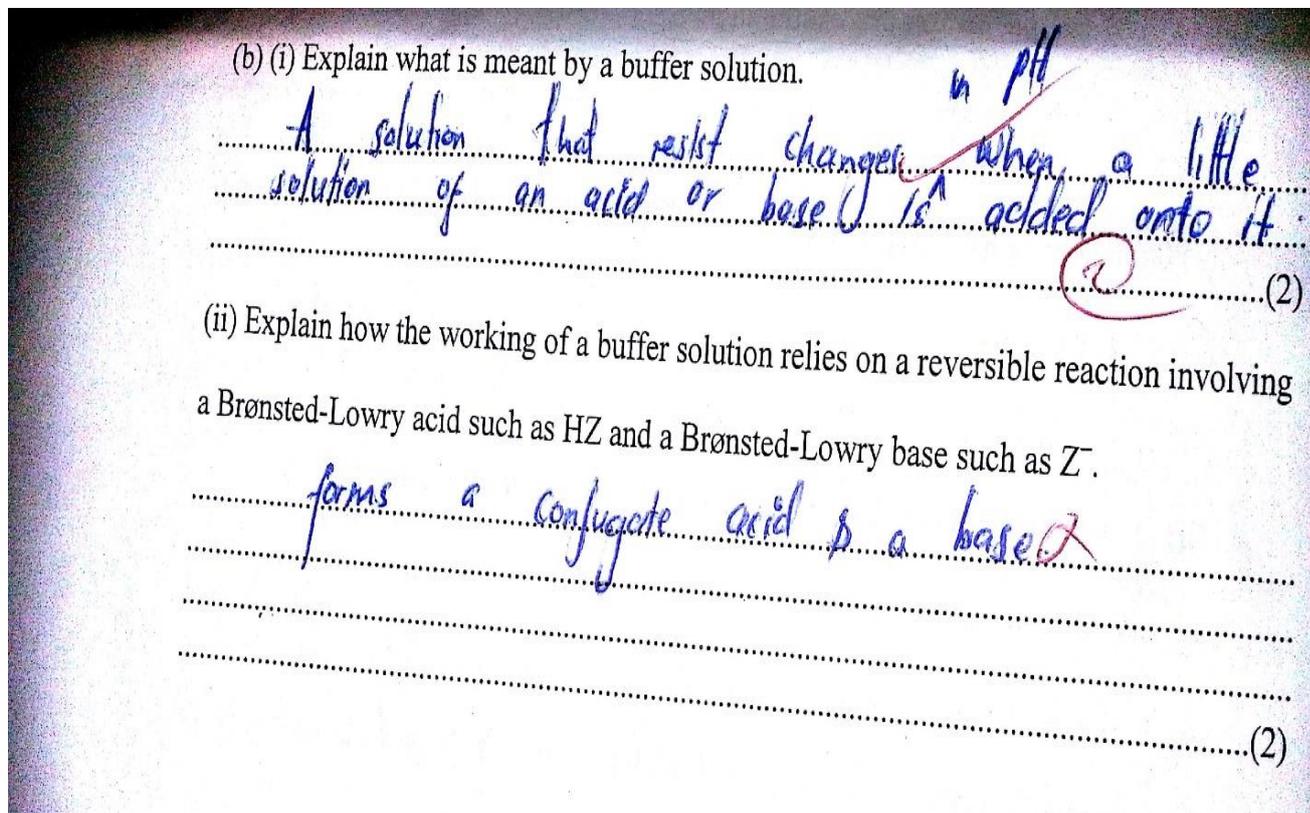


Figure 4.6: Learner's script showing failure to recognize the equilibria present in a buffer Solution

The vignette shows that the learner could not come up with a chemical equation to depict the equilibria in question as a result could not apply the Le Chatelier's principle to explain how a buffer works. This shows lack of conceptual understanding of buffers and fundamental chemical equilibrium principles that are key in the learning of buffers.

Item 27 was meant to assess student difficulties with buffer problems. The learners were asked first to calculate the pH of propanoic acid. Only 30% of the students managed to successfully perform this task while 70% could not. The learners failed to recognize that

propanoic acid was a weak acid and that its degree of dissociation was small. They would then have made the following two assumptions for:



$[\text{H}^+] \sim [\text{CH}_3\text{CH}_2\text{COO}^-]$ as the amount of H^+ from the dissociation of water is insignificant.

$[\text{HA}] \sim [\text{acid}]$, as the amount of HA that has dissociated is very small. They would then apply Oswald's dilution law to determine the $[\text{H}^+]$ concentration then the pH. The majority of the learners had difficulty in performing this task as shown in figure 4.7. This difficulty was common in both groups during the pretest.

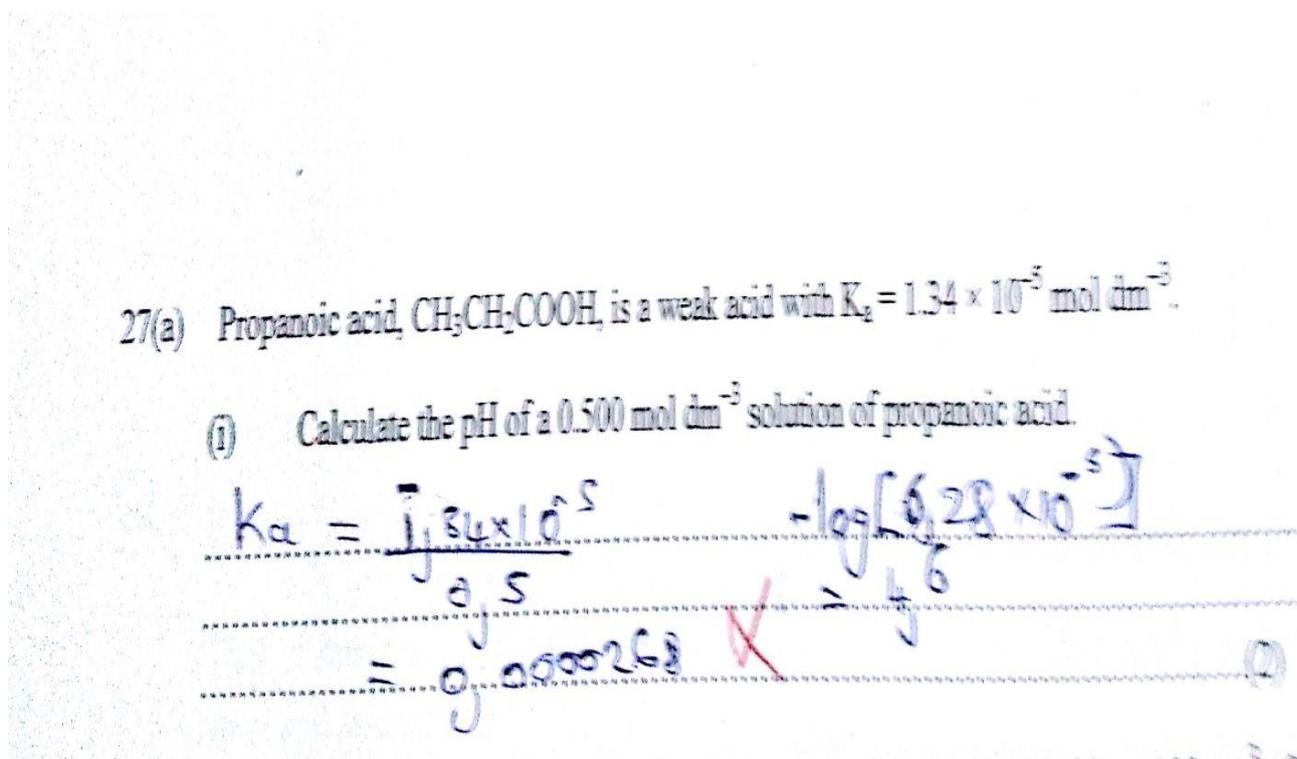


Figure 4.7: Learner's script showing failure to calculate pH of a weak acid

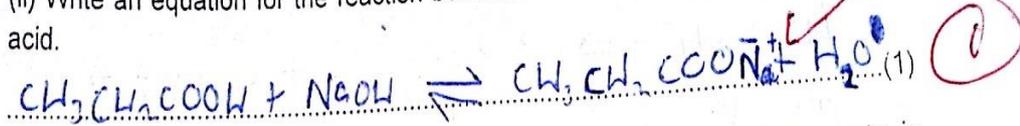
Figure 4.7 shows that the learner could not come up with an equilibrium expression which would enable them to determine $[\text{H}^+]$ concentration and then pH. This again shows that students did not fully grasp equilibrium concepts useful for solving such problems. This difficulty occurred in 40.05% of the learners in the experimental schools and 44.60% of the learners in the control schools during a pre-test. The students demonstrated inadequate

knowledge about strong and weak acids.

The second part of item 27 assessed the understanding of learners about the equilibrium of a weak acid, aqueous stoichiometric reactions as well as buffer calculations. The learners were first required to come up with a chemical equation that described the equilibrium of the weak acid buffer in aqueous solution. The majority of the learners (89%) did well on this part with 11% failing. The remaining part of the problem required the learners to calculate the number of moles of species present when a buffer is prepared by combining solutions of a strong base and a weak acid. Only 22.2% managed to perform the stoichiometric calculations while 77.8% could not. The majority of the learners (85%) could not demonstrate their mastery of the concept of buffer solutions to determine the pH of the buffer solution in question as shown in figure 4.8 below.

Buffer solution F was prepared by adding 0.0300 mol of sodium hydroxide to 100 cm³ of a 0.500 mol dm⁻³ solution of propanoic acid.

(ii) Write an equation for the reaction between sodium hydroxide and propanoic acid.



(iii) Calculate the concentrations of propanoic acid and sodium propanoate in buffer solution F.

[propanoic acid] =

$$nV = 0,03 \times \frac{100}{1000} \\ = 0,003 \text{ mol/dm}^3 \quad X \quad \text{mol dm}^{-3} \quad (1)$$

[sodium propanoate] =

It is 1:1 so the concentration is 0,003 mol/dm³

$$\text{mol dm}^{-3} \quad (1)$$

(iv) Calculate the pH of buffer solution F.

$$\text{pH} = -\log(0,003) \\ = 2,5 \quad X \quad (1)$$

Figure 4.8: Learner's script showing difficulties with buffer problems

The vignette shows that the learner is not conceptually familiar with buffers. The way he/she is solving buffer problems is from an algorithmic perspective hence they seem to suggest that this type of a buffer problem can be solved from only one way. An analysis of the solution seem to indicate that there is a similar way of solving all buffer problems where pH is the final answer. The learner thus does not realize the importance of having a conceptual

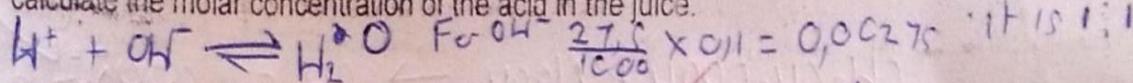
understanding of buffers so that they can be able solve buffer related problems.

Item 28 assessed learners on their understanding of the concepts pertaining to weak acid strong base titrations. Part (a) of the question required the learners to define pH and to calculate the pH of 3.5. Overall, the learners (80%) did well when answering this part. Part (b) was well done by the learners as 85% managed to perform the calculation. When it came to part c(i) where explanations were required 90% of the learners were found wanting with some not even attempting this part of the question. For c (iii) more than 75 % of the learners could not state that acid dissociation was the constant to be determined and could not even determine its numerical value. On the last part of the question 67% of the learners could not justify why phenolphthalein was the most suitable indicator. Figure 4.9 illustrates the nature of difficulties exhibited by the learners.

Orange juice can be titrated with standard alkali.

A 25.0 cm³ sample of orange juice was exactly neutralized by 27.5 cm³ of 0.10 mol dm⁻³ sodium hydroxide using phenolphthalein as indicator.

(b) Assuming orange juice contains a single acid which is monobasic, calculate the molar concentration of the acid in the juice.



$$\frac{n}{V} = \frac{cV}{V} \quad c = \frac{0.00275}{\frac{25}{1000}} = 0.11 \text{ mol/dm}^3 \quad (1)$$

(c)(i) How can you explain the difference between the two results you have obtained in (a) (ii) and (b)?

This is because during the reaction the backward reaction was favoured in the bigger producing more H⁺ which reacted with the NaOH

(iii) What constant can be determined from these two values?

The ionic product (K_w) (1)

(iv) Calculate a numerical value of this constant.

$$K_w = 1 \times 10^{-14} \quad (2)$$

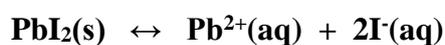
(d) Suggest two reasons why phenolphthalein is a suitable indicator for this titration.

This is because at the endpoint it quickly responds by changing colour and the pH is the same as the reactants (2)

Figure 4.9: Learner's script showing difficulties with weak acid/strong base titrations

The vignette shows that the learners' inability offer explanations and descriptions at the macroscopic level, the microscopic level and the symbolic level as well as inability to establish appropriate connections among the three an indication that they lack conceptual understanding of the phenomenon being investigated.

Item 29 assessed learners on solubility chemistry and require the learners to write a chemical equation to represent the solubility reaction as well as to perform stoichiometric calculations to determine the concentrations of the species present. Generally, half of the students managed to write down the expression for the solubility equation. The students showed confusion about the effect of a coefficient for one of the ions in the dissociation equation. For example, in this case one of the ions has a coefficient of two in the balanced dissociation equation. Failure by half of the students that PbI_2 forms when Pb gives its two valence electrons to different Iodide atoms, each of which can only accommodate one more electron. This creates one Pb^{2+} ion and *two separate* I⁻ ions. So the equation becomes:

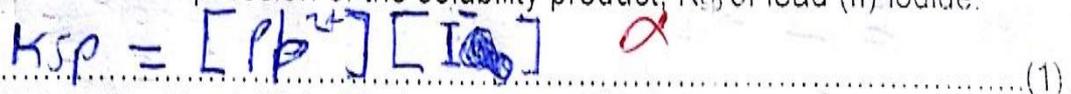


$$K_{\text{sp}} = [\text{Pb}^{2+}] [\text{I}^{-}]^2$$

This led them to write the wrong equation and wrong equilibrium expression. See figure 4.10 below.

29. A student on a field trip investigates some dished lead workings which have been flooded for some time. The presence of lead (II) ions in the water is to be demonstrated by precipitating yellow lead (II) iodide.

(a) Write down an expression of the solubility product, K_{sp} , of lead (II) iodide.



(b) The solubility of lead (II) iodide in water at 15°C is 0.46 g dm⁻³. For a saturated solution of lead (II) iodide at 15°C, calculate

(i) the concentration in mol dm⁻³ of lead (II) ions.

$$\sqrt{0,46 \times 56} = [Pb^{2+}] \quad \alpha$$

$6,14 \times 10^{-2} \text{ mol/dm}^3$

..... (2)

(ii) the concentration in mol dm⁻³ of iodide ions.

$$\sqrt{0,46 \times 56} = [I^-] \quad \alpha$$

$= 5,1 \times 10^{-2} \text{ mol/dm}^3$

..... (2)

Figure 4.10: Learner's script showing difficulties with solubility product calculations

Figure 4.10 shows that learner omitted the squared term in the K_{sp} for PbI_2 . ($K_{sp} = [Pb^{2+}] [I^-]^2$). It is further noted that the learner also failed to perform concentration calculations that required stoichiometric manipulations. This shows lack of understanding of

the concept solubility and its relationship to K_{sp} . This difficulty was observed in 50% of the learners from the experimental group and 47% of the learners from the control group.

4.5 Research Question 2: What is the effect of structured problem-solving strategies on learners' achievement in solving standard chemistry quantitative calculations in stoichiometry and ionic equilibria?

The main purpose of the study was to make a comparative analysis of the effects of using structured problem solving strategies and their nonuse on Advanced Level students' achievement in Stoichiometry and ionic equilibria. The results of the post-test indicated that the experimental schools had greatly improved when compared to control schools for both tests as shown in tables 4.8 and 4.9 below.

Table 4.8: Mean scores and standard Deviations (SD) of students in Stoichiometry

Group	Mean	Standard deviation	N
Control	40.6160	1.15667	250
Exp- Ashmore et al	56.7179	1.15852	117
Exp-Selvaratnam-Fraser	56.6949	0.99149	118
Total	48.4124	8.12678	485

From the data presented in Table 4.8, it was observed that the students in the two experimental groups (Selvaratnam and Frazer, 1982 as well as Ashmore et al.,1979) had mean scores of 56.6949 and 56.7179 and corresponding Standard deviations of 0.99149 and 1.15852, respectively. The mean score for the students in the control group was found to be 40.6160 and the standard deviation being 1.15667.

Table 4.9: Mean scores and standard Deviations (SD) of students in Ionic equilibria

Group	Mean	Standard deviation	N
Control	41.0720	1.34239	250
Exp- Ashmore et al	62.8889	1.56347	117
Exp-Selvaratnam-Fraser	52.2034	2.25532	118
Total	49.0433	9.18363	485

The data presented in Table 4.9 indicate that the students taught using Selvaratnam-Frazer and Ashmore *et al* problem-solving models had mean scores of 52.2034 and 62.8889 and corresponding Standard deviations of 2.25532 and 1.56347, respectively. The mean score for students in the control group was found to be 41.0720 and the standard deviation being 1.34239. The data in tables 4. 8 and 4.9 is graphically depicted in figure 4.11.

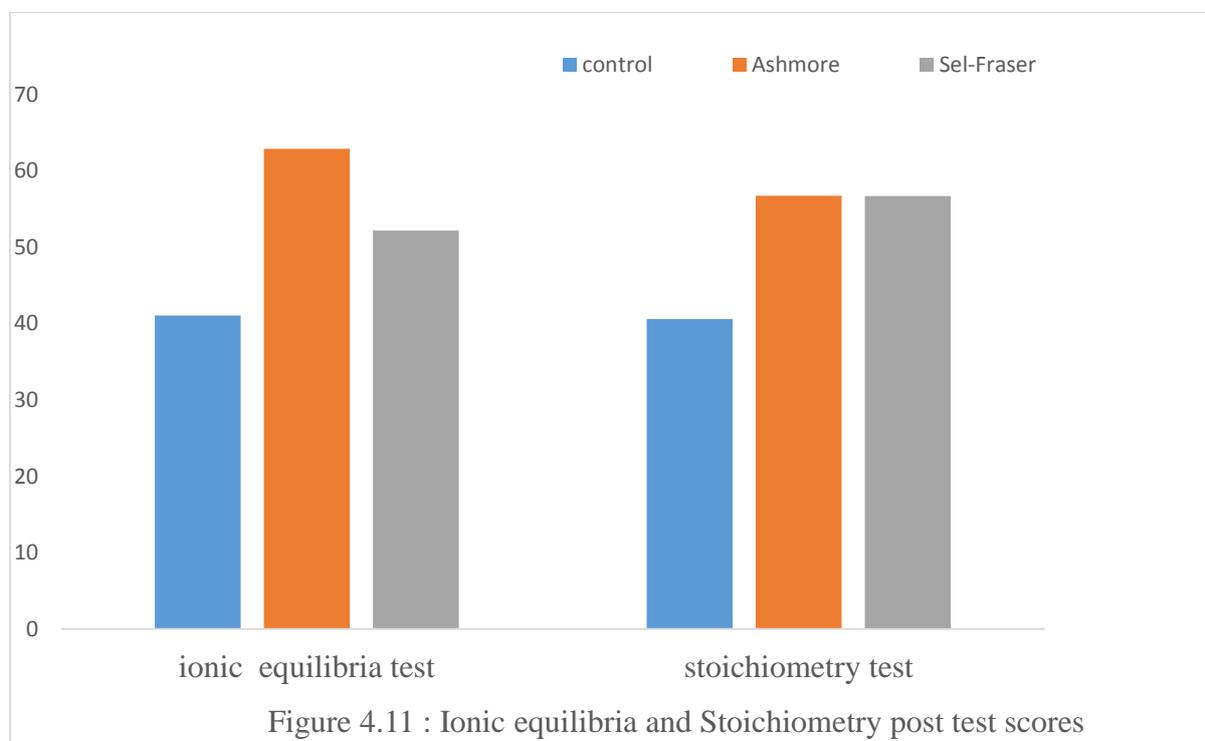


Figure 4.11 : Ionic equilibria and Stoichiometry post test scores

The observation implied that the use of the two models indicated a positive effect on the students' achievement in both ionic equilibria and stoichiometry.

The study went on further to statistically test the main effect of Selvaratnam-Frazer (1982), and Ashmore et al.(1979), problem-solving instruction on participants' overall performance in stoichiometry and ionic equilibria. It was hoped that a significant effect of Selvaratnam-Frazer and Ashmore *et al* problem solving instruction on participants' performance will be identified and thereby affirming the hypothesis attesting to the superiority of the use of problem-solving instructional strategies in comparison to conventional teaching methods in the chemistry classroom.

In the context of this study, the use of ANCOVA enables one to ascertain whether there is an interaction between the control variable and the dependent variable through statistically controlling for the effects of the control variable (covariate). Thus, it should be possible to isolate the effect of Selvaratnam and Frazer (1982), and Ashmore *et al.*(1979), problem solving instructional strategies after having statistically removed the effect of the covariate (pre-test scores).

The following null hypotheses (**H₀**) was tested at 0.05 levels of significance.

Null hypothesis: H₀: There is no significant difference in the mean achievement scores of students' taught using the Selvaratnam-Frazer and Ashmore et al problem-solving models and those taught with the conventional method.

H₀: μ problem solving instruction = μ conventional instruction.

Alternate hypothesis: H₁: There is a significant difference in the mean achievement scores of students' taught using the Selvaratnam-Frazer and Ashmore et al problem-solving models and those taught with the conventional method.

H₁: μ problem solving instruction \neq μ conventional instruction.

The results of the hypothesis test are presented in tables 4.10 and 4.11.

Table 4.10: The test of Between-Subjects Effects; Stoichiometry test

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Pretest	4.312	1	4.312	3.459	.084
Group	31140.261	2	15570.131	12491.765	.000

Table 4.11: The test of Between-Subjects Effects; Ionic Equilibria test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Pretest	7.123	1	7.123	9.011	.108
Group	39457.865	2	19728.933	7187.716	.000

The result in Tables 4.10 and 4.11 suggest that the treatment (Selvaratnam-Frazer and Ashmore et al problem-solving models) is a significant factor on students' achievement in stoichiometry and ionic equilibria. The probability level of 0.05 is greater than 0.000 ($P > 0.05$) as seen in the above tables. Thus, the hypothesis H_0 that there is no significant difference is rejected. The implication is that a significant difference exists in the mean scores of subjects exposed to the two problem-solving models and those not exposed. The results in the above tables further indicate the influence of pre-test scores in predicting the performance of participants in the two tests, as the significance values are more than 0.05 ($p = 0.084$ and $p = 0.108$ respectively). The results thus further confirm the use of ANCOVA analysis in the study.

The findings related to research question one showed that the participants who were taught stoichiometry and ionic equilibria using problem-solving instructional strategies did perform better than those in the control group taught using the conventional lecture method when

exposed to the achievement tests in stoichiometry and ionic equilibria. The hypothesis above also confirmed that there was a significant difference in the performance of students exposed to problem-solving instructional strategies and those taught with the conventional lecture method.

The finding of this study shows that teaching of stoichiometry and ionic equilibria using Selvaratnam- Fraser as well as Ashmore et al problem solving strategies increased the awareness of students' knowledge and ability during the problem solving process. It can therefore be concluded that the application problem-solving strategies is more effective in helping students improve their problem solving performance than conventional lecture method. This clearly supports the implementation of problem-solving instruction in the chemistry classroom. The implication is that students who were taught using problem-solving strategies had well mastered the strategies of solving stoichiometry and ionic equilibrium problems better than those taught using the conventional method.

4.5.1 Analysis of learners' difficulties in stoichiometry and ionic equilibria problem solving

In this section, an analysis based on simple mathematical computations was performed to compare problem-solving instruction to conventional instruction employed by teachers in control schools. The types of difficulties observed in the learners from both groups during pre and post-test have been summarized in Tables 4.12 and 4.13. The number of learners observed to show the difficulty are shown as a percentage.

Table 4.12 Learners' difficulties in stoichiometry at pre-test and post-test stages.

Nature of difficulty	Experimental group		Control group	
	Pretest (%)	Posttest (%)	Pretest (%)	Posttest (%)
The mole concept	60.5	10	66.2	48
Balancing chemical equations	56.6	8	54.5	43
Inconsistent relationships	78	30	78	65
Deducing limiting reagents	87.9	27	87.9	62
Determining theoretical yields and actual yields	84	25	85	64
Identifying substances in excess	72	18	72	55

An analysis of table 4.12 indicates that only six difficulties were encountered by students as they were solving standard quantitative stoichiometric calculations in chemistry. The table also indicate the number of students (as a percentage) showing the difficulty before and after the intervention. The data is graphically displayed in figure 4.12 below.

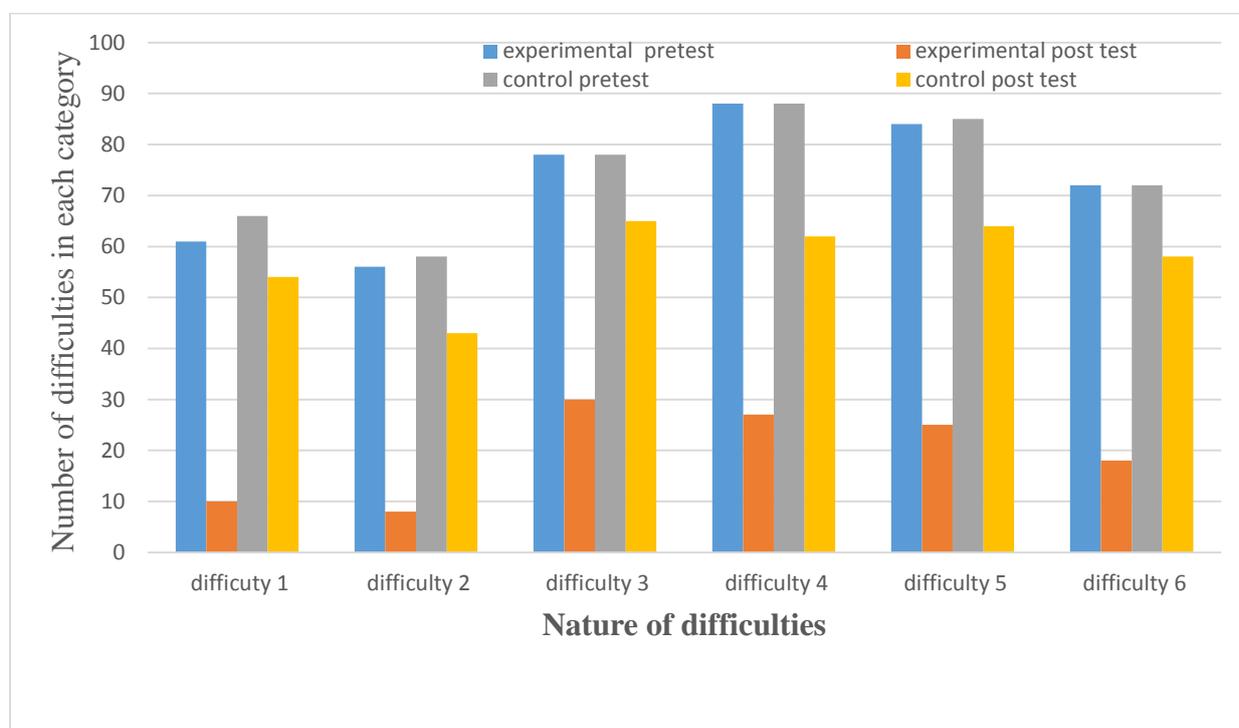


Figure 4.12 Students' difficulties in stoichiometry at pre-test and post-test stages

Figure 4.12 reveals that the implementation of a structured problem-solving strategy is more effective in remedying the difficulties students encounter when solving standard quantitative stoichiometry problems or calculations than the conventional lecture method. The findings further demonstrate that structured problem-solving strategies generally manage to improve the abilities of students to solve standard quantitative chemistry calculations as attested by the reduction in the number of learners encountering the various difficulties at the post test stage (Mandina and Ochonogor, 2017). In addition, the use of structured problem-solving strategies help learners to gain understanding of the Chemistry topics being taught thus promoting teaching and learning. For instance, Figure 4.12 shows that problem-solving instruction reduced difficulty 1 from 61% of the participants at the pre-stage to 10% at the post-stage giving an effective rate of 83% in comparison to 18% in the conventional (control) conditions. The effective rate was obtained as follows:

$$\text{Effective rate (\%)} = \frac{\text{learners with difficulty}_{pretest} - \text{learners with difficulty}_{posttest}}{\text{learners with difficulty}_{pretest}}$$

The data obtained from the stoichiometry achievement test were analyzed using the independent samples t-test. The results shown in Tables 4.13 and 4.14

Table 4.13: Pre-test scores of experimental and control groups.

Structured strategy	Group	N	M	SD	t	df	p
Ashmore, Casey and Fraser	Experimental	117	40.25	3.98	0.10	238	.876
	Control	123	40.20	3.65			
Selvaratnam and Fraser	Experimental	118	38.72	4.46	0.67	243	.605
	Control	127	38.34	4.43			

From table 4.13 above, it can be seen that there was no statistically significant difference between experimental and control groups on the stoichiometry achievement test at the pre-test stage ($df = 238, t = 0.10, p > 0.05$). This indicates that the performance of both the experimental and control group in the pre-test was nearly the same. This made it possible for the researcher to infer the effect of the treatment after the post-test. The post test results of the two groups were compared and analysed using the independent samples t-test to determine the effect of the structured problem-solving strategies. The data are shown in table 4.14 below.

Table 4.14: Post-test scores of experimental and control groups

Structured strategy	Groups	N	M	SD	t	df	p
Ashmore, Casey and Fraser	Experimental	117	56.72	1.16	102	238	.001
	Control	123	41.62	1.13			
Selvaratnam and Fraser	Experimental	118	55.69	0.99	156	243	.001
	Control	127	39.58	1.07			

After the implementation of the intervention it can be seen that the mean difference between the two groups is significant ($t=102, p=.001$) and ($t=156, p=.001$). The results thus confirm that there is a statistically significant difference in the post-test achievement scores of students exposed to the structured problem-solving instructional strategies and those exposed to the conventional lecture method.

In order to determine the main effect of the structured problem-solving instructional strategies on the performance of students in solving standard quantitative stoichiometry

calculations analysis of covariance (ANCOVA) was performed. The following null hypotheses (**H₀**) was tested at 0.05 level of significance.

Null hypothesis: H₀: There is no statistically significant difference between experimental and control groups in solving standard quantitative stoichiometry calculations.

The results are shown in table 4.15 below.

Table 4.15: ANCOVA analysis of the difference on the differences between experimental group and control group in solving standard quantitative stoichiometry calculations

Source	Type III Sum of Squares	df	Mean Square	F cal	F crit	Decision at P < .05
Corrected model	13605.241	2	6285.881	40.112		
Intercept	369245.135	1	369245.135	2.287E3		
Pretest	1342.175	1	1342.175	7.736		
Instructional strategies	12846.163	1	12846.163	75.02	3.47	significant
Error	36428.659	483	165.050			
Total	964252.00	485				
Correted total	49834.679	484				

An examination of Table 4.15 indicates that the determined F-value of 75.02 is greater than the critical F-value of 3.47. Therefore, the Null hypothesis of no statistically significant difference between experimental and control groups in solving standard quantitative stoichiometry calculations is rejected. This implies that there is a significant difference in the performance of chemistry students taught with structured problem-solving instructional strategies and those taught with the conventional lecture method. The result in Table 4.15 shows that the structured problem-solving instructional strategies have improved the ability of students to solve standard quantitative stoichiometry calculations.

The difficulties encountered by students when solving standard quantitative calculations in ionic equilibria were identified by analyzing the solutions given by students as they were answering open ended items during the pre-test. Table 4.16 below reveals the six difficulties identified as well as the number of learners observed to show each difficulty.

Table 4.16 *Learners' difficulties in ionic equilibria at pre-test and post-test stages.*

Nature of difficulty	Experimental group		Control group	
	Pretest (%)	Posttest (%)	Pretest (%)	Posttest (%)
Definition of Bronsted-Lowry acids	70	15	72	38
Explaining how buffers work	89	20	88	62
Calculations involving buffers	70	13	70	45
Calculating pH of weak acids	55	5	56	35
Titrations of weak acid strong bases	68	4	67	38
Determining solubility product	58	6	60	36

The data is graphically displayed in figure 4.13 below.

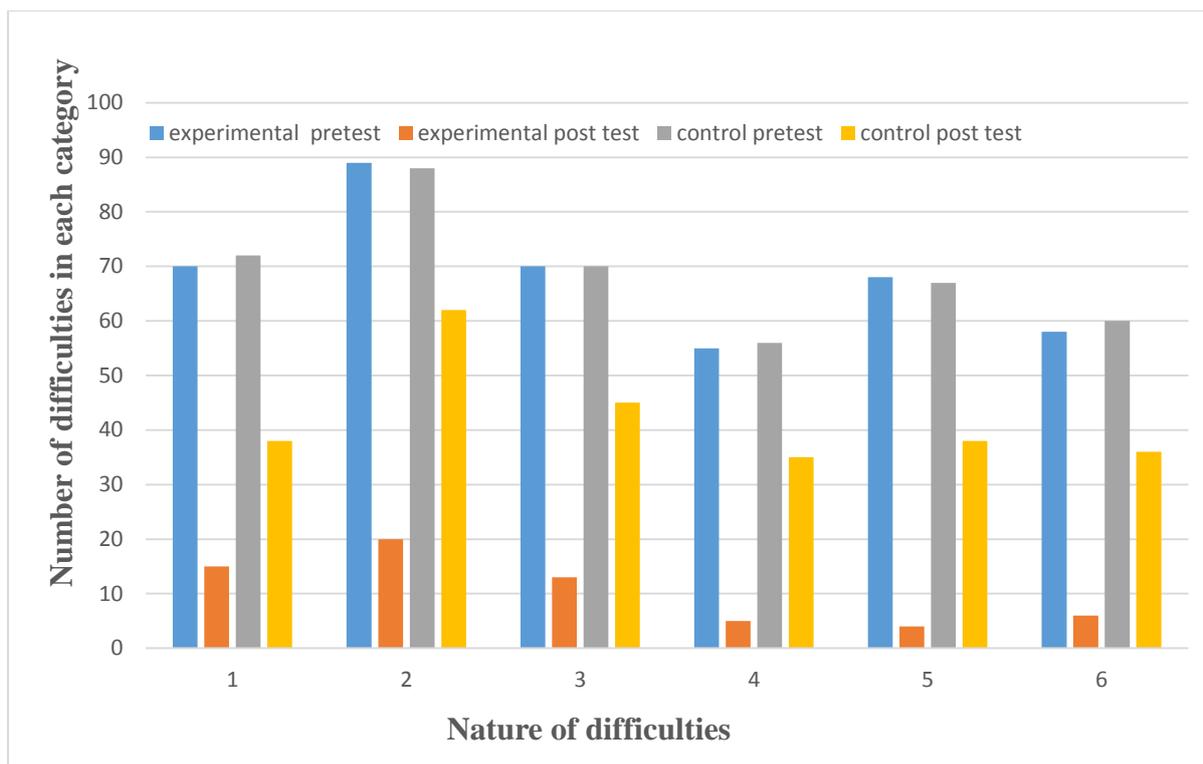


Figure 4.13 Students' difficulties in ionic equilibria at pre-test and post-test stages

The independent samples t-test was used to analyze the data obtained from the ionic equilibria pretest. The results are shown in Tables 4.17.

Table 4.17: Pre-test scores of experimental and control groups

Structured strategy	Group	N	M	SD	t	df	p
Ashmore, Casey and Fraser	Experimental	117	39.89	3.68	0.32	238	.850
	Control	123	39.74	3.52			
Selvaratnam and Fraser	Experimental	118	40.12	3.94	0.14	243	.675
	Control	127	40.05	3.88			

The analysis shows no statistically significant difference between experimental and control groups on the stoichiometry achievement test at the pre-test stage ($df = 238$, $t = 0.32$, $p > 0.05$). This indicates that the performance of both the experimental and control group in the pre-test was nearly the same.

A comparison of the post test scores of the two groups to determine the effect of the structured problem-solving strategies is shown in table 4.18 below.

Table 4.18: Post-test scores of experimental and control groups

Structured strategy	Groups	N	M	SD	t	df	p
Ashmore, Casey and Fraser	Experimental	117	62.89	1.36	133	238	.001
	Control	123	40.11	1.28			
Selvaratnam and Fraser	Experimental	118	52.20	1.05	73	243	.001
	Control	127	42.04	1.12			

The result of the analysis on Table 4.18 shows that there is a significant difference in the post-test achievement scores of students exposed to the structured problem-solving instructional strategies and those exposed to the conventional lecture method. The main effect of the structured problem-solving instructional strategies on the performance of students in solving standard quantitative stoichiometry calculations was analyzed using ANCOVA. The following null hypothesis was tested at 0.05 level of significance.

Null hypothesis: Ho: There is no statistically significant difference between experimental and control groups in solving standard quantitative ionic equilibria calculations.

The results of the analysis are shown in table 4.19

Table 4.19: ANCOVA analysis of the difference on the differences between experimental group and control group in solving standard quantitative ionic equilibria calculations

Source	Type III Sum of Squares	df	Mean Square	F cal	F crit	Decision at P < .05
Corrected model	12879.334	2	6114.542	43.054		
Intercept	325674.323	1	325674.323	3.1833		
Pretest	2674.432	1	2674.432	7.869		
Instructional strategies	11756.221	1	11756.221	72.42	3.47	significant
Error	32492.274	483	158.507			
Total	921213.00	485				
Corrected total	44524.112	484				

The ANCOVA result in Table 4.19 shows that there is a significant difference in the performance of students taught with structured problem-solving strategies, $F(1, 483) = 72.42$. Therefore, the hypothesis was rejected.

The above findings show that the structured problem solving instruction (PSI) is superior to conventional approaches in addressing learners' difficulties during instruction. The results show that structured problem-solving instructional strategies generally addressed participants' difficulties compared to conventional instruction employed by teachers in control schools. Therefore, it may be concluded that PSI is superior to conventional instructional approaches when addressing difficulties relating to solving standard quantitative stoichiometry and ionic equilibria calculations.

4.5.2 Scheffe's post hoc analysis

To determine which of the two methods was most effective in teaching stoichiometry and ionic equilibria, a post-hoc analysis was conducted using Scheffe's Post Hoc test. The results are summarized in tables 4.20 and 4.21.

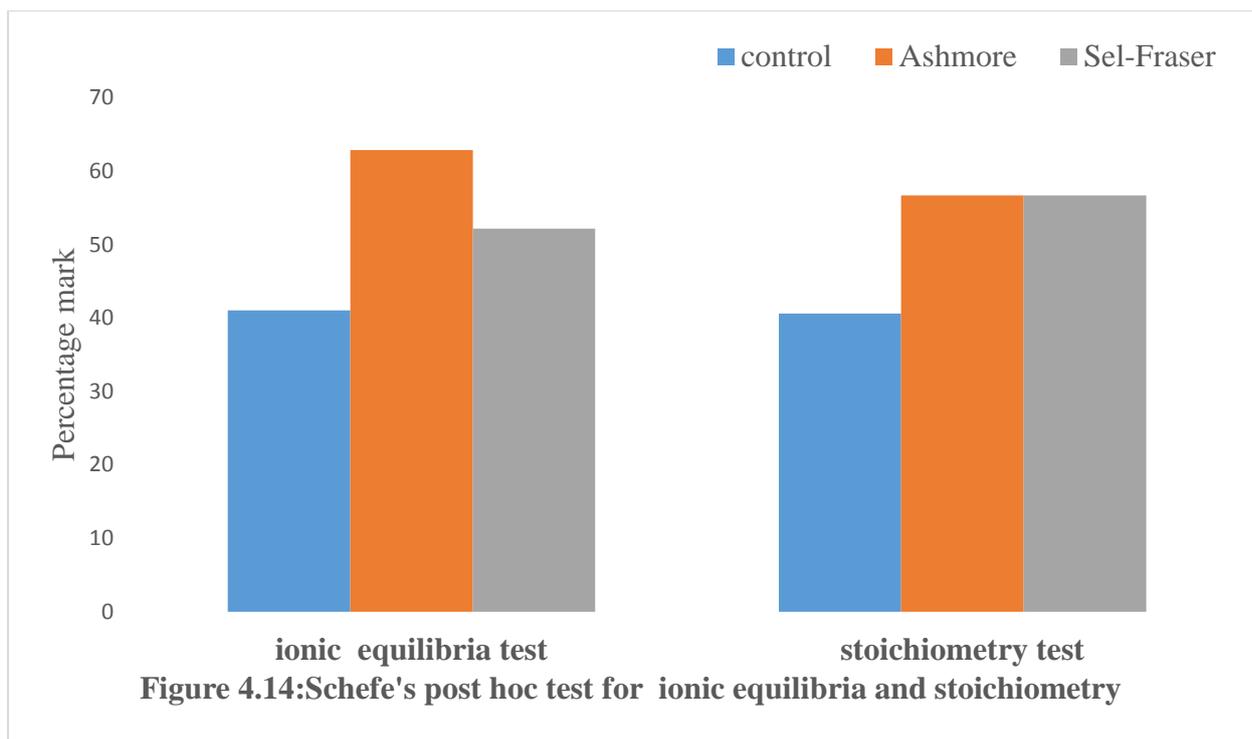
Table 4.20. Scheffe's post hoc analysis for students' performance on the stoichiometry test

group	N	Subset		
		1	2	3
control	250	40.9200		
exp-Sel	118		51.4407	
exp-Ash	117			56.2906
Sig.		1.000	1.000	1.000

Table 4.21. Scheffe's post hoc analysis for students' performance on the ionic equilibria test

group	N	Subset		
		1	2	3
control	250	41.0720		
exp-Sel	118		52.2034	
exp-Ash	117			62.8889
Sig.		1.000	1.000	1.000

The data in tables 4.20.and 4.21 is graphically depicted in figure 4.14 below.



The results from the above tables and figure 4.14 show that learners in the two experimental groups are significantly different from those in the control group and that their performance was better than those in the control group. Moreover, the Scheffe post-hoc test also indicated that there was a significant differences between the two experimental groups (those taught using the Ashmore et al problem solving model did significantly better than those taught using the Selvaratnam-Frazer problem-solving model).

4.6. Research Question 3: What are the experiences of learners taught stoichiometry and ionic equilibria using structured problem-solving instruction?

In order to evaluate the experiences of participants of being taught using problem solving instruction as well as their views towards the use of problem solving instruction in chemistry teaching, the researcher conducted classroom observations, semi structured interviews with teachers and focus group discussions with learners. The classroom observations were conducted in both control and experimental schools during the times that had been set and

agreed upon by both the researcher and the respective teachers. The researcher visited each of the schools thrice during the entire duration of the study. The number of visits had to be limited so as not to disrupt the smooth running of the lessons in all schools as well as to ensure that the lessons were conducted in a natural environment in all the schools. All the eight participating teachers from both experimental and control schools were observed by the researcher as they were conducting their lessons on stoichiometry and ionic equilibria. Learner participants in both control and experimental school were also observed by the researcher during stoichiometry and ionic equilibria lessons. The researcher made notes during classroom observations in both groups that were meant to be used for post-observation analysis.

4.6.1. Teacher observations

In conducting the classroom observations, the researcher was guided by the purposes of the observations as well as the items on the observation schedule. The researcher noted the following observations in control schools:

- (i) Teachers implemented traditional methods of instruction in their classrooms which typically included the teacher lecturing and students taking notes thus allowing for very little discussion of underlying concepts that would help connect conceptual understanding to real-life situations.
- (ii) The method of teaching used was the didactic approach where the teacher gave instructions to students with students being passive recipients of the problem solving knowledge being transmitted by the teacher.
- (iii) The activities and instruction in the classroom were characterized by teachers giving information with little or minimum interaction between learners and the teachers. The

teacher-centered teaching style was most prevalent with minimal learner involvement. The teachers seldom made reference to any problem-solving strategy in their teaching.

(iv) The teachers in the control group used a task to demonstrate how to solve a problem. The students then practiced the demonstrated technique by solving similar tasks the idea being for students to imitate the method they were shown, with the teacher correcting their efforts as necessary. In the majority of cases, learners worked on their own.

(v) The usual process adopted involved "chug and plug" –find the right formula, put the data into it and accept whatever answer comes out of the calculator. Typical problems were usually routine applications of formulae rather than real life problems.

(vi) The teachers did not emphasize problem solution examples that facilitate assimilation of new problem solving skills (in the majority of the cases, the teachers only gave one example to the learners)

4.6.2 Learner observations

The researcher conducted learner observations in both control and experimental schools. The researcher made the following observations:

4.6.2.1 Observations in control schools

(i) The participation, involvement and contribution of learners was minimal during the lessons consequence of the didactic method of teaching being used by the teacher.

(ii) Problem solving strategies and approaches exhibited by the learners were those they emulated from their teacher.

(iii) Learners worked independently and preferred to seek help from their teacher instead of their peers.

(iv) Learners in control schools were observed to inadequately prepare to solve similar problems in novel situations.

4.6.2.2. Observations in experimental schools

(i) In terms of students' reactions to the problem-solving instruction, many students particularly enjoyed and welcomed the learning approach, and some students thought it had particularly helped them to develop their understanding of stoichiometry and ionic equilibria concepts.

(ii) Most learners in experimental schools supported the problem solving intervention.

(iii) For learners in the experimental schools, the cooperative learning strategy using small groups was utilized during the problem solving lessons. Although they had difficulties in adapting to this approach and participating in group discussions they later on adjusted and found the group work enjoyable.

4.6.3 Semi- structured interviews

The researcher communicated with the participants prior to the day of the interviews to establish and ascertain the time and place of conducting the interviews as well as the issues to be explored during the interviews. The researcher sampled four teachers (two from control schools and two from experimental schools) for the interviews. The interviews with the respective teachers were conducted between 1600H and 1700H. The duration of each interview session was between 20min to 30min. In selecting the teacher participants for the interviews the researcher considered their teaching qualifications and their teaching experience. The Teachers' interview questions covered the following themes:

- (i) Stoichiometry and ionic equilibria teaching.
- (ii) Difficulties faced by learners when solving stoichiometry and ionic equilibria problems?
- (iii) The teachers' sentiments and beliefs regarding the teaching of chemistry using problem-solving instructional strategies.

- (iv) The impact of problem-solving instructional strategies in enhancing the performance of learners in solving stoichiometry and ionic equilibria problems.
- (v) Challenges faced in implementing problem-solving instructional strategies.
- (vi) How to incorporate problem solving in chemistry classrooms.

4.6.3.1 Analysis of teacher semi structured interviews

Theme 1: Stoichiometry and ionic equilibria teaching

The four teachers interviewed admitted that they rushed through the topics on stoichiometry and ionic equilibria since they assumed them to be very easy. They did not probe learners' understanding of the fundamental concepts that are prerequisites in the two topics to enable the students to solve stoichiometric and ionic equilibria problems.

T 1: *“As a teacher I am responsible for that, I rushed through the topics thinking that they were easy and I did not emphasize the topics when I was teaching”.*

When asked if the teaching of stoichiometry and ionic equilibria was a difficult thing to do, there were mixed feelings with senior teachers (T1, and 4) hinting that the teaching of the topics to students was an easy thing to do while novice teachers (T2 and 3) felt that it was not easy to teach the topic to students. The senior teachers were however in a dilemma as to why their students are not doing well in stoichiometry and ionic equilibria. They noted that since they do not emphasize on the underlying concepts that are prerequisites in stoichiometry and ionic equilibria this may contribute to poor performance in solving ionic equilibria and stoichiometry problems by their students.

On the other hand novice teachers felt that a number of factors such as knowledge of the mole concept, chemical formulae, balancing chemical equations, the chemical equilibrium concept have to be considered prior to students being given stoichiometry and ionic equilibrium problems.

Another interesting finding emanating from the study was that all the teachers concerned first address the mole concept, balancing chemical equations and writing of chemical formulae before introducing the stoichiometry topic to their students. The teachers would then give a few examples on how to solve stoichiometry problems explaining the steps involved in solving the problems. In most cases the teachers will increase the degree of difficulty of the example problems and then discuss the answers with the students. Later on many exercises and problems are given to the learners to do on their own. All the teachers interviewed are more inclined towards the algorithmic approach in introducing and teaching the topic because of limited time for syllabus coverage. The teachers have the perception that the approach is the most convenient and easiest way to teach the topic as this gives them ample time to finish the syllabus and ample time to prepare the students for examinations.

When it comes to ionic equilibria teaching the four teachers introduced the acid-base concept by first listing acids and bases that students know from everyday life. They then write chemical formulae and students are expected to show that all acids contain hydrogen. The teachers then defined acids as substances that when dissolved in water produced hydrogen ions. All the teachers went on to define acids and bases according to the Bronsted-lowry theory, however they did not clarify why the Bronsted model was introduced. Later, pH values of acidic solutions were determined and related to the concentrations of hydrogen ions. Students were told the pH to be a measure of the hydrogen ion concentration. Similar experiments were conducted with basic solutions. The teachers also showed difficulties they encounter as they use the Bronsted model to explain the properties of acids and bases. The results obtained show that the teaching process does not emphasize the macroscopic presentation of acids and bases at the same time the teachers tended to mix the macroscopic and microscopic conceptual models involved in the explanation of acid–base processes.

Theme 2: Difficulties faced by learners in solving Stoichiometry and Ionic Equilibria problems

All the teachers noted that students have limited knowledge and understanding of mole concept and chemical equations and chemical formulae. They noted that the mole plays a very significant role in all stoichiometric calculations as a basic understanding of it is critical in all chemical calculations. They further highlighted that students do not understand the meaning of the mole. Also, the students were noted to have inadequacies in skills that are required to interpret and use chemical formulae and equations. The learners seemed to have limited understanding of chemical notations (coefficients and subscripts) that are important in balancing chemical equations.

T 4: *“for the students to be able to perform stoichiometric calculations they need to understand the mole concept in its entirety, write and balance chemical equations.”*

All the teachers conceded that students had difficulties in determining the ‘limiting reagent’ in a given problem, when one substance is added in excess.

T 3: *“some students seem to have several alternative conceptions about limiting reagents, some seeing the reagent with the least mass present as the limiting reagent, while for others the one present in excess others as the reagent present in excess. Others choose the compound with the smallest stoichiometric coefficient in the balanced equation and others found the limiting reactant by comparing the masses.”*

This difficulty reveals deficiencies students have on the importance and meaning of stoichiometric coefficients in a chemical equation.

One interesting finding is that most teachers (T1, 3 and 4) indicated that students experience difficulties with the terminology of acid–base theory as they could not come up with equations to represent how substances can act as Brønsted-Lowry acids or bases.

T 3: *“Our students have problems about the Brønsted theory, and between conjugate and non-conjugate acid–base pair concept. The concept of conjugate and non-conjugate acid–base pairs is not clearly defined in textbooks that’s why students misunderstand the concept.”*

Chemistry teachers should clearly explain and discuss the Brønsted-Lowry model as failure by students to clearly understand such acid–base theory could influence their understanding on the subsequent concept of conjugate acid–base pairs.

All the teachers agreed that their students find buffers, buffer related concepts and solving calculations involving buffers a difficult thing to do.

T 2: *“Most of our students seem not to have an understanding of the importance of buffers or how they work and they experience difficulties in solving buffer problems as well as calculations involving buffers.”*

Teachers 2, 3 and 4 claimed that student’s problems with buffers arise because of lack of conceptual understanding of buffers, poor understanding of fundamental chemistry concepts as well as being unable to comprehend and understand how the macroscopic and microscopic levels of representation of buffers are connected.

T 3: *“To understand buffers students must combine a number of fundamental scientific concepts like stoichiometry, chemical equilibria, and chemical formula. The students must also possess the ability to integrate, complement, and interconnect these fundamental chemical precepts with the procedural knowledge and reasoning skills required to scientifically solve problems correctly.”*

Teacher 1 on the other hand lamented the assessment done in the classroom which tends to favor algorithmic approaches to solving buffer problems with little emphasis on understanding the buffers conceptually hence students will always have problems in solving

calculations involving buffers. The teacher went on to highlight the importance of chemical equilibrium concepts in understanding buffers.

T 1: *“Student difficulties are caused by us teachers when we focus on buffer calculations during class and on assessments. Thus students begin to equate the ability to solve buffer problems as the same as understanding buffers and how they function on a microscopic level. They seem to believe that if they can remember facts and procedures this can be equated with learning and knowing.”*

The students can with ease plug numbers into the necessary equations while lacking understanding of acid-base concepts such as dynamic equilibria, pH or buffers. It seems there is heavy reliance by the students on algorithmic approaches for solving buffer problems as a result they will develop the thinking that if one is able to solve many buffer problems their conceptual understanding will improve.

Theme 3: Teachers views and opinions on teaching chemistry using problem-solving instruction.

The study gathered the views and opinions of teachers on teaching chemistry using problem-solving instructional strategies. All the teachers were of the opinion that it was necessary to incorporate problem-solving instructional strategies into chemistry teaching. All the teachers hinted that problem solving instruction is essential in helping learners to understand chemistry concepts. The response of teacher 2 (T2) illustrates this point:

“Problem solving is an essential aspect of chemistry education as it gives the learners an opportunity to reflect on their conceptions of chemistry and develop chemical understanding. When students solve problems in chemistry they gain ways of chemical thinking and become confident in unfamiliar and novel situations that serve them well outside the chemistry classroom.”

In general, the results of the semi structured interviews revealed that teachers held positive beliefs about chemistry problem solving. However they still held traditional beliefs about problem solving and associate problem solving with practicing computational skills, while adhering to predetermined sequence of steps when solving problems.

Theme 4: How problem-solving instruction impacts learners' problem solving performance

The teachers were probed on the impact of problem-solving instruction in enhancing and improving the problem solving skills of learners. All the participating teachers were in favor of, and supported the problem-solving instructional method. Teacher T1 noted that:

T1: "Problem-solving instruction in the classroom improves students' problem-solving abilities and fosters conceptual understanding. If properly implemented the strategy can help develop problem solving skills among learners. Chemistry teachers need training on the use of this strategy in their classrooms."

Teacher T2 also highlighted the need for student to be exposed to this strategy.

T2: "If implemented well it can really work wonders for our learners. Our students need to be exposed to new methods of learning chemistry."

All the teachers alluded to the fact that problem-solving instruction is a very effective method of teaching chemistry. The teachers were positive that the use of problem-solving instruction in their teaching results in an improvement in the problem solving skills of their learners.

Theme 5: Challenges in implementing problem solving instruction

When the teachers were probed on the challenges in implementing problem solving instruction in a chemistry classroom, the following characterized their responses:

T1: 'This teaching approach is excellent, and teachers should be supported through professional development on the use of problem- solving strategies in their

classrooms. Without this training we would not be competent and confident enough to implement such strategies.'

T2: *'The problem-solving tasks were good and appropriate but we need more time to plan and implement such instruction as well as time to reflect on the success, or otherwise of potential changes needed to the implemented instruction. We also need to reduce class sizes.'*

Teacher, T 1 highlighted lack of teacher competence and confidence as a potential threat to the implementation of problem-solving instruction while teacher T 2 raised the issue of time constraints and large class sizes as obstacles in implementing the problem-solving instruction.

Theme 6: How to incorporate problem solving in chemistry classrooms

The researcher asked teachers for their opinions on how best problem-solving instruction can be incorporated into the chemistry classroom. The following responses were given by the teachers:

T2: *'The first thing I will do is to present an ill-structured problem to the learners in an attempt to stimulate and motivate the learners allow them to develop their own constructs based on individual experience and exploration of various related disciplines. This gives the learner the opportunity to examine evidence and develop logical pathways to potential answers/solutions.'*

T1: *'I will divide my learners into groups and provide an easy problem for students to work through. The students will have an opportunity to discuss the problem amongst themselves as well as consult their teacher for clarification of information.'*

4.6.4 Focus group discussions with learners

In the focus group discussions, the researcher explored how learners viewed the use of problem-solving instructional strategies in the teaching of chemistry. Two focus group

discussions consisting of learners from the experimental group and the control group respectively took part in the discussions. Two schools each from the treatment group and control group participated in the focus group discussions. From each of the selected schools ten (10) learners participated in each of the focus group discussions.

In selecting participants for the focus group discussions in each of the participating schools, the researcher utilized the stratified random sampling technique based on their performance in the post test. The learners were categorized as low, average and high performers. Five learners were picked from each of those categories. The participants therefore represented all categories of performance. The discussions at experimental schools were classified as FE1 and FE2 and those from control schools as FC1 and FC2. The analysis of data collected from the focus group discussions is summarized as follows:

Theme 1: Difficulties in learning stoichiometry and ionic equilibria

Most of the students (FE1, FE2, FC1, and FC2) did not consider that ionic equilibria and stoichiometry were difficult topics to understand. They seemed to give an impression the topics were easy to learn. They (FE1, FC1, and FC2) perceived the topics to be a matter of plugging in the correct numbers into the formula. The students viewed ionic equilibria and stoichiometry problem solving as involving simple calculations.

The students noted that their difficulties in stoichiometry emanate from deficiencies and inadequate understanding of terms used in learning the topic. The terms and concepts such as the mole, molecule, molar mass, amount of substance, number of particles sounded similar and confused the students. When it then comes to applying relationships involving these concepts in stoichiometry calculations the students are thus found wanting.

The students also highlighted that they had problems in understanding conjugate acid base pairs as well as the concept of weak and strong acids. Comments from participants in control schools included the following examples.

L 1: *'I have a difficulty in describing the difference between a base and its conjugate acid.'*

L 9: *'It's difficult for me to identify a conjugate pair containing the strongest acid and weakest base.'*

Learner from experimental schools had difficulties as characterized by the following responses.

L 5: *'Our teachers and books we use do not clearly describe the concept of conjugate and non-conjugate acid–base pairs so we have problems in understanding.'*

L 12: *'The terms Strength and concentration often confuse me and I sometimes take them to mean the same thing.'*

Furthermore the findings from the focus group discussions with learners indicated that learners from both groups had difficulties in explaining how buffers work can in terms of Le Chatelier's principle. They also noted that they have challenge in dealing with buffer problem calculations. This might stem from the fact that students do not understand the conjugate acid-base concept which is necessary to be successful at buffer problems.

Theme 2: Factors contributing to success in solving stoichiometry and ionic equilibria problems

When students were asked about the factors that contribute to their success in solving stoichiometry problems they conceded that the ability of problem representation is a very key factor that influences performance in stoichiometric problem solving. The students seemed to agree that if they are able to translate word problems into appropriate chemical equations they would be successful in solving stoichiometry problems. Learner 4, 7 and 13 noted that it

is important for them to write balanced equations as failure to do so would lead to unsuccessful problem solving.

The students further noted that the memorization of formulae as well as definitions, without understanding the underlying concepts required in solving stoichiometry problems.

L: 13 ‘We must be able to think and reason through problems in chemistry, rather than rely on memorization, which is inadequate and restrictive to meaningful problem solving.’

In summary, students noted that the ability to understand underlying stoichiometry concepts, balance the chemical equations satisfactorily and translating word problems into appropriate chemical and mathematical equations as key factors in stoichiometry problem solving.

Successful ionic equilibria problem-solving as noted by the students requires a mastery of the acid-base concepts. The students further explained that failure to grasp and master the underlying ionic equilibria theories, concepts and processes would result in them making systematic errors when solving ionic equilibria problems. Learners 5, 8, 10 and 13 noted that for one to be successful in solving ionic equilibria problems they need to understand acid-base theories as well as related concepts like conjugate acid-base pairs.

The learners further noted that stoichiometric skills and knowledge of chemical equilibrium are a prerequisite for successfully solving ionic equilibrium problems.

L: 10 ‘Some ionic equilibria problems like buffers require that a student be familiar with a number of concepts like stoichiometry, chemical equilibria, and chemical formula.’

L: 13 'Being familiar with the mentioned concepts is not adequate, one should be able interlink these concepts with procedural knowledge as well as reasoning skills to solve the problems correctly.'

Thus the students are of the belief that success in ionic equilibria problem solving is influenced by having adequate knowledge of the acid-base concepts, chemical equilibrium as well as stoichiometric skills.

The learners, however, had mixed views on whether mathematical ability of the learner would greatly influence his or her performance in stoichiometry and ionic equilibria problem solving. Some learners (learners 1, 3, 4, 7, 9, 14) thought that a sound mathematical ability of the students is very critical in helping the learner in solving stoichiometry and ionic equilibria problems. The other learners (learners 2, 5, 6, 8, 10,11,12,13 and 15) do not seem to agree with this. They perceived that even students with minimal mathematical ability would be able to solve the problems if they had a sound understanding of basic and fundamental concepts in stoichiometry and ionic equilibria.

Theme 3: Learners' views on the importance of problem-solving instruction

Most learners (83%) from experimental schools welcomed and supported the problem solving instruction.

L3: 'I like this method of teaching because it is better than what we used to with our teacher.'

L7: 'This method of teaching I like it because it is much better than the other method which we used before.'

The respondents in the experimental group noted that the problem-solving instructional strategies enabled them to demonstrate and display their problem solving skills as a result they were able to realize meaningful learning in the classroom.

Learners from the control group noted that the problem-solving tasks they were exposed to were good but lamented the fact that their teachers did not engage them into actively solving the problems.

L11: *'The problem- solving tasks were relevant but our teacher is not exciting.'*

L13: *'Our teacher did not give us a chance to work with our friends. I think I will ask my friends when we get out of class.'*

The verbatim extracts indicate that learners from the control group did not participate actively in the teaching and learning activities as a result did not benefit immensely from the classroom activities.

The majority (97%) (Twenty nine respondents) from experimental schools were of the opinion that the problem-solving instruction (PSI) is a better and preferred method of teaching chemistry. They highly valued the approach and encouraged teachers to adopt the method in chemistry teaching.

L5: *'Problem-solving instruction is much better than our old method because it enables us to work together and discuss as learners.'*

L7: *'I think this method is the best and it will enable us to pass chemistry well.'*

L11: *'The lecturers at colleges and universities must expose our teachers to new ways of teaching chemistry like this one we have had.'*

The findings revealed that learners from experimental group welcomed the problem-solving instruction while those in the control group showed some dissatisfaction in the way their teachers had presented the problem solving tasks to them. The views from the control group showed that these learners need an alternative approach to teach chemistry problem solving.

Theme 4: Effect of problem-solving instruction on learners' performance in problem solving

In analyzing the focus group discussions, learners' responses from experimental schools were characterized by phrases such as '.....I like this method', '.....this method is the best', 'I enjoyed the lessons.....', '.....we will obtain better grades now'.

These views from learners seem to suggest that the method they had been exposed to had a positive impact on the performance of the learners in solving stoichiometry and ionic equilibria problems. In addition, learners from the treatment group were happy and motivated to learn chemistry.

L5: *'This new method is better than the old method used by our teachers previously. I enjoyed throughout the lessons since the problems were interesting.'*

L7: *'My chemistry test marks have improved because of this new method.'*

L10: *'I had been struggling with chemistry but this time managed to perform better because we were working together doing more examples.'*

L6: *'I think with this type of teaching method we can pass chemistry with good grades.'*

From the preceding responses it can be seen that learners from the experimental schools had high regard for the new method which had a positive impact on their problem solving in stoichiometry and ionic equilibria, consequently improving their problem solving performance in chemistry.

Theme 5: Views of learners on teaching chemistry using problem-solving instructional strategies

This research study explored the views of participating learners on teaching chemistry using problem-solving instructional strategies. The focus of the deliberations was mainly on the challenges encountered and how best the instruction could be implemented. All (100%) the

participants exposed to the new teaching method highly valued the problem-solving instruction and favored it as an excellent method of teaching. The learners also noted that challenges will always be there when you start something new but implored that teachers must use this method and properly implement it in the classroom for effective teaching and learning.

L4: *'This is an excellent method if our teachers properly use it'.*

L6: *'Our teachers should use this method more often as it is interesting and motivating.'*

4. 7. Discussion of the findings

4.7.1 Difficulties in stoichiometry problem solving

This research question sought to determine learners' weaknesses in stoichiometry and ionic equilibria problem solving. This was accomplished by analyzing the solutions that were given by the learners. The findings indicate the learners could not apply the relationship involving the amount of substance (the mole) and the Avogadro's number in calculations that involve chemical formulas (see figure 4.1). The finding is consistent with Cardellini (2014), who found that most students got the wrong solutions in stoichiometric calculations because they used inconsistent relationships. The students showed lack of understanding of the difference between atoms and molecules as result they showed confusion when the concepts were inserted in stoichiometric calculations.

Students often find the limiting reagent concept problematic when solving stoichiometry problems. From the findings of this study it was revealed that students failed to identify limiting reagents in a chemical reaction from the given equation (figure 4.2). The finding indicates that learners do not understand the concept of the limiting reagent. The finding is in agreement with Gauchon and Méheut (2007), who note that students face major obstacles in

identifying the limiting reactant. A study by Boujaoude and Barakat (2000), revealed that in choosing the limiting reagent, students tended to do it randomly and did not justify their choice. As noted by Hanson (2015), most students have difficulties in believing that some reactants could limit reactions especially if the amounts of reactants are not stoichiometrically equivalent the students will find it difficult to understand that the used up species would be the limiting reactant. Dahsah and Coll (2007), also found that students view the limiting reagent as the smallest quantity of mass and not the mole in a chemical reaction. The finding is also consistent with Chandrasegaran et al. (2009) who found that students do not clearly demonstrate their understanding of the limiting reactant concept when solving stoichiometry problems. As noted by Upahi and Olorundare (2012), the difficulties students have in identifying limiting reactants arise from frustrations when mole ratios of the given substances in a chemical equation are not one on one.

An analysis of student responses revealed that students failed to demonstrate their understanding of what actual yields and theoretical yields are as a result they could not determine percentage yield (figure 4.3). This finding is consistent with Hanson (2015), who demonstrated that Ghanaian trainee teachers could neither understand what actual yield is neither nor did they show adequate understanding of what a theoretical yield was. They failed to use the given chemical equations to perform the relevant calculations.

A review of a study by Gulacar, Overton, Bowman and Fyneweverd (2013), also revealed that students have difficulties with calculations involving percentage yields because of mathematical problems. The students were unable to use the percentage yield formula and had difficulty in remembering the percentage yield formula. Gulacar, Overton and Bowman (2013) noted that the difficulties students experience with stoichiometric calculations arise from the inability by the students to link and use their knowledge of chemistry and

mathematical abilities to solve simple problems, they cannot use and link their knowledge of different topics to carry out complex calculations.

Balancing chemical equations is an important step in stoichiometry problem solving. Students in this study could not determine actual and theoretical yields as a result of failure to balance chemical equations. Gauchon and Méheut (2007), have noted that if students interpret and correctly balance chemical equations and use them they are likely to be more successful in solving stoichiometric problems. The finding of this study is consistent with Ozmen and Ayas (2003), who noted that chemistry students have difficulty in reaction stoichiometry especially the application of the law of conservation of mass demonstrated through balanced chemical equations. The finding is also in agreement with Croeau, Fox and Varazo (2007), who demonstrated that students' persistent inability to solve stoichiometric problems largely stems from difficulty both in acquiring and systematically applying skills pertaining to balancing of chemical equations. The results support earlier conclusions by Agung and Schwarz (2007), that Indonesian students have difficulties with both the balancing of chemical equations and in recognizing the conceptual implications of such equations. They do not understand the role of coefficients as well as fail to comprehend the law of conservation of mass. Furthermore, the Indonesian students' were found to have challenges in recognizing the association between balanced equations and the conservation of matter as presented in the conceptual problems, hence often find difficulties in correctly balancing chemical equations.

An analysis of semi-structured interviews with teachers indicated that teachers do not probe their learners' understanding of the fundamental prerequisites of stoichiometry. As noted by Hanson (2015), the fundamental concepts such as the mole, concentrations of solutions, limiting reagents, writing of chemical equations and balancing of equations enable students to

understand relationships among entities of matter and required amounts for use when necessary and be successful in stoichiometry problem-solving. The students do not understand the underlying scientific concepts in stoichiometry at the macroscopic (e.g., mole) or microscopic levels (e.g., molecules and atoms). A failure by the students to understand and connect between these results in lack of conceptual understanding of stoichiometry. Students who understood the concepts could better solve quantitative numerical problems, while students who did not fully understand the concepts could not solve problems correctly. Interviews with teachers further revealed that teachers rush through the teaching of the topic due to inadequate time as a result they do not thoroughly explain the fundamental concepts to the students.

4.7.2 Difficulties in ionic equilibria problem solving

This study has shown that students lacked understanding and knowledge about acid-base reactions based on the Bronsted-Lowry theory. They could not precisely define Bronsted Lowry acids and bases (figure 4.5). They experience confusion in terminology. This finding is consistent with Sheppard (2006), who observed that students have difficulty in embracing acid-base concepts as well as defining basic concepts related to the topic. The findings support earlier findings by Schmidt (1995), who studied German students with regard to their understanding of Brønsted-Lowry theory on acids and bases and concluded that students mix up concepts such as conjugated and non-conjugated acid-base pairs. Artdeja, Ratanaroutaia, Coll and Thongpanchang (2010), note that alternative conceptions in senior high school students about the Brønsted theory, and between conjugate and non-conjugate acid–base pairs, arise from the fact that neither the concept of conjugate and non-conjugate acid–base pairs nor the distinction between the two terms is clearly described in textbooks. Abdul, Slobotka and Durmishi (2015), also opine that students do lack fundamental knowledge of

the basics of acid base chemistry as a result they show confusion with acid base terminology. They further point out that positively and negatively charged ions are often misunderstood as conjugate acid–base pairs, a situation also exhibited by learners in this study.

Evidence from this study has shown that difficulties in explaining buffers and concepts related to buffers as well as performing buffer calculations exist among the A' level chemistry students (figure 4.6). The students are failing to apply stoichiometric principles and balancing chemical equations in calculating buffer problems. The difficulties stem from a lack of conceptual understanding of buffers, poor understanding of fundamental chemistry concepts as well as failure to understand the link and interconnectedness between the macroscopic and microscopic representations of buffers. The findings of the study are consistent with Orgill and Sutherland (2008), who noted that students have difficulties in understanding the importance and functioning of buffers as well as solving buffer calculations. Further evidence from the study indicates that A' level chemistry learners could not apply the Le Chatelier's principle in explaining how buffers work (figure 4.7). This finding is in agreement with Bilgin and Geban (2006), who emphasise on the importance of understanding chemical equilibrium concepts if one is to understand chemical buffers. As noted by Orgill and Sutherland (2008), if one has deficiencies in understanding the key concepts in chemical equilibrium they will have problems with buffers.

The findings do show that some of the difficulties students have with buffers are caused by teachers who tend to focus more on algorithmic calculations during lessons and assessments. Such a focus by teachers entails that students will equate their ability to solve buffer problems as being synonymous with conceptual understanding of how buffers work at the sub microscopic representational level. (Orgill and Sutherland, 2008). Yet as noted by Raviolo (2001), it is the ability of the student to explain buffer concepts at the macroscopic,

microscopic, and symbolic levels which demonstrates that students conceptually understand buffers. It has been noted by Lyall (2005), that students who rely on algorithms for solving problems yet lacking the necessary conceptual background, tend to apply the algorithms inappropriately, a situation similar to students in this study.

4.7.3 The effect of structured problem-solving models on achievement in stoichiometry and ionic equilibria

The findings related to research question one showed that students in the experimental group who were exposed to the treatment had improved performance and performed better than those in the control group taught using the conventional lecture method when exposed to the achievement tests in stoichiometry and ionic equilibria. The hypothesis (see section 4.3.1) also confirmed that there was a significant difference in the performance of students exposed to problem-solving instructional strategies and those taught with the conventional lecture method.

This finding is in agreement with Alabi and Nureni (2015), who found that students taught using guided discovery and problem solving obtained higher mean achievement scores in Chemistry than their counterparts taught Chemistry using conventional teaching method, an indication that that guided discovery and problem solving strategies enhance achievement in Chemistry more than the conventional lecture method of teaching. The finding is also in line with Mwelese and Wanjala (2014), Jegede and Fatoke (2014), Shehu (2014), as well as Mobolaji (2016), who found that who students exposed to problem-solving approaches performed better than did students exposed to lecture methods. It was also in agreement with Olaniyan and Omosewo (2015), who found students exposed to Target-Task Problem-Solving Model performed better than those exposed to conventional teaching methods. The finding of this study shows that teaching of stoichiometry and ionic equilibria using

Selvaratnam and Fraser (1982), as well as Ashmore et al. (1979), problem solving strategies increased the awareness of students' knowledge and ability during the problem solving process. It can therefore be concluded that the application of problem-solving strategies is more effective in helping students improve their problem solving performance than conventional lecture method. This clearly supports the implementation of problem-solving instruction in the chemistry classroom. The implication is that students who were taught using problem-solving strategies had well mastered the strategies of solving stoichiometry and ionic equilibrium problems better than those taught using the conventional method (table 4.15 and table 4.19).

4.7.4 Experiences of participants taught using problem solving instruction

The semi-structured interviews with teachers and focus group discussions with learners asked questions that solicited information regarding how teachers and learners view the use of problem-solving instructional strategies chemistry teaching. The results suggested that both teachers and learners supported the use of problem-solving instruction in chemistry teaching. The responses of learners demonstrated positive views about problem-solving instruction in chemistry teaching. The views of teachers also followed a similar trend. The findings of this study are in agreement with Akhter, Akhtar and Abaidullah (2015), who reported that mathematics teachers in Pakistan view using problem solving instruction as important. The results of this study are consistent with Ferreira and Trudel (2012), as well as Ekici (2016), who found that students had a positive and high level of personal view related to problem-solving instructional strategies. The students in this study enjoyed and benefited from the problem-solving strategies. As previously found by other researchers such as Dhlamini (2012), as well as Ferreira and Trudel (2012), the students in this study were actively

involved in the learning and were more motivated to learn during the various stages of the problem-solving instruction.

The findings of the study further attest to the importance and positive impact of problem-solving instruction on learners' performance in problem solving. Both teachers and students testified to the fact that the use of problem-solving teaching methods enhance the effective teaching and learning of chemistry. The findings concur with Çaliskan, Selçuk and Erol (2010), who examined the effects of problem solving strategies on problem solving performance in physics and found that teaching of problem solving increased the awareness of students' knowledge and ability during the problem solving process. It can be seen that the implementation of problem-solving instructional strategies is more effective in improving learners' problem solving performance in stoichiometry and ionic equilibria, consequently improving their problem solving performance in chemistry. In conjunction with this, Gongden (2016), reached a similar conclusion in his research.

The findings from semi-structured interviews did highlight some of the obstacles that militate against the effective implementation of problem solving instruction. The challenges that were identified include: lack of teacher competence and confidence; time constraints and large class sizes. The findings of this study seem to concur with Eison (2010), who reported that limited time for content coverage, large class sizes and inadequate materials and equipment as hindering the implementation of active learning strategies such as problem-solving in the chemistry classroom. Furthermore, the implementation of problem-solving instruction requires a lot of pre-class preparation than the preparation time needed to for conventional lectures. The findings of this study are not different from earlier studies. Dhlamini (2012), investigated how the teaching of mathematics can be impacted by using a context-based problem solving instruction. The study found that teachers raised the issue of lack of training

and large class sizes as potential threats to the implementation of problem-solving instructional strategies in chemistry classes.

Considering how the problem-solving instructional strategies can be included or integrated in the teaching and learning of chemistry, it is reasonable to conclude that teachers noted the need to contextualize the problems and laboratory work, using ill-structured problems in an attempt to stimulate and motivate the learners as well as using the group approach to encourage collaborative learning among the learners. While working in groups, Pass et al. (2010), notes that participants discuss, argue and reflect upon the problem solving tasks. This helps the learner to overcome individual working memory limitations and thus, derive maximum benefit from working as a group in solving chemical problems (Kirschner et al., 2011). As students work cooperatively and collaboratively with each other, content is reinforced, thus, resulting in deeper learning.

In particular, the study results showed that students in the experimental group committed few problem solving errors in comparison to those committed by their counterparts in the control schools after they had been exposed to the problem-solving instruction (table 4.12 and table 4.16). This indicates that problem-solving instruction has enabled the learners to improve their performance in problem solving. The improvement in problem solving performance of learners in the experimental group upon exposure to the treatment can be explained by invoking the constructivist learning theory. From a constructivist perspective, active involvement of students is emphasized and learners actively take knowledge, connect it to previously assimilated knowledge and make it theirs by constructing their own interpretation (Oludipe and Oludipe, 2010).

The teacher in a constructivist classroom is a facilitator where classroom activities are organized so that students can interact with and learn from each other as well as the teacher and the world around them. Such an environment is student centered, placing more value on

student learning rather than the teacher teaching. In other words, the learner is active a characteristic exhibited in the experimental classes in this study. Overall, the results of the study are in agreement and provide evidence that affirms findings from earlier studies pertaining to the positive effect of constructivist related teaching strategies whose purpose is to improve performance of learners in chemistry (see for example Lenah, 2015; Kibos, Wachanga and Changeiywo, 2015).

4.8 Chapter Summary

This chapter presented and analyzed quantitative data using statistical methods. The paired samples t-test was performed to analyze learners' achievement test scores obtained from the pilot study. Results from this test showed that problem solving instruction is effective in improving the performance of chemistry students in stoichiometry and ionic equilibria. ANCOVA analysis was also performed to determine if there was any statistical significant difference in the post-test achievement scores of the experimental and control groups. Through the results of the ANCOVA analysis, the findings from the pilot study were further confirmed indicating the superiority of problem-solving instructional strategies to the conventional lecture method that was being used by teachers teaching the control group. The findings also showed that students faced several difficulties in solving stoichiometric and ionic equilibria problems.

The analysis of focus group discussions showed that learners in the experimental group highly valued, favored and supported the problem-solving instruction over conventional problem solving instruction. Analysis of classroom observations indicated that the method (problem-solving instruction) was favored by the participants from experimental schools. Analysis of semi structured interviews indicated that all teachers agreed that the implementation of this new method should be made mandatory in all chemistry classes. All the teachers hinted that problem solving instruction is essential in helping learners to

understand chemistry concepts. However, they highlighted lack of teacher competence and confidence as a potential threat to the implementation of problem-solving instruction as well as time constraints and large class sizes as other obstacles in implementing the problem-solving instruction.

This chapter has also discussed the quantitative and qualitative results of this research study. The findings emanating from this investigation suggest that the use of problem-solving instructional strategies is a very effective method of teaching. This study showed that problem-solving instruction helps in improving the performance of learners in solving stoichiometry and ionic equilibria problems. Furthermore, the findings of the study demonstrate that the inclusion of collaborative group work helped in reducing individual working memory limitations as a result learners benefited from group problem solving actions. The following chapter provides the summary, conclusions and recommendations of the study.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The achievement of students in chemistry is largely dependent on the instructional strategies used. The purpose of the present study was to investigate the effect of structured problem-solving instructional strategies in influencing the academic achievement of A' level chemistry students in stoichiometry and ionic equilibria. The study was guided by the following objectives: (i) to identify student difficulties in stoichiometry and ionic equilibria problem solving. (ii) to determine the effect of the Ashmore, Casey and Frazer (1979), problem-solving model as well as the Selvaratnam and Frazer (1982), problem-solving model on the academic achievement of students in stoichiometry and ionic equilibrium and (iii) to evaluate the experiences of learners taught using these problem-solving instructional strategies. This chapter summarizes the findings of the study, draws conclusions, makes recommendations and suggests areas for further research.

5.2 Summary of findings

The study investigated the comparative effects of two problem solving instructional strategies namely Selvaratnam-Fraser and Ashmore et al on A' level chemistry Students' achievement in Stoichiometry and ionic equilibria in Zimbabwe. The study adopted the constructivist theory as the underpinning theoretical framework to guide the researcher in interpreting and explaining the performance of participants in problem-solving. The present study is located within a pragmatic paradigm following a mixed methods approach in which quantitative data was collected first followed by the collection of qualitative data. The study adopted a quasi-experimental design (3 x 2 non-randomized pre-test, post-test control group) comprising three

groups made up of two experimental groups and one control. To assist in the explanation, interpretation and elaboration of the quantitative findings, semi structured interviews with teachers, focus group discussions with learners as well as classroom observations were conducted.

A sample of 525 A' level chemistry learners was studied. Participants were drawn from eight high schools in Gweru district. 250 learners from four of the high schools constituted the experimental group while the control group was made up of the other four remaining high schools with a total of 275 learners. The principal instruments for data collection were standardized achievement Tests in stoichiometry and ionic equilibria that were aligned to the Zimbabwe Schools Examinations Council A' level National syllabus for chemistry. All the learners who participated in the study sat for the pre- test and post-test at the initial as well as final stages of the experiment. The pre-tests were designed to determine participants' initial problem solving status before intervention. The results from the pre-test scores proved that the two groups under investigation were homogeneous in relation to their performance in problem solving performance. The participants were later subjected to a post- test at the end of the two week treatment programme to see if there was a change in their performance in problem solving.

The research assistants who had been trained on the use of the problem-solving strategies in chemistry teaching implemented the problem-solving instruction in four experimental schools. Two assistants were trained on the use of Selvaratnam-Fraser problem-solving instructional strategy while the other two were trained on the use of Ashmore et al. problem-solving instructional strategy. The chemistry teachers at the four schools were trained as research assistants. The four control schools were taught by their teachers using the conventional lecture method. The data collected were analyzed using quantitative (ANCOVA analysis on SPSS) and qualitative approaches.

The findings of the study revealed a better and improved performance for participants in the experimental group in comparison to those in the control group. Furthermore, the qualitative findings from interviews, observations and focus group discussions gave an indication that problem-solving instruction was highly favored among the participants. They viewed it as a teaching strategy that is effective in enhancing the capacity of A' level chemistry learners to solve chemical problems. The result of the study further revealed that there was a statistically significant difference ($p < 0.05$) in the mean scores of subjects exposed to the two problem-solving models. Out of the two models, the Scheffe's post hoc test indicated that students taught using the Ashmore et al problem-solving instructional strategy produced a higher achievement.

The study also revealed that students had difficulties with the mole concept, Avogadro's number, limiting reagents as well as determining theoretical and percentage yields. Students were also found to have difficulties with acid-base theory, buffer solutions, and application of Le Chatelier's principle in solving buffer equilibria problems and solubility equilibria. Furthermore the study revealed that students rely on algorithmic strategies when solving stoichiometry and ionic equilibria problems and do not demonstrate adequate understanding of the concepts involved.

5.2.1 Implications of the Study Results'

The implications for teaching and learning emanating from this study are highlighted and discussed below.

5.2.1.1 Epistemological implications

Lifelong learning as guided by the constructivist theory has emphasized on the learner being at the centre of their own learning, and hence that learning should not be seen as teacher-

centric or curriculum-centric, but learner-centric (Bhatia, 2015). A number of studies that have emphasized the benefits of active learning strategies such as problem-solving and collaborative group work are abound in literature (Wood, 2006; Surif et al., 2012; Gok,2010; Ngu, Mit, Shahbodin and Tuovinen, 2009; Cardellini,2006; Warfa, 2016). It is against this background that this study incorporated collaborative group work in the while examining the effect of problem-solving instruction on achievement of students in stoichiometry and ionic equilibria. The current study adds insights into the significance of utilization of active learning strategies that stimulate learner participation and enhance learning as well as improving problem-solving capabilities of learners in the chemistry classroom.

Stoichiometry and ionic equilibria teaching and learning has largely been characterized by the use of procedural and algorithmic methods of teaching (Kaundjwa, 2015; Pappa and Tsaparlis, 2011; Okanlawon, 2010; Nyachwaya et al, 2014; Bartholaw and Watson, 2014). Such teaching methods have been found not to conceptual understanding of fundamental concepts in the topics. As noted by McLaren et al. (2007), chemistry students may experience success when solving similar problems to the ones given in textbooks or demonstrated in the classroom they tend to have difficulties with novel problems that require similar techniques. The difficulty arises from student's lack of conceptual understanding. In this particular study students were taught stoichiometry and ionic equilibria using problem-solving instruction incorporation collaborative group work which support constructivist learning. Overall the knowledge accrued from the study contributes immensely to the on-going deliberations pertaining efforts to use constructivist teaching strategies in chemistry.

5.2.1.2 Methodological implications

The study was unique in the sense that it used research assistants in experimental schools to implement the problem-solving instruction. The absence of the researcher in the

implementation of problem solving instruction in experimental schools was designed to eliminate biasness and leanness to one problem-solving method since two strategies were being investigated. The problem-solving instruction was implemented in four experimental schools. Chemistry teachers of the sampled schools were trained for a period of two weeks on the implementation of the methodologies used for treatment groups in order to control teacher-effect factor. The use of training of class teachers as research assistants was meant to minimize the creation of an artificial and unusual learning atmosphere caused by the presence of a stranger (the researcher himself).

As noted by Gay *et al.*, (2011), when conducting experimental research it is required that the researcher equates all the groups that are receiving the different treatments on all the variables that are likely to influence performance on the dependent variable. In the present study the researcher strove to achieve this by ensuring that all teachers handling experimental schools were trained prior to the implementation of the problem-solving instruction. This ensured that implementation of the intervention in experimental schools was done in a natural and usual learning environment.

5.2.1.3 Pedagogical implications

The current study has shown beyond doubt that the use of problem-solving instruction in chemistry teaching enhances the performance of learners in stoichiometry and ionic equilibria problem solving. The problem solving instruction was found to be a much better method in enhancing of the problem solving skills of learners in comparison to the conventional method. The problem-solving instruction that was implemented effectively improved and fostered the skills of learners in solving stoichiometry and ionic equilibria problems through actively engaging them in working out tasks from problem solving work sheets and making learners to become familiar each stage in the problem solving process. The use of problem-solving instruction in comparison to conventional instruction has proved to be a better

teaching method. Consequence of the findings of this investigation, the researcher strongly endorses that problem-solving instruction be used in the chemistry classes to improve the performance of learners in chemistry problem solving.

Furthermore a significant difference in the post test achievement scores was observed between the experimental and control group. The group taught using problem-solving instruction showed better and improved performance in the post-test when compared to the control group that was not exposed to the treatment. The implementation of problem-solving instruction also embraced collaborative group work enabling participants to discuss, argue and reflect upon the problem solving tasks at hand thus minimizing individual working memory limitations and learners consequently benefiting from group problem solving actions. Based on the preceding observations, the study provides some evidence for the use problem-solving instruction embedding collaborative group work in effectively teaching chemistry. This study therefore recommends that the use of problem-solving instruction incorporating collaborative group work be given due consideration in chemistry teaching in a quest to improve performance of learners in chemistry.

Given that the use of structured problem solving is promising in this study, teachers should emphasis on the logical process during solving problems, lest students become more proficient at applying the formulas rather than to reason. Requiring learners to justify (argue for) their positions while solving problems (especially ill-structured problems) should be an essential part of problem-solving instruction by teachers so that students can overcome the challenges they experience in solving stoichiometric problems. It is necessary for teachers to teach the reasoning involved in the problem solutions in ways that are meaningful for students and make sense to them, because research has made it clear that procedures must take on meaning and make sense or they are unlikely to be used in any situation that is at all different from the exact ones in which they are taught (Resnick, 1983). The representation of

the problem is certainly an important aspect in problem solving, but even more important are the logical processes that help solve the problems correctly. The adoption of worked examples really helped the students to improve their skills in this part of stoichiometric calculations.

It must be remembered that teachers can't teach people to solve all novel problems better. What they can do, is turn novel problems into exercises. Worked examples can help in that aim. The purpose of worked examples is precisely to turn problems into exercises. Once sufficient knowledge concerning the problems of an area has been stored in long-term memory, all problems become exercises and high levels of expertise have been attained.” (Cardellini, 2014). Another educational aspect deserves to be considered. Teachers should allow students to work in cooperative groups, according to some role, exercising and practicing solving numerous problems. In this way they also become skilled at solving more complex problems. This is an important aspect of meaningful learning because “explaining another person’s reasoning, especially a more correct one, raises additional opportunities for comparing and contrasting the other person’s reasoning with one’s own. Any conflicts observed will naturally elicit more repairs of one’s representation. Exposing a learner to multiple perspectives on a problem (or perhaps even multiple representation of a problem solution), either from a text or from another peer’s reasoning, seems to support effective explaining and thereby learning (Roy and Chi, 2005).

In order for teachers to increase students’ problem solving abilities, in addition to working on student understanding of key ideas (stoichiometry and ionic equilibria) related to the problem in order to increase conceptual understanding, it is necessary to teach students an organized problem-solving approach that explicitly shows them all the steps involved in the problem-solving process to help them address new problems in a systematic manner. There is reason to believe that an increase in students’ conceptual and procedural knowledge will benefit

their attitude and confidence towards problem-solving tasks, and therefore, to improve their problem-solving proficiency.

5.3 Conclusions

The study has gathered evidence indicating that high school chemistry students have difficulties in solving stoichiometric and ionic equilibria problems similar to those reported in western educational contexts. The difficulties that were identified in this study mostly occur as a result of lack of conceptual understanding of the basic concepts related to stoichiometry and ionic equilibria. In solving stoichiometry problems, the students did not demonstrate a clear understanding of basic concepts such as the mole concept, balancing chemical equations, limiting and excess as well as using consistent relationships in performing stoichiometric calculations thus showing a lack of problem solving skills. It was further shown that student's inability to perform buffer and pH calculations, explain acid-base models as well as how buffers work characterized the difficulties students have in solving ionic equilibria problems.

On the basis of the findings, it was concluded that, instructional strategies that teachers employ in teaching Chemistry have significant effects on students' performance and that problem-solving instructional strategies are more effective in enhancing students' problem solving performance in stoichiometry and ionic equilibria than the conventional method. The problem-solving instruction enabled the learners to be actively engaged in solving stoichiometry and ionic equilibria problems in a socio-constructivist environment.

The intervention employed in this study created an environment that not only promoted social interaction, but also facilitates the participation in group actions that are relevant for the accomplishment of the common goals. The use of social interaction, cooperative problem-solving instruction supports the effective development of problem solving abilities of

learners. The evidence from the study suggests that students in such an environment showed improved problem-solving hence providing an environment that is conducive to social interaction and reflection allows students to develop these desirable problem solving skills. Furthermore the the Ashmore, Casey and Frazer (1979) problem-solving model was found to be more effective in the teaching of stoichiometry and ionic equilibria than the Selvaratnam and Frazer, (1982) problem-solving model.

According to the results of the current study, participants held positive views on the infusion of problem solving instruction in chemistry classrooms. Both teachers and learners agreed that problem solving instruction is more effective than conventional lecture, in promoting the problem solving skills of learners. Thus, through the use of PSI, the teaching and learning of chemistry in high schools could be made lively, interesting and motivating to the students. Based on the foregoing, there is therefore the need for PSI to be effectively institutionalized in the teaching and learning of chemistry in high schools in Zimbabwe..

5.4 Recommendations

Based on the major findings of this study, the following recommendations are made:

It is evident from the study that, problem-solving instructional teaching methods are effective in improving students' achievement in stoichiometry and ionic equilibria. Therefore, chemistry teachers are strongly recommended to use these teaching methods in their lessons to facilitate students' problem solving performance.

The writers and publishers of chemistry text books would have to include the problem-solving instructional strategies in their write ups so that teachers and learners can benefit.

Considering that the goal of chemistry education is to improve problem solving skills of learners, findings from the study suggest need for proper training of pre service teachers in problem solving instruction as well as how to implement effectively problem-solving instruction. Furthermore in-service training through symposiums and workshops should be

organized and made compulsory for practicing chemistry teachers so that they can embrace the skills of the problem-solving strategies for effective implementation of the strategies in teaching chemistry.

The curriculum planners, education stakeholders and the Ministry of Primary and Secondary Education should advocate making problem-solving instructional strategies the essential instructional strategies for teaching and learning in the secondary school curriculum. Also chemistry class sizes should be kept within manageable limits to ensuring that teachers have adequate time to effectively implement problem-solving strategies in their classroom.

Students also need to be given sufficient time and opportunities to practice using what they have learned in order to improve their problem-solving self-efficacy. This is because problem-solving is a mental process that involves the use of metacognition, prior knowledge, and strategies which needs to be developed slowly over time.

Pre-service chemistry teachers should teach students how to select the most appropriate strategies for solving different types of problems since they cannot feasibly work through all of the strategies that they know for each problem they try to solve. As a result, teachers need to make a substantial commitment in time and effort to developing their students' problem-solving skills. They also need to teach problem-solving with the same importance that they teach other concepts in the chemistry curriculum.

5.5 Limitations of the study

This investigation was not without limitations as a result it is important to acknowledge and recognize such limitations in order to be able to make sound interpretations of the findings.

The following limitations were found to be inherent in the study:

The length of time (two weeks) for the implementation of the treatment in experimental schools may be considered too short to be able to impact the problem solving skills and

performance of learners. If a study could be conducted for a long period of time it could yield results that are significant.

The study focused on only two topics in the Advanced level chemistry syllabus and was restricted to only Advance level learners excluding learners from other levels. As such the impact or effect that the intervention had in these two topics is also assumed to be appropriate to other levels and topics in the Advanced level chemistry syllabus.

Since the study could not assign the participants randomly to the control and experimental group and that the study was conducted in high schools in Gweru district, the findings are therefore limited to the participants who took part in the study and as such generalizing beyond the participants should be done with caution.

5.6 Suggestions for further research

In view of the limitations that are highlighted above, the following suggestions are made for further research. Future researchers may conduct longitudinal studies on the effect of problem-solving instructional strategies on student achievement in the chemistry classroom.

Furthermore, future studies may consider replicating the study in other chemistry topics.

This present study did not consider the influence of other moderating variables such as parental education, students' cognitive styles etc. Future research studies may consider these variables.

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APPENDIX A: ACHIEVEMENT TESTS

Stoichiometry Achievement Test (Pretest)

Read These Instructions First:

Do not write your name on the question paper and answer sheet.

Answer all questions.

Electronic calculators may be used.

Duration: **1½ hours**

Marks: 50

Section A

For each question there are four possible answers, A, B, C, and D. Choose the one you consider to be correct and record your choice by circling in soft pencil on the Answer Sheet.

1. Tanzanite is used as a gemstone for jewellery. It is a hydrated calcium aluminium silicate mineral with a chemical formula $\text{Ca}_2\text{Al}_x\text{Si}_y\text{O}_{12}(\text{OH}) \cdot 6\frac{1}{2}\text{H}_2\text{O}$. Tanzanite has Mr of 571.5. Its chemical composition is 14.04% calcium, 14.17% aluminium, 14.75% silicon, 54.59% oxygen and 2.45% hydrogen.

(Ar values: H = 1.0, O = 16.0, Al = 27.0, Si = 28.1, Ca = 40.1)

What are the values of x and y?

	X	Y
A	1	1
B	2	3
C	3	3
D	6	1

2. Use of the Data Booklet is relevant to this question.

Nickel makes up 20% of the total mass of a coin. The coin has a mass of 10.0g.

How many nickel atoms are in the coin?

A 2.05×10^{22} **B** 4.30×10^{22} **C** 1.03×10^{23} **D** 1.20×10^{24}

3. Ammonium sulfate in nitrogenous fertilizers in the soil can be slowly oxidized by air producing sulfuric acid, nitric acid and water.

How many moles of oxygen gas are needed to oxidize completely one mole of ammonium sulfate?

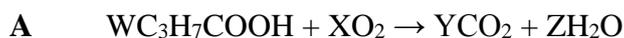
A 1 **B** 2 **C** 3 **D** 4

4. In leaded petrol there is an additive composed of lead, carbon and hydrogen only. This compound contains 29.7% carbon and 6.19% hydrogen by mass.

What is the value of x in the empirical formula PbC_8H_x ?

A 5 **B** 6 **C** 16 **D** 20

5. The following equations the letters W, X, Y and Z all represent whole numbers. When correctly balanced, which equation requires one of letters W, X, Y or Z to be 5?



6. 0.02 mol of aluminium is burned in oxygen and the product is reacted with 2.00 mol dm^3 hydrochloric acid. What minimum volume of acid will be required for complete reaction?

A 15 cm^3 **B** 20 cm^3 **C** 30 cm^3 **D** 60 cm^3

7. A solution of Sn^{2+} ions will reduce an acidified solution of MnO_4^- ions to Mn^{2+} ions. The Sn^{2+} ions are oxidized to Sn^{4+} ions in this reaction.

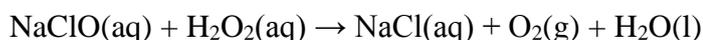
How many moles of Mn^{2+} ions are formed when a solution containing 9.5 g of SnCl_2 (Mr: 190) is added to an excess of acidified KMnO_4 solution?

A 0.010 **B** 0.020 **C** 0.050 **D** 0.125

8. 0.200 mol of a hydrocarbon undergo complete combustion to give 35.2 g of carbon dioxide and 14.4g of water as the only products. What is the molecular formula of the hydrocarbon?

A C_2H_4 **B** C_2H_6 **C** C_4H_4 **D** C_4H_8

9. A household bleach contains sodium chlorate (I), NaClO , as its active ingredient. The concentration of NaClO in the bleach can be determined by reacting a known amount with aqueous hydrogen peroxide, H_2O_2 .



When 25.0cm^3 of bleach is treated with an excess of aqueous H_2O_2 , 0.0350mol of oxygen gas is given off.

What is the concentration of NaClO in the bleach?

A $8.75 \times 10^4\text{mol dm}^{-3}$

B 0.700mol dm^{-3}

C 0.875mol dm^{-3}

D 1.40mol dm^{-3}

10. In the Basic Oxygen steel-making process the P_4O_{10} impurity is removed by reacting it with calcium oxide. The only product of this reaction is the salt calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$.

In this reaction, how many moles of calcium oxide react with one mole of P_4O_{10} ?

A 1

B 1.5

C 3

D 6

11. Use of the Data Booklet is relevant to this question.

A typical solid fertiliser for use with household plants and shrubs contains the elements N, P, and K in the ratio of 15g: 30g: 15g per 100g of fertiliser. The recommended usage of fertiliser is 14g of fertiliser per 5dm^3 of water.

What is the concentration of nitrogen atoms in this solution?

A 0.03mol dm^{-3}

B 0.05mol dm^{-3}

C 0.42mol dm^{-3}

D 0.75mol dm^{-3}

12. The density of ice is 1.00gcm^3 .

What is the volume of steam produced when 1.00 cm^3 of ice is heated to 323°C (596 K) at a pressure of one atmosphere (101kPa)?

[1mol of a gas occupies 24.0dm^3 at 25°C (298K) and one atmosphere.]

- A** 0.267dm^3 **B** 1.33dm^3 **C** 2.67dm^3 **D** 48.0dm^3

13. When a sports medal with a total surface area of 150 cm^2 was evenly coated with silver, using electrolysis, its mass increased by 0.216g .

How many atoms of silver were deposited per cm^2 on the surface of the medal?

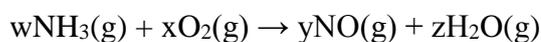
A 8.0×10^{18}

B 1.8×10^{19}

C 1.2×10^{21}

D 4.1×10^{22}

14. The first stage in the manufacture of nitric acid is the oxidation of ammonia by oxygen.



Which values for w , x , y and z are needed to balance the equation?

	w	x	y	z
A	4	5	4	6
B	4	6	4	5
C	5	6	5	4
D	6	5	6	4

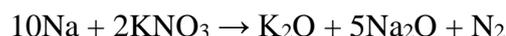
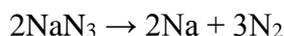
15. A 50 cm³ sample of water containing dissolved calcium sulphate was passed through the ion exchange resin. Each calcium ion in the sample was exchanged for two hydrogen ions. The resulting acidic solution collected in the flask required 25 cm³ of 1.0 × 10² mol dm³ potassium hydroxide for complete neutralisation.

What was the concentration of the calcium sulphate in the original sample?

- A** 2.5 × 10³ mol dm³
B 1.0 × 10² mol dm³
C 2.0 × 10² mol dm³
D 4.0 × 10² mol dm³
16. The petrol additive tetraethyl-lead(IV), Pb(C₂H₅)₄, is now banned in many countries. When it is completely burned in air, lead(II) oxide, CO₂ and H₂O are formed.

How many moles of oxygen are required to burn one mole of Pb(C₂H₅)₄?

- A** 9.5 **B** 11 **C** 13.5 **D** 27
17. On collision, airbags in cars inflate rapidly due to the production of nitrogen. The nitrogen is formed according to the following equations.



How many moles of nitrogen gas are produced from 1 mol of sodium azide, NaN₃?

- A** 1.5 **B** 1.6 **C** 3.2 **D** 4.0

18. Lead (IV) chloride will oxidize bromide ions to bromine. The Pb^{4+} ions are reduced to Pb^{2+} ions in this reaction.

If 6.980 g of lead (IV) chloride is added to an excess of sodium bromide solution, what mass of bromine would be produced?

A 0.799 g **B** 1.598 g **C** 3.196 g **D**

6.392 g

19. Given the equation: $2\text{KOH}_{(\text{aq})} + \text{H}_2\text{SO}_{4(\text{aq})} \rightleftharpoons \text{K}_2\text{SO}_4 + 2\text{H}_2\text{O}_{(\text{l})}$

20.0 cm^3 of a sulphuric acid solution was titrated with a standardized solution of 0.0500 mol dm^{-3} (0.05M) potassium hydroxide. Using phenolphthalein indicator for the titration, the acid required 36.0 cm^3 of the alkali KOH for neutralization what was the concentration of the acid?

A 0.035M **B** 0.090M **C** 0.069M **D** 0.045M

20. The number of atoms of each element in a molecule is shown in a(n)

A Empirical formula **B** molecular formula **C** mole **D** molecular

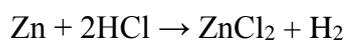
mass

Section B

For each of the questions in this section, one or more of the three numbered statements 1 to 3 may be correct. Decide whether each of the statements is or is not correct (you may find it helpful to put a tick against the statements that you consider to be correct). The responses A to D should be selected on the basis of

A	B	C	D
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

21. Zinc reacts with hydrochloric acid according to the following equation.



Which statements are correct?

[All volumes are measured at room conditions.]

- 1 A 3.27g sample of zinc reacts with an excess of hydrochloric acid to give 0.050mol of zinc chloride.
- 2 A 6.54g sample of zinc reacts completely with exactly 100cm³ of 1.00mol dm⁻³ hydrochloric acid.
- 3 A 13.08 g sample of zinc reacts with an excess of hydrochloric acid to give 9.60 dm³ of hydrogen.
22. On a scale in which the mass of a ¹²C atom is 12 the relative molecular mass of a particular sample of chlorine is 72.

Which properties of the atoms in this sample are always the same?

- 1 radius
- 2 nucleon number
- 3 isotopic mass

23. For complete combustion, 1 mol of an organic compound X was found to require 2.5 mol of molecular oxygen.

Which compounds could be X?

1 C₂H₅OH

2 C₂H₂

3 CH₃CHO

24. Which compounds have the empirical formula CH₂O?

1 methanal

2 ethanoic acid

3 methyl methanoate

25. The number of moles of chlorine that react with 1 mol of X is twice the number of moles of chlorine that react with 1 mol of Y.

Which of these pairs could be X and Y?

	X	Y
1	Mg(s)	Na(s)
2	H ₂	KBr(aq)
3	cold NaOH(aq)	hot NaOH(aq)

Section C

Structured Questions

Answer all questions

Candidates answer on the Question Paper

The number of marks is given in brackets () at the end of each question or part question.

26. The compound NaHCO_3 is commonly known as baking soda. A recipe requires 1,6 g of baking soda, mixed with other ingredients, to bake a cake.

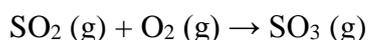
(a) Calculate the number of moles of NaHCO_3 used to bake the cake.

.....
.....
.....
.....(2)

(b) How many atoms of oxygen are there in 1,6 g baking soda?

.....
.....
.....
.....
.....
.....(2)

27. The contact process is given by the equation below.



(a) Balance the chemical equation

(1)

In an investigation 256 g SO_2 reacts with 80 g O_2 in a reaction vessel.

(b) Calculate the number of moles of each reactant present at the start of the reaction.

.....
.....

.....
.....
.....(3)

(c) Identify the limiting reagent in the reaction and justify your answer.

.....
.....
.....
.....(2)

(d) Calculate the mass of SO_3 produced in the reaction

.....
.....
.....
.....(2)

28. (a) Calculate the percentage water of crystallisation in $\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}$

.....
.....
.....
.....(2)

(b) Calculate the concentration of a 250 ml solution of sodium hydroxide if 10 g of the solute is dissolved.

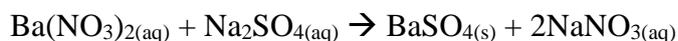
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.....(2)

29. (a) If 5.00 grams of sodium metal and 18.25 grams of copper (II) sulfate are combined, how many grams of copper metal can theoretically be produced?

.....
.....
.....
.....
.....
.....
.....(3)

(b) Barium sulfate, BaSO₄, is made by the following reaction:



An experiment was begun with 75.00g of Ba(NO₃)₂ and an excess of Na₂SO₄. After collecting and drying the product, 63.45g BaSO₄ was obtained. Calculate the theoretical yield and percent yield of BaSO₄.

.....
.....
.....
.....
.....
.....(3)

30. Silver nitrate, AgNO₃, reacts with iron(III) chloride, FeCl₃, to give silver chloride, AgCl, and iron(III) nitrate, Fe(NO₃)₃. A solution containing 18.0g AgNO₃ was mixed with a solution containing 32.4g FeCl₃. How many grams of which reactant *remains* after the reaction is over?

.....
.....
.....
.....
.....
.....
.....(3)

Ionic Equilibria Achievement Test (Pre Test)

Read These Instructions First:

Do not write your name on the question paper and answer sheet.

Answer all questions.

Electronic calculators may be used.

Duration: 1½ hours

Marks: 50

Section A

For each question there are four possible answers, A, B, C, and D. Choose the one you consider to be correct and record your choice by circling in soft pencil on the Answer Sheet.

1. What is the expression for K_a for the following reaction?



- A** $K_a = [\text{CH}_3\text{COO}^-_{(\text{aq})}][\text{H}^+_{(\text{aq})}]/[\text{CH}_3\text{COOH}_{(\text{aq})}]$
- B** $K_a = 2[\text{H}^+_{(\text{aq})}]/[\text{CH}_3\text{COOH}_{(\text{aq})}]$
- C** $K_a = [\text{H}^+_{(\text{aq})}]^2/[\text{CH}_3\text{COOH}_{(\text{aq})}]$
- D** $K_a = [\text{CH}_3\text{COOH}_{(\text{aq})}]/[\text{H}^+_{(\text{aq})}]^2$

2. A 0.1-molar solution of acetic acid (CH_3COOH) has a pH of about

- A** 1 **B** 3 **C** 7 **D** 10

3. What is the $[\text{OH}^-]$ of a solution with a pH of 9.0?

- A** $1 \times 10^{-5} \text{ M}$ **B** $1 \times 10^{-9} \text{ M}$ **C** $1 \times 10^{-4} \text{ M}$ **D** $1 \times 10^{-7} \text{ M}$

4. Arrange the following 1 M solutions in order of increasing pH.

HCl KOH CaCl₂ CH₃COOH Na₃PO₄

- A** KOH < CaCl₂ < Na₃PO₄ < CH₃COOH < HCl
B HCl < CaCl₂ < CH₃COOH < KOH < Na₃PO₄
C HCl < CH₃COOH < Na₃PO₄ < CaCl₂ < KOH
D HCl < CH₃COOH < CaCl₂ < Na₃PO₄ < KOH

5. Which best describes the difference between a base and its conjugate acid?

- A.** The base has an additional OH^- ion.
B. The base has an additional H^+ ion.
C. The conjugate acid has an additional OH^- ion.
D. The conjugate acid has an additional H^+ ion.

6. Consider the following equilibrium:



Which of the following correctly identifies the order of Brønsted–Lowry acids and bases?

- A.** base, acid, acid, base
B. acid, base, base, acid
C. acid, base, acid, base
D. base, acid, base, acid

7. Consider the equilibrium:



Which conjugate pair contains the strongest acid and weakest base?

	Strongest Acid	Weakest Base
A.	H_3BO_3	H_2BO_3^-
B.	CO_3^{2-}	HCO_3^-
C.	HCO_3^-	H_2BO_3^-
D.	H_3BO_3	HCO_3^-

8. What is the $[\text{H}_3\text{O}^+]$ of a KOH solution that has a pH of 13.48?

- A. $3.0 \times 10^{13} \text{ M}$ B. $3.3 \times 10^{-14} \text{ M}$ C. 0.30 M D. 0.52 M

9. Consider the following acid equilibrium:



When writing the K_a expression for HCN, why is $\text{H}_2\text{O}(\text{l})$ not included in the expression?

- A. The concentration of $\text{H}_2\text{O}(\text{l})$ is relatively constant.
B. The concentration of $\text{H}_2\text{O}(\text{l})$ does not exist.
C. The concentration of $\text{H}_2\text{O}(\text{l})$ is too small.
D. The concentration of $\text{H}_2\text{O}(\text{l})$ is too large.

10. The K_a for the acid H_2AsO_4^- is 5.6×10^{-8} . What is the value of K_b for HAsO_4^{2-} ?

- A. 3.2×10^{-14} B. 5.6×10^{-22} C. 2.4×10^{-4} D. 1.8×10^{-7}

11. Consider the titration of $\text{CH}_3\text{COOH}(\text{aq})$ with $\text{NaOH}(\text{aq})$. Which of the following net equations accounts for the pH that exists at the equivalence point?
- A. $\text{CH}_3\text{COOH}(\text{aq}) + \text{NaOH}(\text{aq}) \rightleftharpoons \text{NaCH}_3\text{COO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- B. $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightleftharpoons \text{H}_2\text{O}(\text{l})$
- C. $\text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{COOH}(\text{aq}) + \text{OH}^-(\text{aq})$
- D. $\text{CH}_3\text{COOH}(\text{aq}) + \text{OH}^-(\text{aq}) \rightleftharpoons \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$
12. A student wishes to reduce the zinc ion concentration in a saturated zinc iodate solution to $1 \times 10^{-6} \text{ M}$. How many moles of solid KIO_3 must be added to 1.00 liter of solution? ($K_{\text{sp}} \text{Zn}(\text{IO}_3)_2 = 4 \times 10^{-6}$ at 25°C)

- A** 1 mol **B** 0.5 mol **C** 4 mol **D** 2 mol

13. One of the species in the chemical indicator HIn^- exhibits a yellow colour. If acid is added, the indicator turns red. Which of the following is correct?

	Red	Yellow
--	-----	--------

- | | | |
|-----------|-----------------------|-----------------------|
| A. | H_2In | HIn^- |
| B. | In_2^- | H_2In |
| C. | In_2^- | HIn^- |
| D. | HIn^- | H_2In |

14. Consider the following buffer equilibrium system:



What is the net result of adding a small amount of LiOH ?

- A.** The $[\text{HNO}_2]$ increases slightly.
- B.** The pH increases slightly.

- C. The pH decreases slightly.
- D. The $[\text{NO}_2^-]$ decreases slightly.

15. Which of the following would be used to prepare an acidic buffer solution?

- A. HNO_3 and NaNO_3
- B. HF and H_3O^+
- C. H_2S and NaHS
- D. NH_3 and NH_4Cl

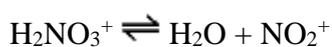
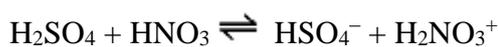
Section B

For each of the questions in this section, one or more of the three numbered statements 1 to 3 may be correct. Decide whether each of the statements is or is not correct (you may find it helpful to put a tick against the statements that you consider to be correct). The responses A to D should be selected on the basis of

A	B	C	D
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

16. The Brønsted-Lowry theory describes acid and base character.

When concentrated sulfuric acid and concentrated nitric acid are mixed, the following reactions occur.



Which species are bases in these reactions?



17. The following reaction takes place using liquid ammonia as a solvent.



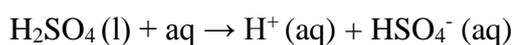
Which statements best explain why this reaction should be classified as a Brønsted-Lowry acid base reaction?

1 The ammonium ion acts as a proton donor.

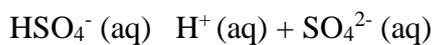
2 Na^+Cl^- is a salt.

3 Ammonia is always basic.

18. Concentrated sulfuric acid behaves as a strong acid when it reacts with water.



The HSO_4^- ion formed behaves as a weak acid.



Which statements are true for 1.0 mol dm⁻³ sulfuric acid?

1 $[\text{H}^+(\text{aq})]$ is high

2 $[\text{SO}_4^{2-}(\text{aq})]$ is high

3 $[\text{HSO}_4^-(\text{aq})] = [\text{SO}_4^{2-}(\text{aq})]$

19. Which statements are correct in terms of the Brønsted-Lowry theory of acids and bases?

- 1 Water can act as either an acid or a base.
- 2 Sulfuric acid, H_2SO_4 , does not behave as an acid when dissolved in ethanol, $\text{C}_2\text{H}_5\text{OH}$.
- 3 The ammonium ion acts as a base when dissolved in liquid ammonia.

20. Which of the following can act as a Bronsted-Lowry acid?

- 1 H_3O^+
- 2 NH_4^+
- 3 H_2O

Section C

Structured Questions

Answer all questions

Candidates answer on the Question Paper

The number of marks is given in brackets () at the end of each question or part question.

26. (a) (i) Using the symbol HZ to represent a Brønsted-Lowry acid, write equations which show the following substances acting as Brønsted-Lowry bases.



.....(1)



(ii) Using the symbol B^- to represent a Brønsted-Lowry base, write equations which show the following substances acting as Brønsted-Lowry acids.



(b) (i) Explain what is meant by a buffer solution.

.....
.....
.....
..... (2)

(ii) Explain how the working of a buffer solution relies on a reversible reaction involving a Brønsted-Lowry acid such as HZ and a Brønsted-Lowry base such as Z^- .

.....
.....
.....
..... (2)

27(a) Propanoic acid, CH_3CH_2COOH , is a weak acid with $K_a = 1.34 \times 10^{-5} \text{ mol dm}^{-3}$.

(i) Calculate the pH of a $0.500 \text{ mol dm}^{-3}$ solution of propanoic acid.

.....
.....
..... (2)

Buffer solution F was prepared by adding 0.0300 mol of sodium hydroxide to 100 cm³ of a 0.500 mol dm⁻³ solution of propanoic acid.

(ii) Write an equation for the reaction between sodium hydroxide and propanoic acid.

.....(1)

(iii) Calculate the concentrations of propanoic acid and sodium propanoate in buffer solution F.

[propanoic acid] =

.....
.....
.....mol dm⁻³ (1)

[sodium propanoate] =

.....
.....
.....mol dm⁻³ (1)

(iv) Calculate the pH of buffer solution F.

pH =

.....
.....(1)

28. (a) Orange juice has a pH of 3.5

(i) Define pH.

.....(1)

(ii) Calculate the molar concentration of hydrogen ions in orange juice.

.....
.....(2)

Orange juice can be titrated with standard alkali.

A 25.0 cm³ sample of orange juice was exactly neutralized by 27.5 cm³ of 0.10 mol dm⁻³ sodium hydroxide using phenolphthalein as indicator.

(b) Assuming orange juice contains a single acid which is monobasic, calculate the molar concentration of the acid in the juice.

.....
.....
.....(1)

(c)(i) How can you explain the difference between the two results you have obtained in (a) (ii) and (b)?

.....
.....
.....(2)

(iii) What constant can be determined from these two values?

.....(1)

(iv) Calculate a numerical value of this constant.

.....
.....
.....
.....(2)

(d) Suggest two reasons why phenolphthalein is a suitable indicator for this titration.

.....
.....
.....
.....(2)

29. A student on a field trip investigates some disused lead workings which have been flooded for some time. The presence of lead (II) ions in the water is to be demonstrated by precipitating yellow lead (II) iodide.

(a) Write down an expression of the solubility product, K_{sp} of lead (II) iodide.

.....(1)

(b) The solubility of lead (II) iodide in water at 15°C is 0.46gdm⁻³. For a saturated solution of lead (II) iodide at 15°C, calculate

(i) the concentration in mol dm⁻³ of lead (II) ions.

.....
.....
.....(2)

(ii) the concentration in mol dm⁻³ of iodide ions.

.....
.....
.....(2)

STOICHIOMETRY ACHIEVEMENT TEST (POST TEST)

Read These Instructions First:

Do not write your name on the question paper and answer sheet.

Answer all questions.

Electronic calculators may be used.

Duration: $1\frac{1}{2}$ hours

Marks : 50

Section A

For each question there are four possible answers, A, B, C, and D. Choose the one you consider to be correct and record your choice by circling in soft pencil on the Answer Sheet.

1. N_2O_4 is a poisonous gas. It can be disposed of safely by reaction with sodium hydroxide.



What is the minimum volume of 0.5mol dm^{-3} $\text{NaOH}(\text{aq})$ needed to dispose of 0.02mol of N_2O_4 ?

A 8cm^3 B 12.5cm^3 C 40cm^3 D 80cm^3

2. Use of the Data Booklet is relevant to this question.

Lead (IV) chloride will oxidize bromide ions to bromine. The Pb^{4+} ions are reduced to Pb^{2+} ions in this reaction. If 6.980g of lead (IV) chloride is added to an excess of sodium bromide solution, what mass of bromine would be produced?

A 0.799g B 1.598g C 3.196g D 6.392g

3. Analytical chemists can detect very small amounts of amino acids down to 3×10^{-21} mol.

How many molecules of an amino acid ($M_r = 200$) would this be?

- A 9 B 200 C 1800 D 40000

4. What volume of 0.1 mol dm^{-3} aqueous silver nitrate reacts with 20 cm^3 of 0.2 mol dm^{-3} barium chloride?

- A 10 cm^3 B 20 cm^3 C 80 cm^3 D 40 cm^3

5. Which of the following contains 1 mol of the stated particles

- A. chlorine molecules in 35.5g of chlorine gas.
B. electrons in 1g of hydrogen gas
C. hydrogen ions in 1 dm^3 of 1 mol dm^{-3} aqueous sulphuric acid.
D. oxygen atoms in 22.4 dm^3 of oxygen gas at s.t.p

6. How many atoms of carbon are present in 18g of glucose $\text{C}_6\text{H}_{12}\text{O}_6$?

- A. 6.0×10^{22} B. 3.6×10^{23} C. 6.0×10^{23} D. 3.6×10^{24}

7. Use of the Data Booklet is relevant to this question.

A sample of potassium oxide, K_2O , is dissolved in 250 cm^3 of distilled water. 25.0 cm^3 of this solution is titrated against sulfuric acid of concentration 2.00 mol dm^{-3} . 15.0 cm^3 of this sulfuric acid is needed for complete neutralization. Which mass of potassium oxide was originally dissolved in 250 cm^3 of distilled water?

- A 2.83g B 28.3g C 47.1g D 56.6g

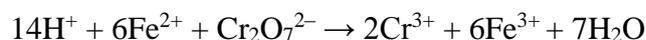
8. Use of the Data Booklet is relevant to this question.

In some countries, anhydrous calcium chloride is used as a drying agent to reduce dampness in houses. The anhydrous salt absorbs enough water to form the dihydrate $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$. What is the percentage increase in mass?

- A 14% B 24% C 32% D 36%

9. Use of the Data Booklet is relevant to this question.

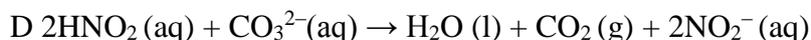
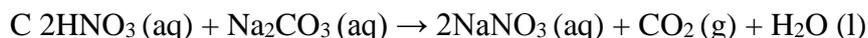
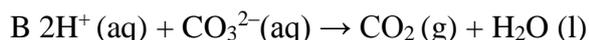
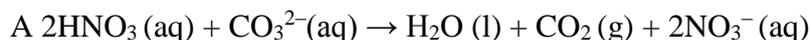
Ferrochrome is an alloy of iron and chromium. Ferrochrome can be dissolved in dilute sulfuric acid to produce a mixture of FeSO_4 and $\text{Cr}_2(\text{SO}_4)_3$. The FeSO_4 reacts with $\text{K}_2\text{Cr}_2\text{O}_7$ in acid solution according to the following equation.



When 1.00g of ferrochrome is dissolved in dilute sulfuric acid, and the resulting solution titrated, 13.1cm^3 of 0.100mol dm^{-3} $\text{K}_2\text{Cr}_2\text{O}_7$ is required for complete reaction. What is the percentage by mass of Fe in the sample of ferrochrome?

- A 1.22 B 4.39 C 12.2 D 43.9

10. What is the ionic equation for the reaction between aqueous sodium carbonate and dilute nitric acid?



11. A sample of 2.00g of iron (III) sulphate, $\text{Fe}_2(\text{SO}_4)_3$, is dissolved in water to give 100cm^3 of aqueous solution. What is the concentration of SO_4^{2-} ions? [The relative formula mass of $\text{Fe}_2(\text{SO}_4)_3$ is 400]

- A. $1.5 \times 10^{-3}\text{M}$ B. $5 \times 10^{-3}\text{M}$ C. $1.5 \times 10^{-2}\text{M}$ D. $1.5 \times 10^{-1}\text{M}$

12. How many oxygen atoms are there in 22.0 g of carbon dioxide?

- A. 1.42×10^{24} B. 6.02×10^{23} C. 1.20×10^{24} D. 5.09×10^{23}

13. The empirical formula for an oxide of nitrogen that is 30.4% by mass nitrogen is

- A. NO B. NO₂ C. N₂O D. NO₄

14. In some fireworks there is a reaction between powdered aluminium and powdered barium nitrate in which heat is evolved and an unreactive gas is produced.

What is the equation for this reaction?

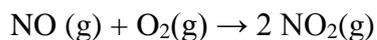
- A. $2\text{Al} + \text{Ba}(\text{NO}_3)_2 \rightarrow \text{Al}_2\text{O}_3 + \text{BaO} + 2\text{NO}$
- B. $4\text{Al} + 4\text{Ba}(\text{NO}_3)_2 \rightarrow 2\text{Al}_2\text{O}_3 + 4\text{Ba}(\text{NO}_2)_2 + \text{O}_2$
- C. $10\text{Al} + 3\text{Ba}(\text{NO}_3)_2 \rightarrow 5\text{Al}_2\text{O}_3 + 3\text{BaO} + 3\text{N}_2$
- D. $10\text{Al} + 18\text{Ba}(\text{NO}_3)_2 \rightarrow 10\text{Al}(\text{NO}_3)_3 + 18\text{BaO} + 3\text{N}_2$

15. The petrol additive tetraethyl-lead (IV), Pb(C₂H₅)₄, is now banned in many countries.

When it is completely burned in air, lead (II) oxide, CO₂ and H₂O are formed. How many moles of oxygen are required to burn one mole of Pb(C₂H₅)₄?

- A** 9.5 **B** 11 **C** 13.5 **D** 27

16. Nitrogen oxide is oxidized in air to give brown nitrogen dioxide.



If you have 2.2 moles of NO,

- A. you need 2.2 moles of O₂ for complete reaction and produce 2.2 moles of NO₂.
- B. you need 1.1 moles of O₂ for complete reaction and produce 2.2 moles of NO₂.
- C. you need 1.1 moles of O₂ for complete reaction and produce 3.3 moles of NO₂.
- D. you need 1.0 moles of O₂ for complete reaction and produce 2.0 moles of NO₂.

17. Given the equation: $2\text{KOH}_{(\text{aq})} + \text{H}_2\text{SO}_{4(\text{aq})} \Rightarrow \text{K}_2\text{SO}_4 + 2\text{H}_2\text{O}_{(\text{l})}$

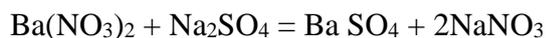
20.0 cm³ of a sulphuric acid solution was titrated with a standardized solution of 0.0500 mol dm⁻³ (0.05M) potassium hydroxide. Using phenolphthalein indicator for the titration, the acid required 36.0 cm³ of the alkali KOH for neutralization what was the concentration of the acid?

- A** 0.035M **B** 0.090M **C** 0.069M **D** 0.045M

18. A 20.0 cm³ sample of 0.200M Na₂CO₃ solution is added to 30.0cm³ of 0.400M Sr(NO₃)₂ solution. Strontium carbonate precipitates. The concentration of strontium ion, Sr²⁺, in solution after reaction is

- A** 0.15M **B** 0.16M **C** 0.20M **D** 0.24M

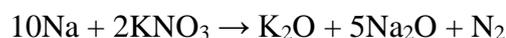
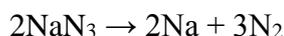
19. Consider the titration involving the following reaction:



25.00 mL of Na₂SO₄ was placed in a flask. This solution was titrated with 0.1500 M Ba(NO₃)₂ solution. It was found that 30.00 mL of Ba(NO₃)₂ was needed for complete reaction. Calculate the molarity of the Na₂SO₄ solution.

- A.** 0.0900 M **B.** 0.360 M **C.** 0.150 M **D.** 0.180 M

20. On collision, airbags in cars inflate rapidly due to the production of nitrogen. The nitrogen is formed according to the following equations.



How many moles of nitrogen gas are produced from 1 mol of sodium azide, NaN_3 ?

- A** 1.5 **B** 1.6 **C** 3.2 **D** 4.0

Section B

For each of the questions in this section, one or more of the three numbered statements 1 to 3 may be correct. Decide whether each of the statements is or is not correct (you may find it helpful to put a tick against the statements that you consider to be correct). The responses A to D should be selected on the basis of

A	B	C	D
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

21. On a scale in which the mass of a ^{12}C atom is 12 the relative molecular mass of a particular sample of chlorine is 72. Which properties of the atoms in this sample are always the same?

1 radius

2 nucleon number

3 isotopic mass

22. Consider the hypothetical chemical reaction represented by the equation



Which of the following is a correct interpretation of this equation?

1. 3 grams of A react with 2 grams of B to form 1 gram of A_3B_2
2. 3 atoms of A react with 2 atoms of B to form 1 molecule of A_3B_2
3. 3 moles of A react with 2 moles of B to form 1 mole of A_3B_2

23. Which of the following statements is true

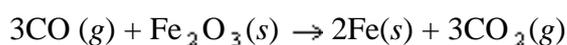
1. the molar mass of $CaCO_3$ is 100g/mol
2. 50g of $CaCO_3$ contains 9×10^{23} oxygen atoms.
3. a 200g sample of $CaCO_3$ contains 2 mol of $CaCO_3$

24. Which of the following is true about the total number of reactants and the total number of products in the reaction shown below?



1. 9 moles of reactants chemically change into 11 moles of product.
2. 9 grams of reactants chemically change into 11 grams of product.
3. 9 liters of reactants chemically change into 11 liters of product.

25. Which statement is true if 12 mol CO and 12 mol Fe_2O_3 are allowed to react?



1. The limiting reagent is CO and 8.0 mol Fe will be formed.
2. The limiting reagent is CO and 3.0 mol CO_2 will be formed.
3. The limiting reagent is Fe_2O_3 and 24 mol Fe will be formed.

Section C

Structured Questions

Answer all questions

Candidates answer on the Question Paper

The number of marks is given in brackets [] at the end of each question or part question.

26. The major ore of barium is barytes, BaSO_4 . This is very unreactive, and so other barium compounds are usually made from the sulfide, BaS . This is obtained by heating the crushed ore with carbon, and extracting the BaS with water.



When 250 g of ore was heated in the absence of air with an excess of carbon, it was found that the CO produced took up a volume of 140 dm^3 at 450 K and 1 atm .

(i) Calculate the number of moles of CO produced.

.....[2]

(ii) Calculate the number of moles of BaSO_4 in the 250 g sample of the ore.

.....[2]

(iii) Calculate the percentage by mass of BaSO_4 in the ore.

.....[2]

27. When crystals of ammonium dichromate $[(\text{NH}_4)_2\text{Cr}_2\text{O}_7]$, are heated strongly they decompose fully according to the balanced equation :



When 12.6g of the crystals were heated strongly, calculate:

(a) The moles of ammonium dichromate that reacted.

.....
.....
.....[3]

(b) The mass of chromium III oxide [Cr₂O₃] formed.

.....
.....
.....[2]

(c) The volume at stp of nitrogen gas evolved.

.....
.....
.....[3]

d(i) The number of molecules of water produced.

.....
.....
.....
.....[2]

(ii) How many atoms did this quantity of water contain?

.....
.....
.....
.....[2]

28. In a titration between dilute sulfuric acid and 0.1 molar sodium hydroxide, 21.70 cm³ of the sodium hydroxide was needed to neutralize 25.00 cm³ of the dilute sulfuric acid.

(a) Write a balanced equation for this reaction.

.....
..... [1]

(b) Calculate the molar concentration of the acid in mol dm⁻³:

.....
.....
.....[3]

29. Hydrated zinc sulphate can be represented by the formula $\text{ZnSO}_4 \cdot x\text{H}_2\text{O}$. In an experiment 3.51 g of hydrated zinc sulphate were heated and 1.97 g of anhydrous zinc sulphate were obtained. Use these data to calculate the value of the integer x in $\text{ZnSO}_4 \cdot x\text{H}_2\text{O}$.

.....
.....
.....
.....
.....[3]

IONIC EQUILIBRIA ACHIEVEMENT TEST (POST TEST)

Read These Instructions First:

Do not write your name on the question paper and answer sheet.

Answer all questions.

Electronic calculators may be used.

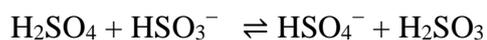
Duration: **1½ hours**

Marks: 50

Section A

For each question there are four possible answers, A, B, C, and D. Choose the one you consider to be correct and record your choice by circling in soft pencil on the Answer Sheet.

1. Consider the equilibrium:



Identify the two Brønsted–Lowry bases.

A. HSO_4^- and H_2SO_4

B. HSO_3^- and H_2SO_3

C. HSO_3^- and HSO_4^-

D. HSO_4^- and H_2SO_3

2. Water will react as an acid most completely with which of the following?

A. HCO_3^-

B. NH_2^-

C. PO_4^{3-}

D. SO_4^{2-}

3. The conjugate base of HBO_3^{2-} is

- A. H_2BO_3^- B. BO_3^{2-} C. BO_3^{3-} D. HBO_3^-

4. Consider the following equilibrium at 25 °C:



What happens to $[\text{OH}^-]$ and pH as 0.1 M HCl is added?

A. $[\text{OH}^-]$ increases and pH decreases.

B. $[\text{OH}^-]$ decreases and pH increases.

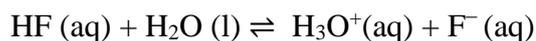
C. $[\text{OH}^-]$ decreases and pH decreases.

D. $[\text{OH}^-]$ increases and pH increases.

5. What is the pH of a 2.5 M KOH solution?

- A. 14.40 B. -0.40 C. 0.40 D. 13.60

6. Consider the following buffer equilibrium:



What would limit the buffering action if acid were added?

- A. $[\text{HF}]$ B. $[\text{F}^-]$ C. $[\text{H}_3\text{O}^+]$ D. $[\text{H}_2\text{O}]$

7. What is the solubility constant expression for $\text{Zn}_3(\text{PO}_4)_2$?

A $K_{\text{sp}} = [\text{Zn}^{2+}][\text{PO}_4^{3-}]$

B $K_{\text{sp}} = [\text{Zn}^{2+}][2\text{PO}_4^{3-}]$

C $K_{\text{sp}} = [\text{Zn}^{2+}]^3[\text{PO}_4^{3-}]^2$

D $K_{\text{sp}} = [3\text{Zn}^{2+}]^3[2\text{PO}_4^{3-}]^2$

8. How would the concentration of $\text{Pb}^{2+}(\text{aq})$ ions in equilibrium with $\text{PbI}_2(\text{s})$ be affected if the concentration of $\text{I}^{-}(\text{aq})$ ions were doubled?

A no change

B increased by a factor of 2

C decreased by a factor of 2

D decreased by a factor of 4

9. Which set below contains only weak acids?

A $\text{HC}_2\text{H}_3\text{O}_2$, HCN , HNO_2

B $\text{HC}_2\text{H}_3\text{O}_2$, HCN , HNO_3

C $\text{HC}_2\text{H}_3\text{O}_2$, HCl , HNO_2

D HClO , HCN , HBrO_3

10. A 0.1-molar solution of propanoic acid (CH_3COOH) has a pH of about

A 1 **B** 3 **C** 7 **D** 10

11. Which best describes the difference between a base and its conjugate acid?

A. The base has an additional OH^{-} ion.

B. The base has an additional H^{+} ion.

C. The conjugate acid has an additional OH^{-} ion.

D. The conjugate acid has an additional H^{+} ion.

12. The ionization of water is endothermic. Which of the following could be correct if the temperature of water is decreased?

	K_w	pH	Classification
A.	stays the same	7.0	neutral
B.	decreases	7.1	basic

A	B	C	D
1, 2 and 3 Are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

16. Four samples of rain are collected from different geographic regions and the pH is measured for each sample. Which of the samples would be classified as acid rain?

Sample	pH
1	2.8
2	4.0
3	6.2

17. Which of the following are strong acids?

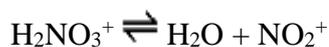
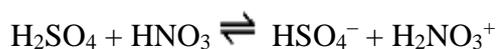
1. HI
2. HNO₃
3. HBr

18. Which of the following would you predict to be basic when dissolved in water?

- 1 Ammonium iodide NH₄I
- 2 Sodium bicarbonate NaHCO₃
- 3 Sodium hypochlorite NaOCl

19. The Brønsted-Lowry theory describes acid and base character.

When concentrated sulfuric acid and concentrated nitric acid are mixed, the following reactions occur.



Which species are bases in these reactions?

20. Which statements are correct in terms of the Brønsted-Lowry theory of acids and bases?

- 1 Water can act as either an acid or a base.
- 2 Sulfuric acid does not behave as an acid when dissolved in ethanol, C₂H₅OH.
- 4 The ammonium ion acts as a base when dissolved in liquid ammonia

Section C

Structured Questions

Answer all questions

Candidates answer on the Question Paper

The number of marks is given in brackets () at the end of each question or part question.

21. (a) Sulphuric acid is a strong acid. Explain what this means?

.....
.....
.....(2)

(b)(i) 20g of calcium carbonate reacts with excess dilute sulphuric acid. Write a balanced equation for this reaction.

.....
.....(3)

(ii) Calculate the volume of carbon dioxide produced at STP.

.....
.....
.....
.....(3)

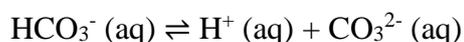
(c) What is a standard solution?

.....
.....(2)

(d) What is a Bronsted-Lowry acid?

.....
.....(2)

22. Water from Lake Kariba contains dissolved sodium carbonate and sodium hydrogen carbonate. The following equilibrium exists:



(a) Explain how this solution acts as a buffer on the addition of acid or alkali.

.....
.....
.....
.....
.....
.....[4]

23. (a) Write an expression for the solubility product of calcium hydroxide, $\text{Ca}(\text{OH})_2$.

.....
.....(2)

(b) A 20cm^3 sample of saturated aqueous calcium hydroxide require 18.2 cm^3 of 0.05mol dm^{-3} hydrochloric acid for neutralization. Calculate

(i) The hydroxide ion concentration of the saturated solution.

.....
.....
.....
.....
.....(3)

(ii) The pH of the saturated solution.

.....
.....
.....

.....
.....(3)

(iii) The value for the solubility product of calcium hydroxide, stating the units.

.....
.....
.....
.....
.....
.....(3)

24. Define the term K_w and explain why, at 25°C water has a pH of 7.

.....
.....
.....
.....
.....
.....
.....(3)

APPENDIX B: INTERVIEW GUIDE FOR TEACHERS

1. How do your students perform in stoichiometry/ionic equilibria problems?
2. Do you probe students understanding of the underlying chemical concepts that are prerequisite in order for the students to solve stoichiometric/ ionic equilibria problems proficiently?
3. Is the teaching of stoichiometry / ionic equilibria to students a difficult thing to do?
4. What is problem solving in chemistry?
5. Why do students not do well in solving stoichiometry /ionic equilibria problems if so?
6. How do you normally introduce the topics to your students?
7. What are the major difficulties faced by students when solving stoichiometry/ ionic equilibria problems?
8. What factors contribute to students' success in solving stoichiometry/ ionic equilibria problems?
9. Is there any effect of students' understanding of the concept of mole on their performance in stoichiometry/ ionic equilibria problem solving?
10. What is the effect of students' mathematical ability on their performance in stoichiometry/ ionic equilibria problem solving?
11. How can learners acquire problem solving skills for chemistry problem solving?
12. What strategies do learners use in chemistry problem solving?
13. Do you think it is good to incorporate problem solving in chemistry classrooms?
14. Can problem solving instruction enhance learners' performance in stoichiometry and ionic equilibria? How and Why?
15. How can you teach your learners through a problem solving approach?
16. Do you think there are challenges in implementing problem solving instruction in a chemistry class?

APPENDIX C: FOCUS GROUP DISCUSSION GUIDE FOR LEARNERS

1. Is the topic stoichiometry/ionic equilibria important in chemistry? Why?
2. In your own view, is stoichiometry/ ionic equilibria a difficult topic?
3. What major difficulties do you encounter in learning stoichiometry/ ionic equilibria?
4. In your own view, what factors contribute to students' success in solving stoichiometry/ ionic equilibria problems?
5. Does an understanding of the concept of mole affect proficiency in stoichiometry/ ionic equilibria problem solving?
6. Does mathematical ability influence proficiency in stoichiometry/ ionic equilibria problem solving?
7. In your own understanding, what is problem solving in chemistry?
8. Do you think problem solving is important in chemistry? Why?
9. What methods do you use in chemistry for problem solving?
10. How can learners in a chemistry class learn problem solving skills?
11. Do you think problem solving strategies can improve your performance in stoichiometry /ionic equilibria?

APPENDIX D: OBSERVATION SCHEDULE

OBSERVATION FOCUS	FOCUS VARIABLE
TEACHERS	<ol style="list-style-type: none"> 1. Type of instructional approach/strategy used by the teacher 2. Problem-solving strategies employed 3. Quality of teacher- learner interaction 4. Stages in the lesson where teacher incorporated problem solving strategies 5. Determine how the teacher developed problem –solving skills in learners 6. Identify tendencies of teachers to rely on routine procedures of solution
CONTROL GROUP	<ol style="list-style-type: none"> 1. Problem –solving strategies and approaches 2. Involvement / contribution/ participation of learners during lesson. 3. Level of exposition of previously acquired knowledge. 4. Challenges faced during problem solving.
EXPERIMENTAL GROUP	<ol style="list-style-type: none"> 1. How learners react to the problem –solving model used. 2. How learners adapted to the problem solving models. 3. How the treatment influenced learners problem solving skills. 4. Challenges faced due to exposure to the treatment 5. Learners experiences in learning new strategies for problem solving

APPENDIX E: CONSENT LETTERS

Letter to Permanent Secretary Ministry of Primary and Secondary Education

Mr Mandina Shadreck
House N^o 448
Senga Area II
Gweru , Zimbabwe
16 September 2014

The Permanent Secretary
Ministry of Primary and Secondary Education
P Bag 9068
Causeway
Harare

Dear Sir/Madam

Request For Permission To Conduct A Research In Gweru Urban District Of Midlands Province.

I am an educator at the above mentioned university and currently studying for a Doctoral degree with UNISA in Science, Mathematics and Technology Education with a specialization in Chemistry Education. My student number is 55761437. The major component of the study is to carry out a research, therefore I am requesting for permission to conduct a research in the three schools in Gweru district. The topic of study is: **The impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria.** The purpose of the study is to investigate the impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria. The study seeks to further explore the teaching strategies that can be used to enhance the performance of learners in chemistry. The findings of the study will help chemistry educators to make informed decision on teaching strategies that can be used to improve the performance of learners in chemistry. I have randomly selected three high schools in Gweru district for this study and hope my request will be considered. The period of research is from January – June 2015.

For more information feel free to contact me or my supervisor on the below contact details

Prof C.E. Ochonogor (0216801570)

ochonogorc@cput.ac.za

Thanks in anticipation of your cooperation.

Yours faithfully

Mandina Shadreck.

Mandina Shadreck (0773470556)

mandinas@msu.ac.zw

Letter to High School Headmasters

Mr Mandina Shadreck
House N^o 448
Senga Area II
Gweru, Zimbabwe
16 September 2014

The Principal
High School A
P Bag 5054
Gweru

Dear Sir/Madam

Request for Permission to Conduct Research study at your School

I am writing to request for permission to conduct a research study in your school. I am currently studying for a Doctoral degree with UNISA in Science, Mathematics and Technology Education with a specialization in Chemistry Education. My student number is 55761437. The topic of study is: **The impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria**. I have selected your school because it can provide data that I need for this study. The findings of the study will help chemistry educators to make informed decision on teaching strategies that can be used to improve the performance of learners in chemistry. During the study, learner will be taught using different teaching strategies after which they will be assessed using validated achievement tests in stoichiometry and ionic equilibria. I have already requested for permission from the permanent secretary in the Ministry of primary and secondary education and assure that there will be no class interruption and disturbance during the study.

For more information feel free to contact me or my supervisor on the below contact details

Prof C.E. Ochonogor
ochonogorc@cput.ac.za
0216801570

Mandina Shadreck
mandinas@msu.ac.zw
0773470556

Thanks in anticipation of your cooperation.

Yours faithfully

Mandina Shadreck.

Consent Letter for learners

Mr Mandina Shadreck
House N^o 448
Senga Area II
Gweru, Zimbabwe
16 September 2014

To whom it may Concern

Dear Sir/Madam

I am conducting a research study for a Doctoral degree with UNISA in Science, Mathematics and Technology Education with a specialization in Chemistry Education. My research topic is: **The impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria.** The purpose of the study is to investigate the impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria. The study seeks to further explore the teaching strategies that can be used to enhance the performance of learners in chemistry. Participation in this study is voluntary and you are free to withdraw from the study at any time without any consequences or punishment. As a participant in this study your identification will remain anonymous and the information you supply will remain confidential and will not be used for any other purposes other than for the purposes of this research.

For more information feel free to contact me or my supervisor on the below contact details

Prof C.E. Ochonogor
ochonogorc@cput.ac.za
0216801570

Mandina Shadreck
mandinas@msu.ac.zw
0773470556

Thanks in anticipation of your cooperation.

Yours faithfully

Mandina Shadreck.

Iam aware of the purposes and procedures of this study and hereby agree to participate. I am also aware that my participation is voluntary and that I can withdraw my participation at any time if I so wish.

.....
.....

Signature

Date

Consent Letter for teachers

Mr Mandina Shadreck
House N^o 448
Senga Area II
Gweru, Zimbabwe
16 September 2014

To whom it may Concern

Dear Sir/Madam

I am conducting a research study for a Doctoral degree with UNISA in Science, Mathematics and Technology Education with a specialization in Chemistry Education. My research topic is: **The impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria.** The purpose of the study is to investigate the impact of two problem-solving strategies on the performance of A' level Chemistry learners in stoichiometry and ionic equilibria. The study seeks to further explore the teaching strategies that can be used to enhance the performance of learners in chemistry. I intend to work with A level chemister teachers and. I therefore ask for your permission to participate in this research. As a teacher, you will be observed together with the learners that you will be teaching. At the end of all lessons you will also be interviewed by the researcher to provide your views and ideas on the implementation of the problem solving approach. Interviews will be conducted between 1600H and 1700H, after contact time. Participation in this study is voluntary and you are free to withdraw from the study at any time without any consequences or punishment. As a participant in this study your identification will remain anonymous and the information you supply will remain confidential and will not be used for any other purposes other than for the purposes of this research.

For more information feel free to contact me or my supervisor on the below contact details

Prof C.E. Ochonogor
ochonogorc@cput.ac.za
0216801570

Mandina Shadreck
mandinas@msu.ac.zw
0773470556

Thanks in anticipation of your cooperation.

Yours faithfully

Mandina Shadreck.

Consent forms: To the School Head and to all the participating teachers

I (please print your name in full) the principal/ an Advanced level chemistry teacher agree to be a participant in the research conducted by Shadreck Mandina in which he will be investigating “**the effect of two problem solving strategies on the performance of A level chemistry learners’ in stoichiometry and ionic equilibria**”.

I give consent to the following:

My school to participate in the research. Yes or No (use a cross to indicate your selection)

To give lessons in my class(es) for problem solving activities.

Yes or No (use a cross to indicate your selection)

To administer an achievement test in my class(es). Yes or No (use a cross to indicate your selection)

To be interviewed. Yes or No (use a cross to indicate your selection)

To be observed during lessons. Yes or No (use a cross to indicate your selection)

Signed :

Date :

APPENDIX F: CLEARANCE FROM MINISTRY

All communications should be addressed to
"The Secretary for Primary and Secondary
Education"
Telephone: 799914 and 705153
Telegraphic address : "EDUCATION"
Fax: 791923



Reference: C/426/3 Midlands
Ministry of Primary and
Secondary Education
P.O Box CY 121
Causeway
Harare
ZIMBABWE

2 March 2015

Mandina Shadreck
House No. 448
Senga Area 2
Gweru

**RE: PERMISSION TO CARRY OUT RESEARCH IN MIDLANDS PROVINCE:
GWERU DISTRICT: GWERU DISTRICT HIGH SCHOOLS**

Reference is made to your application to carry out a research at the above mentioned schools in Midlands Province on the research title:

**"USING PROBLEM-SOLVING APPROACHES TO IMPROVE THE TEACHING OF
STOICHIOMETRY AND ICONIC EQUILIBRA AT ADVANCED LEVEL DISTRICT"**

Permission is hereby granted. However, you are required to liaise with the Provincial Education Director Midlands, who is responsible for the schools which you want to involve in your research.

You are required to provide a copy of your final report to the Secretary for Primary and Secondary Education by June 2015.

A handwritten signature in black ink, appearing to be 'P. Muzawazi'.

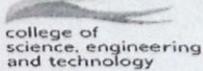
P. Muzawazi

Director: Policy Planning, Research and Development

For: **SECRETARY FOR PRIMARY AND SECONDARY EDUCATION**

cc: PED – Midlands Province

APPENDIX G: ETHICAL CLEARANCE

UNISA | 
college of science, engineering and technology
Date: 2014-09-10

Dear Mr Mandina, S. (55761437)

Application number:
2014_CGS/ISTE_014

REQUEST FOR ETHICAL CLEARANCE: (Using Problem-solving approaches to improve the teaching of stoichiometry and ionic equilibria at advanced level.)

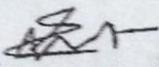
The College of Science, Engineering and Technology's (CSET) Research and Ethics Committee has considered the relevant parts of the studies relating to the abovementioned research project and research methodology and is pleased to inform you that ethical clearance is granted for your research study as set out in your proposal and application for ethical clearance.

Therefore, involved parties may also consider ethics approval as granted. However, the permission granted must not be misconstrued as constituting an instruction from the CSET Executive or the CSET CRIC that sampled interviewees (if applicable) are compelled to take part in the research project. All interviewees retain their individual right to decide whether to participate or not.

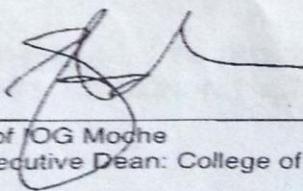
We trust that the research will be undertaken in a manner that is respectful of the rights and integrity of those who volunteer to participate, as stipulated in the UNISA Research Ethics policy. The policy can be found at the following URL:
http://cm.unisa.ac.za/contents/departments/res_policies/docs/ResearchEthicsPolicy_apprvCounc_21Sept07.pdf

Please note that the ethical clearance is granted for the duration of this project and if you subsequently do a follow-up study that requires the use of a different research instrument, you will have to submit an addendum to this application, explaining the purpose of the follow-up study and attach the new instrument along with a comprehensive information document and consent form.

Yours sincerely



Prof Ernest Mnkandla
Chair: College of Science, Engineering and Technology Ethics Sub-Committee



Prof JOG Moghe
Executive Dean: College of Science, Engineering and Technology

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2015 -02- 13
OFFICE OF THE EXECUTIVE DEAN
College of Science, Engineering
and Technology

