EVALUATING PROBLEM SOLVING PROFICIENCY OF GRADE 12 PHYSICAL SCIENCE LEARNERS IN HIGHVELD RIDGE EAST AND WEST CIRCUITS WHEN SOLVING STOICHIOMETRY PROBLEMS

By

EDWIN TIGERE

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ABSTRACT

The aim of this study was to evaluate the problem solving proficiency of Physical Science learners in Highveld Ridge East circuits in Mpumalanga Province of South Africa. The objectives of this study were to determine the relationship between proficiency in conceptual and algorithmic problem solving, to compare the percentage of algorithmic and conceptual problems that were correctly and incorrectly answered, problems not attempted at all and finally to categorize Physical Science learners according to their stoichiometry problem solving proficiencies. The target population for this study was Grade 12 Physical Science learners in Highveld Ridge East and West circuit in Mpumalanga Province of South Africa. To achieve the aim of this study and its subsequent objectives random sampling was used to select the three schools and the sample after a stoichiometry achievement test was administered by Physical Science teachers, who were teaching the participants at their respective schools. The researcher scored the tests using a memorandum.

The results of this study indicated that learners' proficiency in both algorithmic and conceptual problem solving was low, there was a weak positive correlation between algorithmic and conceptual

problem solving proficiency, the percentage of solutions that were correctly solved was the lowest compared to the percentage of incorrect solutions and problems not attempted. The other result of this study was that there were no grade 12 Physical Science learners with high algorithmic and high conceptual abilities, a few learners had high algorithmic and low conceptual abilities and the majority of the learners had low algorithmic and low conceptual problem solving abilities. This implies that Physical Science teachers in these circuits should focus on developing both algorithmic and conceptual problem solving strategies when teaching stoichiometry.

Declaration

Student number 43331181

I declared that **EVALUATING PROBLEM SOLVING PROFICIENCY OF GRADE 12 PHYSICAL SCIENCE LEARNERS IN HIGHVELD RIDGE EAST AND WEST CIRCUITS WHEN SOLVING STOICHIOMETRY PROBLEMS** 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.

…………………………… ………………

Signature Date

Mr. E Tigere

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CHAPTER 1

1 Overview of the study

1.1 Introduction

Problem solving has been widely investigated by educational researchers in an effort to help learners improve their problem solving skills. The advantages of problem solving may be implemented anywhere as long as the environment enables the learners to express their own understanding of the problem. These include determining whether the information given is sufficient or there is need to solve sub-goals; using their prior knowledge and sharing their problem solving strategies and solutions with their peers (Ministry of National Education, as cited in Karaoglan, 2009). In stoichiometry, the advantage of problem solving is that it supports and elucidates concepts (Selvaratnam & Canagarama, 2008). This begins in high school when stoichiometry is introduced to learners. It is in high school where learners are either motivated or demotivated to learn stoichiometry, develop a positive or negative attitude towards stoichiometry and learn to solve stoichiometry problems mechanically or conceptually. All these factors affect learners' proficiency in solving stoichiometry problems hence high school education is critical in the acquisition of proficiency in stoichiometry.

Proficiency in solving stoichiometry problems is important because it is one of the factors that determine learners' achievement in chemical equilibrium, acids and bases problems at high school, and analytical chemistry at tertiary education. In the chemical industry, proficiency in solving stoichiometry problems is required, for example, to determine the quantities of reactants, products, levels of water, air and ground pollution. However, acquisition of problem solving proficiency in stoichiometry is affected by the way the topic was taught, the worked examples learners encountered, prior knowledge, metacognition and the mathematical skills of the learners.

Proficiency in solving stoichiometry problems was previously investigated by Chui (2001), Schmidt (1994), Toth and Sebestyen (2009) as well as Yilmaz, Tuncer and Alp (2007). BouJaude and Barakat (2003) investigated stoichiometry problem solving proficiency of learners from a highly selective school with academically gifted learners. Unlike the study conducted by BouJaude and Barakat (2003) this study investigated proficiency in stoichiometry problem solving among learners with mixed academic abilities and from varied socio-economic status.

In South Africa, when investigating concepts inventory of Grade 12 learners up to foundation year students, Potgieter, Rogan and Howie (2005) reported that first year tertiary students perform poorly in stoichiometry. This was confirmed by Potgieter and Davidowitz (2010). However, participants in these studies were tertiary students and high school learners from Gauteng Province in South Africa only. One of the intentions of this study is to establish whether the performance of Physical Science learners in Highveld Ridge East and West circuits was the same as the performance of participants identified in the literature.

Another aspect of stoichiometry problem solving previously investigated was the relationship between algorithmic and conceptual achievements. Stamovlasis, Tsaparlis, Kamilatos, Papavikonomau and Zarotiadou (2005) reported that there is no relationship between algorithmic and conceptual achievements whereas Dahsah and Coll, (2008) claim that there is a positive relationship. An additional objective of this study is to determine whether there is a relationship between algorithmic and conceptual problem solving achievement and identify whether the relationship is consistent with the findings of studies that have been conducted before.

The categorization of learners according to their problem solving proficiencies is a further aspect of stoichiometry problem solving that is located in literature. Chui (2001) and Yilmaz, Tuncer and Alp (2007) categorize learners as high conceptual and high algorithmic problem solvers while Stamovlasis et al (2005) categorize learners as high algorithmic and low conceptual problem solvers. This study seeks to categorize Physical Science learners in Highveld Ridge East and West circuits according to their stoichiometry problem solving proficiency and subsequently to compare the categorization to the findings of studies that have been previously conducted.

1.2 Context

This study was conducted in Highveld Ridge East and West circuits in Mpumalanga Province, South Africa, after Grade 12 Physical Science learners had completed their study of stoichiometry and were preparing for their Trial examinations. These Grade 12 learners were introduced to stoichiometry during the second quarter of Grade 10 and were taught mole concept in one hour, molecular masses and formula masses, determination of composition of substances, amounts of substances, percentage yield and basic stoichiometric calculations. In Grade 11 the learners were taught stoichiometry in the second quarter of the year and during that time they were taught the following stoichiometric concepts; molar volumes of gases or volume relationships in gaseous reactions and the limiting reagents. During the period after the second quarter of Grade 10 and the second quarter of Grade 11 the learners were taught Physics topics and Chemistry topics. During Grade 12, these learners used the mole concept and concentration knowledge learnt in Grades 10 and 11 to determine equilibrium constants or use equilibrium constants to calculate initial amounts of reactants. This is normally accomplished by completing a table. The Physical Science textbooks mostly used in Highveld Ridge East and West circuits solve stoichiometry problems using the mole and the proportionality methods. Lastly, there were no special admission requirements for learners to study Physical Science apart from passing Grade 9.

1.3 Problem statement

Huddle and Pillary (1996) claim that 25% of students failed to solve chemical equilibrium problems because they ignored stoichiometry concepts. This report highlights the need to examine proficiency in stoichiometry problem solving because success in solving chemical equilibrium problems is dependent on the problem solver's proficiency in solving stoichiometry problems. Proficiency in stoichiometry problem solving also affects the proficiency in solving acids and bases problems.

Mphachoe (2009) suggested that Physical Science teachers in Mpumalanga Province, where Highveld Ridge East and West circuits are situated should assist learners to represent stoichiometry problems. In 2012 Mphachoe stated that learners in Mpumalanga Province who wrote the National Curriculum Statement Physical Science Paper 2 failed to correctly answer question 7.2 below:

An engineer injects 5 moles of nitrogen and 5 moles of hydrogen into a container and equilibrium was reached at 450^0C after a *while. Upon analysis of the equilibrium mixture the engineer finds that the mass of* NH_3 *was 20,4g. Calculate the value of the equilibrium constant at* 450^0C.

The reason the learners could not solve this problem was the stoichiometry part of the problem. The weakness of the surveys conducted by Mphachoe is that she did not specify whether she reached these conclusions from descriptive statistics or inferential statistics. Therefore, these results cannot be generalized to the population which includes learners from Highveld Ridge East and West circuits.

As previously stated, in Mpumalanga Province, Physical Science learners begin studying stoichiometry in Grade 10 and its continued in Grade 11 and applied in Grade 12. Since problem solving should be an integral part of teaching Physical Science learners in Highveld Ridge East and West circuits are expected to have learnt to solve stoichiometry problems in Grades 10 and 11. However, in Grade 10 only one hour is allocated to teach the atomic mass and the mole concept. This study again seeks to determine the proficiency of learners in stoichiometry.

In South Africa an essential chemistry concept that is inadequately mastered by students and learners is stoichiometry (Potgieter &

Davidowitz, 2010). This assertion concurs with a study conducted by Potgieter, Rogan and Howie (2005) who found that first year students in South Africa perform poorly in stoichiometry and mole concepts. The studies cited above were conducted in tertiary institutions. Consequently, it is significant to examine learners' proficiency in solving stoichiometry problems in South African high schools because prior knowledge is a determinant factor of learning in any given situation (Ausubel, 1968). The studies cited above also do not reveal whether there is a relationship or not between algorithmic problem solving and conceptual problem solving in stoichiometry. Teaching of stoichiometry requires good teaching practice.

Okanlawon (2010) suggests that in order to teach stoichiometry; a teacher must not only have a concrete understanding of stoichiometry, but a sound knowledge of effective pedagogical practice relative to Chemistry. However, Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) claim that in South Africa, Physical Science teachers view Chemistry as a group of facts to be mastered alongside with algorithms. Teachers thus have to be trained to approach the teaching of Chemistry from a conceptual viewpoint. According to Selvaratnam (2011) 40% of 73 Physical Science teachers from Dinaledi schools (Schools that provide extra tuition in Mathematics and Physical Science) in KwaZulu Natal and the Eastern Cape Provinces failed problem-solving tests. The African National Congress discussion paper of 1991 noted that Physical Science teachers in South Africa were unlikely to develop process skills and conceptual thinking in their learners because of their low qualifications. If Physical Science teachers, lack conceptual understanding of the subject, the ability to develop conceptual understanding in learners is compromised (Gabel & Sherwood, 1983). Additionally, an over reliance on traditional teaching methods has contributed to learners' lack of proficiency in stoichiometry. Based on this evidence, it is necessary to investigate the proficiency of learners in an abstract topic like stoichiometry. The aim of the study was as follows.

1.4 Aim and objectives of the study

The aim of this study was to evaluate problem solving proficiency of Grade 12 Physical Science learners in Highveld Ridge East and West circuits in solving stoichiometry problems. The following objectives were used to attain the above mentioned aim:

(i) To determine the relationship between proficiency in conceptual and algorithmic problem solving strategies.

(ii) To categorize Grade 12 Physical Science learners in

Highveld Ridge East and West circuits according to their problem solving proficiency.

(iii) To compare the percentage of correct incorrect solutions between algorithmic and conceptual problem solving as well as the problems not attempted.

(iv) To identify weaknesses in stoichiometry problem solving that could be rectified during the teaching of the topic.

The main research question and subsidiary questions that guided this study are presented below:

1.5 Research question and subsidiary research questions

1.5.1 Main research question

What is the proficiency of Grade 12 Physical Science learners in solving stoichiometry problems?

1.5.2 Subsidiary research questions

(i) What is the relationship between conceptual problem solving and algorithmic problem solving proficiency of Grade 12 Physical Science learners?

(ii) How the problem solving proficiency of Physical Science learners in stoichiometry be classified according to problem solving strategies.

(iii) What are the stoichiometry problems that learners are able to solve?

(iv) What are the weaknesses that exist in stoichiometry problem solving that could be rectified during teaching?

1.6 Significance of the study

Based on surveys conducted by Mphachoe (2009; 2012) and Potgieter, Rogan and Howie (2005) this study seeks to establish whether the results of their studies may be generalized to learners in Highveld Ridge East and West circuits. In addition, it is anticipated that this study will highlight the level of preparedness of these learners when solving acids and bases problems.

The anticipated results from this study pertaining to the relationship between proficiency in algorithmic and conceptual problem solving in stoichiometry could inform educators whether it is appropriate to teach learners to solve stoichiometry problems algorithmically or conceptually or to use a combination of both strategies.

The Mpumalanga Department of Education conducts annual content enrichment workshops in an attempt to improve Physical

Science results in the Province. The results of this study could provide information pertaining to the areas of weakness that may possibly be addressed in the enrichment workshops. Algorithmic and conceptual problem solving strategies are essential to succeed in stoichiometry.

Success in stoichiometry problem solving requires the problem solver to apply algorithmic and conceptual problem solving strategies (Huddle & Pillary, 1996). Previous chemical equilibrium problems in the Grade 12, Chemistry Examination Paper 2 required learners to recall and apply stoichiometry knowledge.

1.7 Summary

This chapter presented the introduction, context, aim, objectives, research questions, significance and problem statement of the study. The outline of chapters in this dissertation presented below.

1.8 Outline of chapters

Chapter One includes the introduction, problem statement, significance, aims, research questions and organization of this study. The literature review follows in chapter Two, which presents the conceptual framework and current, relevant literature on problem solving in stoichiometry. Chapter Three discusses the research methodology, research design, sampling, instrumentation, validity and reliability of instruments and data analysis. Chapter Four presents the results of the study. This includes descriptive results, inferential analysis and quantitative analysis. Lastly Chapter Five focuses on the discussion of results, recommendations and conclusion of the study.

1.9 Abbreviations and definitions

1.9.1 Abbreviations

NDoE	National Department of Education
FET	Further Education and Training
ANC	African National Congress
PISA	Programme for International Student Assessment

1.8.2 Definitions

Wheatly (1984) defined problem solving as what the problem solver does when faced with a challenge and does not know how to overcome. According to Mokhele (2008) problem solving is a mental process that a problem solver undergoes when faced with a novel problem. This includes looking for previously acquired information that is deemed applicable to the problem and integrating it. According to Perez and Torregros (1983) problem solving is a scientific investigative task. Frazer (1986) defined problem solving as overcoming obstacles or barriers between a problem statement and its solution using information and reasoning.

Problem solving proficiency is an individual's ability to employ cognitive processes to comprehend and determine problem situations where means of the answer is not instantaneously

According to Schmidt and Jigneus (2003), “Stoichiometry is the branch of chemistry evaluating the results of quantitative measurements connected to chemical compounds and reactions” (p. 308). Kemner (2007) defined stoichiometry as a mathematical Chemistry concept used to establish how much product can be produced from a known quantity of reactant. According to Whitten and Gailey (1981) stoichiometry is a quantitative association between elements and compounds as they go through chemical alterations. The next chapter discusses the conceptual framework and literature relevant to this study.

CHAPTER TWO

Literature review

2.1.1 Introduction

This chapter presents conceptual framework that underpins this study and its justification. Also presented in this chapter is literature pertaining to stoichiometry problem solving proficiency worldwide and in South Africa. Additionally, the literature review focuses on factors which affect problem solving proficiency. A conceptual framework is necessary to locate a study.

2.1.2 Conceptual framework

This study is underpinned by the differences between an exercise and a problem. This is because familiarity of a problem to a teacher determines how the teacher demonstrates solving stoichiometry problems and how the problem solver will perceive the problems in the instrument. The other aspect that is discussed in this section is the difference between generic and harder problems. It is of paramount importance to look at these differences because they determine whether the problem will be solved algorithmically or conceptually.

The working memory is included in this section because it enables the problem solver to distinguish between familiar and unfamiliar situations and this determines whether the problem solver will use low transfer or high transfer of knowledge. Memory also permits the problem solver to recall rules, assumptions, laws and theories relevant in solving the problems at hand while attention maintenance allows the problem solver to gain information, observe and solve the problems.

2.1.3 Types of problems

‘Exercise’ and ‘problem’ are two words that are sometimes used interchangeably. However, these words do not have the same meaning. According to Van de Walle (2003) an exercise is a challenge without any potential to provide academic challenges that improves a learner’s comprehension, way of thinking and exchange of ideas. In other words, if learner is faced with a challenge and automatically identifies a strategy to solve it then the challenge is an exercise (Chi, Fletovich, & Glaser, 1981). On the other hand a problem exists when there is a gap between the status quo of the learner and where the learner envisages being and does not know how to cross that gap (Hayes, 1989). In other words, a problem exists when there is an anomaly between ideal and real situations with no solution. The difference between an exercise and a problem stem from the fact that a familiar challenge is an exercise, while an unfamiliar challenge is a problem (Okanlawon, 2008). This difference affects the way learners are taught problem solving in stoichiometry.

Teachers being familiar with problems in the curriculum tend to commence solving familiar problems by representing them quantitatively (Bodner, 2003). This way of teaching problem solving does not show the learners the importance of understanding concepts that are relevant to solving the problem and how different components of the problem are related. Problems are classified as well-structured and ill-structured problems.

Ill-structured problems are problems with ambiguous goals, numerous strategies to resolve them and do not have a definite solutions. On the other hand well-structured problems are problems with well defined goals, pre-determined answers, preferred strategies to solve them and requires the problem solver to use a limited number of concepts (Jonassen, 2010). Most of stoichiometry problems encountered in high school are well-structured problems. Well-structured problems are sub-divide into generic and harder problems (Middlecamp & Kean, 1987).

Generic problems are problems that can be solved applying sets of operations that do not require intelligence (Bowen & Bunce, 1997;

Hung, 1997). These are problems that require the use of lower order cognitive skills to find the solution (Zoller, Dori, & Lebezky, 2002). On the other hand solving harder problems are problems that require the problem solver to apply a rule to a novel situation or to integrating more than one concept. In other words harder problems are problems that probe for understanding of concepts (Zoller, Dori, & Lebezky, 2002). The ability of learners solve problems can improve if learners can differentiate generic problems from harder problems (Middlecamp & Kean, 1987). Generic and harder problems have been used to categorize learners according to their problem solving abilities (Nakhleh, 1993), identify the problem solving abilities of learners (Pickering, 1990), determine the relationship between conceptual and algorithmic problem solving achievements (BouJaude, Salloum, & Abd-Khatick, 2004). Alternative conceptions can also be identified using hard problems (Okanlawon, 2008).

2.4 Problem solving

2.1.4.1. Problem solving in general and in particular, stoichiometry

The one the importance of learning chemistry is that it leads to the acquisition of problem solving skills (Okanlawon, 2008). These skills include reasoning, practical and algebraic manipulations

(Ochonogor, 2002). The significance of problem solving in stoichiometry is that it leads to comprehension of concepts (Bowen & Bunce, 1997; Sawrey, 1990; Selvaratnam & Canagarama, 2008). Problem solving in stoichiometry involves writing and balancing chemical equations, stoichiometry coefficients, limiting reagents, mole ratios of reactants and products, theoretical and yields **(**Perera & Wijeratne, 2006). This requires the problem solver to apprehend the chemical reactions and to use ratios and proportions (Upahi & Olorundare, 2012). Problem solving in stoichiometry can be categorized as algorithmic and conceptual problem solving.

According to Bertz, Smith and Nakhleh (2004) as cited in Bruck and Towns, (2009) algorithmic problem solving involves changing quantities, use of stoichiometric and mathematical associations as well as algebraic manipulations of formulae. On the other hand the same authors defined conceptual problem solving as problem solving that involves explaining fundamental thoughts, examination of pictorial representations, interpretation of data and predict outcomes.

A proficient problem solver should be able to scrutinize information in the problem statements, identify a potential and implement plans to solve the problems. A proficient problem solver should be able to recognize the associations between quantities, comprehend and utilize symbols. The other trait of a proficient problem solver is that he/she should be capable of determine answers successfully, create clear-cut explanations (OSED, 2012).

2.4.2 Polya's problem solving model

Polya (1957) outlined four steps involved in problem solving. The steps are understanding, devising a plan, problem execution and ascertain if the goal has been attained. Understanding the problem involves identifying given data, unknown data, determining if the information given is sufficient or insufficient to solve the problem. The stage of formulating a plan involves linking information in the problem with missing information and finally devising the plan of action. The third stage involved implementing the problem solving plan until a solution is obtained. The final stage involves ascertaining if the goal has been attained, judging the problem solving plan. This portrays problem solving as a linear activity rather than a cyclic process (Wilson, Fernandez & Hadway, 1993) One of the weaknesses of Polya's model is that it ignores meta-cognitive actions that are involved in problem solving (Lester, 1985). Meta-cognition is pivotal in problem solving because it can improve problem solving (Van de Walle, 2004). However, the environment in which problem solving is learnt affect problem solving.

2.1.4.3 Environment

The best environment for teaching problem solving is an environment which enables the learners to express their understanding of the problem, to establish whether the information given in the problem is sufficient or insufficient to solve the problem, use their prior knowledge to solve problems, share their solutions and strategies with their peers (Ministry of National Education Turkey as cited in Karaoglan (2009). In addition to the above, an environment that fosters problem solving is one that enables learners to explore new ideas, techniques and relationships.

2.1.4.4 The memory

Atkinson and Schifrin (1968) suggested that the memory consists of the sensory memory, short-term memory and the long term memory. The short-term memory is responsible of receiving information from the external environment and processing the information. The processed information is passed to the short-term memory which has a limited capacity. In the short-term memory information is temporarily stored and processed. The processed information is then transferred to the long term memory and unprocessed information is lost. In the long term memory processed information is stored for later use.

Previously studies have found a positive correlation between achievement in science and the working memory capacity (Danili & Reid, 2004; Gathercole, Pickering, Knight, & Stegmann, 2004; Yuan, Steedle, Shavelson, Alonzo, & Oppezzo, 2006). This positive correlation stops when information that is being processed (in the working memory) greater than the working memory capacity (Johnstone & El-Barina, 1986). On the contrary Staver and Jacks (1988) found no relationship between achievement in balancing chemical equations and the capacity of the working memory.

2.2 Factors that affect problem solving

2.2.1 Teachers' pedagogical knowledge

Stoichiometry problem solving is dependent upon the knowledge of facts (Greenbowe, 1983). The acquisition of the knowledge of facts is, among others things, affected by the instructional technique used to teach the content. A common approach to the teaching of Chemistry is that teachers present facts, concepts, demonstrate mathematical manipulations and emphasize rules and algorithms that need to be mastered. Haider and Naqabi (2008) supported this claim when they observed that in the United Arab Emirates when stoichiometry is taught, teachers outline the steps involved, give examples and ask learners to solve problems. Okanlawon (2010) reported 84, 5% of participants in his sample taught learners to identify limiting reagents in chemical reactions algorithmically. Below is an example of the steps that were given to learners.

1. Calculate the number of moles supplied from the amounts given in the problem statement
2. Divide each of the values by the coefficient.
3. The chemical with the smallest number is the limiting reagent.

The disadvantage of giving learners algorithms is that learners will be passive in the learning situation and for this reason there will be minimal interaction with the knowledge and consequently conceptual understanding is not developed. If learners lack conceptual understanding they are unlikely to determine underlying principles essential to the problem (Okanlawon, 2010). On the other hand Okanlawon (2010) also found that 16% of Chemistry teachers in his sample taught their learners to identify limiting reagents from first principle and this facilitated the development of conceptual understanding.

Okanlawon (2010) also reported that Chemistry teachers do not elicit learners' prior knowledge. Failure to elicit prior knowledge is that teachers will not create disequilibrium in the cognitive processes of learners and for this reason the existing schema of the learners will not be modified nor will it be discarded, consequently little or no learning will occur. The other observation was that some teachers used worked examples to teacher limiting reagents. The disadvantage of this is that learners are not interact with information therefore there is minimal learning. The strength of Okanlawon (2010) study is that information was collected was in the natural environment of the teachers, therefore the teachers' behaviour was natural. However, a convenient sample was used in this study and this restricted generalizations to this sample only because it was not representative of all the Chemistry teachers in Nigeria. The significance of this study to the current study is that the instructional method used to teach stoichiometry affect the development of conceptual understanding which in turn affects problem solving.

2.2.2 Teacher content knowledge

Another observation made by (Okanlawon, 2010) is that Chemistry teachers in Nigeria who lacked pedagogical knowledge had adequate content knowledge. This is because of their qualifications and that they were teaching their subject of speciality. On the contrary Rollnick, Bennett, Rhemtula, Dharsey and Ndlovu (2008) as well as Ramnarian and Fortus (2013) stated that Physical science teachers in South Africa lack subject content knowledge and conceptual understanding of the subject. This confirms the claim in the ANC congress position paper of 1996. Physical science teachers in South Africa lack content knowledge because black teachers trained prior to 1994 were trained in poorly resourced colleges (Arnott, Kubeka, Rice, & Hall, 1997). Teachers who lack content knowledge and view Physical Science as a collection of facts probably possess alternative conceptions which are likely to be passed on to learners (Lemma, 2013). In addition Physical Science teachers who lack content knowledge are likely to fail to show learners the limitations of analogies which in turn lead to alternative conceptions among learners. Pittman (1999) observed that teachers who possess less content knowledge fail to generate and use appropriate analogies. Consequently, this makes abstract concepts inaccessible to learners at the concrete level. The other implication of lack of content knowledge of Physical Science teachers is that they are likely to resort to traditional teaching methods which promote mechanical problem solving without developing conceptual understanding. Teaching methodology is a very important aspect that requires attention.

2.2.3 Teaching methodology

Teaching methodology may be broadly classified as traditional teaching methods and constructivist teaching methods. The underlying philosophy of traditional teaching is that learners are empty vessels and the job of the teacher is to fill these empty vessels with information. This teaching method is characterized by the teacher providing passive learners with information. On the other hand, the philosophy of constructivist teaching requires learners to construct their own knowledge as they interact with the physical environment and teaching method is learner centered as compared to the former which is teacher-centered.

The effectiveness of traditional teaching methods as opposed to different teaching methods has been compared by many researchers. Zarotiadou and Tsaprlis (2000) compared the effects of teaching Chemistry using a constructivist method and teacher–centered method and found that the overall achievement of the constructive method group was statistically higher than the teacher-centered method despite the fact that both groups had low achievements. The higher achievement of the constructivist method group was probably due to the fact that the participants in this group were given an opportunity to interact with concepts and the construction of knowledge motivated them. The lower achievement of the teacher-centered group was possible because the participants in this group did not interact with the concepts as with their peers hence little knowledge was constructed. The overall achievement of both the control group and the experimental groups was low probably because of the inclusion of mole problems which the participants probably lacked prior knowledge of (Gabel & Sherwood, 1984) and probably the participants had an alternative conception of assuming that the molar volume of all substances is $22{,}4dm^3$ (Coll & Dahsab, 2007). The other possible cause of the low achievement could be that molar volume problems in the test required formal operational thinking and probably there was a mismatch between the cognitive demands of the problem and the cognitive development of the learners which led to working memory overload.

This study however, has the following strengths; the learners were randomly selected into two equivalent learning groups and the longitudinal design of the study enables the researchers to determine change associated with maturation. The weakness of this study was that the experimental and control groups were at the same school which increased the chance of information contamination. The significance of this study is that demonstrates that the use of constructive teaching does not automatically mean high achievement.

Ahmad and Mahmood (2010) compared the effects of cooperative learning and traditional instruction and confirmed the superiority of constructivist teaching over traditional teaching. However, the mean scores of the experimental and the control groups reported by Ahmad and Mahmood (2010) were higher than the mean scores reported by Zarotiadou and Tsaprlis (2000).This is probably because the participants (masters students) of the study conducted by Ahmad and Mahmood (2010) were older more experienced at problem solving compared to the participants (high school learners) of the study conducted by Zarotiadou and Tsaprlis (2000). Hence the former had developed the problem solving schema from solving previous problems and their neurons were mature.

Bilgin, Senocak and Sozbilir (2008) investigated the effects of problem-based learning instruction on university students' performance of conceptual and quantitative problems in gas concepts. These researchers found that the achievement of the students who had experienced traditional learning on conceptual problems was significantly surpassed by the achievement of learners who had experienced problem-based learning. The higher achievement of students who experienced problem-based learning was possibly because the participants in the problem-based learning group actively constructed knowledge individually, when they were gathering information from literature and investigating the solutions for their peers. On the other hand the participants in the traditional learning group acquired knowledge passively. The strength of this study was random sampling was used to assign participants of the intact classes into problem-based and traditional learning groups which minimized sampling bias and in turn enhanced population validity. The other advantage was that random sampling permitted the researchers to use a parametric test to check if the difference between the experimental and control group means was statistically significant. The findings of this study confirmed Nurrenbern and Pickering (1987) who substituted teacher-centred teaching with student-centered teaching using molecular models, blocks and circles and asked students to show bonds between different particles. Higher conceptual achievement observed by Nurrenbern and Pickering (1987) was possibly because the use of models which enabled learners to test their prediction, compare their results with their pre-existing knowledge and this made abstract concepts accessible to concrete thinkers. The other possible effect of using models was that the models enhanced modification of students' schema and promoted hierarchical organization of information which made retrieval of information unproblematic.

The disadvantage of traditional teaching is that it does not cater for the different cognitive levels of the learners; it only caters for learners at the formal level. However, successful problem solving requires higher order cognitive skills that are developed through learner-centered teaching for solving conceptual problems and lower cognitive skills that are promoted by traditional teaching for solving algorithmic problems. Therefore it is important to have a balance between learner-centred and teacher-centred teaching strategies. Another teaching method that is recommended is visual representation.

2.2.3.1 Visual representations

One of the tools that teachers could use to improve problem solving is visual representation. Lugemwa (2012) investigated how to foster basic problem-solving skills in Chemistry and found that 80% of the participants who solved the problems correctly used triangles and were motivated. High achievement in this case could probably be due to the fact that the use of triangles assisted learners to visualize relationships between variables in the problem. However, there is no evidence in this study that the use of the triangle method improved conceptual understanding because all the questions posed required learners to manipulate equations which could be done algorithmically. The other weakness of this study was differential attribution which reduced external validity and internal validity of this study. The strength of this study was its duration of 2 years which allowed the researcher to measure changes as they occurred.

Similar results were presented by Cankoy and Ozder (2011) when they investigated the impact of visual representation on contextual mathematical word problem solving. These researchers found that there was a positive correlation between visual representation and solving worded problems and that visual representation enhanced solving of familiar worded problems more than unfamiliar worded problems. The positive correlation between visual representation and problem solving was probably because visual representations enabled the problem solvers to link problems with their pre-existing schema and that visual representations reduced the level of cognitive load. Reducing the cognitive load facilitates problem solving because there is a negative relationship between the cognitive load and problem solving once the maximum working memory capacity is reached (Johnstone & El-Banana, 1986). The weakness of this study was the use of volunteers because volunteers were not representative of the population since they are normally motivated and motivation is not a universal trait of the population from which the sample was drawn from. The strength of the study conducted by Cankoy and Ozder (2011) was the use of a quantitative descriptive research design which enabled these researchers to determine the prevailing state of problem solving of the participants.

The studies by Cankoy and Ozder (2011) and Lugemwa (2012) do not show whether the use of visual representations could improve conceptual problem solving which is a pre-requisite for problem solving. However, the use of visual representations could improve problem solving because learners will experience concrete representations which will assist them to link their pre-existing schema to abstract concepts (Moreno, Ozogul, & Risslein, 2011). Visual tools are recommended and concept mapping is one of them.

2.2.3.2 Concept mapping – a visual tool

A visual tool that may be used to represent information externally is concept maps. According to Novak (2002), “Concept maps are schematic tools that represent related concepts in a framework of propositions”. Concept maps maybe used by teachers to introduce or summarize topics and by learners to summarize a topic or concepts. Among the numerous researchers who have investigated the effects of concept maps on achievement are BouJaoude and

Attieh (2008) who found a significant difference between the post-test mean scores and the pre-test mean score of the experimental group. The higher post-test achievement of the experimental group in this study was probably due to the fact that concept maps assisted learners to refine their concepts; link existing knowledge with new knowledge, enhance hierarchical organization of information as well as to develop higher order cognitive skills such as metacognition. The other possible causes of the higher achievement of the experimental group are that the experimental group in this study experienced learner-centered teaching which allowed the participants to interact with concepts that gave the participants a chance to discard or modify their existing schema. Also, collaborative learning reduced the working memory load which led to superior concepts maps. On the other hand, learners in the control group hardly interacted with the concepts and with each other. This probably limited the acquisition of knowledge.

On the contrary Wenyi (1999) investigated the effectiveness of concept mapping on the transferability of metacognitive skills in problem solving and found that there was no significant difference between the pre-test and post-test achievement of the experimental and control groups. This result might be due to pre-test sensitization since the space of one week between the administration of the pre-test and the post-test was not long enough for the pre-testing effects to diminish. The other possible causes of this result are that the participants in the experimental and control groups were drawn from the population by convenience sampling and there was a probability that all the participants had already acquired metacognitive skills since they were above 12 years of age. The major weakness of this study was that it was affected by differential attrition because 22 participants withdrew from the study. Consequently, this withdrawal reduced the external validity of the study and information pertaining to the participants who had withdrawn, as well as the potential implications were not discussed.

Bamidele and Oloyede (2013) compared the effectiveness of the use of hierarchical, flowcharts and spider concept maps and found that there was no significant difference between the post-test means of the learners in the hierarchical, flowchart and spider concept map groups. However, the pre-test means of the hierarchical, flowcharts and spider concept map groups were lower than their corresponding post-test means. The enhanced post-test achievement of learners observed in the study conducted by Bamidele and Oloyede (2013) might possibly be due to the fact that concept maps assisted the learners to integrate their prior knowledge with the new knowledge, recognize relationships between concepts and organize information hierarchically which promoted retrieval of information from the long term memory during problem solving. The strength of this study was the use of analysis of covariance to test for the significance between the three means after randomly assigning intact groups into hierarchical, flowcharts and spider concept map groups. The usefulness of visual diagrams is dependent on the level of expertise of the problem solver.

Treagust and Chittleborough (2001) reported that novices have difficulty in interpreting chemical diagrams. However, according to Roseman (2011), “If novices are presented with a progression of several diagrams to work through their interpretation of diagrams improves”. The initial difficulty faced by novices when interpreting chemical diagrams is probably because as novices, they lack the chemical diagram schema or they have the schema in a traditional format and consequently fail to link the chemical diagrams to the problem and information is not spontaneously retrieved from the working memory. However, the improvement that occurs after several diagrams are presented to novices could be due to the fact that novices can easily retrieve information from the schema that was formed as they had worked through the diagrams previously. Yet another strategy that may assist with problem solving is heuristic training".

2.2.3.3 Heuristic training for problem solving

According to Katsikopoulos (2011) heuristics " Rely heavily on core human capabilities, do not necessarily use all available information and process information they use by simple computation and are easy to apply, understand and explain" (pp. 3) Schoenfold (1979a) discovered that learners who received heuristics training in problem solving outperformed learners who did not receive heuristic training. The high achievement of learners who received heuristic training could be attributed to the fact that direct instructions of domain specific strategies are beneficial to the teaching of problem solving. This was confirmed by Camacho (1986). On the contrary Lythcott (1990) found that performance of the control group was slightly higher than the performance of the experimental group. The higher performance of control group may be attributed to the fact that the participants could have memorized the problems; if the test problems were slightly changed the performance of the experimental group would have surpassed the performance of the control group because algorithmic problem solving inhibits the reflective ability of the learners. Schoenfold's (1979a) findings, also contradict BouJaude and Barakat (2003), who found that there was no relationship between the learning approaches and conceptual understanding of stoichiometry. However, these results cannot be generalized beyond the sample because BouJaude and Barakat (2003) used a sample that was not representative of the Grade 12 Science learners in Lebanon and the sample was taught by a teacher who focused on the development of algorithms meaning that he/she was most likely using traditional teaching methods which do not develop conceptual understanding. According to Lythcott (1990), extensive practice improves algorithmic problem solving. Analogies are recommended as a means to improve problem solving.

2.2.3.4 Analogies as a Teaching Tool

Gick and Holyoak (1983) claim that another useful teaching tool that maybe used to improve learners' acquisition of knowledge and ultimately problem solving proficiency is analogies. This is because analogies make unfamiliar concepts familiar by linking new knowledge to pre-existing schema (Grayson, 2004) and this helps learners to modify or discard their pre-existing schema hence facilitating acquisition of knowledge. Yilmazoglu (2004) investigated the effects of analogy enhanced instruction accompanied by concept maps on the understanding of acids and bases and found that the post-test mean of the experimental group was higher than the post-test mean of the control group in achievement and attitude and that the difference between the means were statistically significant. The high achievement of the experimental group was because there was a meaningful link between learners' pre-existing knowledge and the new knowledge hence formal concepts were accessible to concrete thinkers. The other possible reason could be that the learners actively interacted with the concepts when filling in the concept maps. On the other hand, the prior knowledge of the control group was ignored and the learners were passive recipients of information. This possibly reduced cognitive conflict hence little knowledge was acquired. The weakness of this study was that the experimental and control groups where from one school meaning that the results cannot be generalized beyond that school.

Results similar to the results of the study cited above were reported by Naseriazar, Ozmen and Badrain (2011), who investigated the effectiveness of analogies on students understanding of chemical equilibrium. The similarity between these results is probably because in these studies experimental designs, analysis of co-variance and t-tests were used. The other factor that might have caused this similarity is probably the fact that the achievement tests had 20 multiple choice questions each. The differences were the ages of the participants and their educational experience which might indicate that the use of analogies improves learning irrespective of the age of the learners and educational experience.

However, Friedel, Gabel and Samuel (1990) used an experimental design to investigate the effects of analogies and found that there was no significant difference in the post-test scores of the experimental group and control group. This was possible because analogies are mostly effective in making intangible concepts accessible to learners at tangible level in this case the participants could be above the concrete level because they were college students. This was confirmed by Gabel and Sherwood (1984) who found that analogies were effective for learners of low proportional reasoning ability and high mathematical anxiety than for learners with high proportional reasoning. This result was possible because the participants were high school learners at the formal level, between formal and concrete levels and at concrete level. Besides the cognitive level of the problem solver, the level of expertise of the problem solver also affects the effectiveness of analogies.

Ross (1984) observed that novice problem solvers notice and use superficial analogies while expert problem solvers notice and use analogies based on laws. This means that the type of analogy used in problem solving determines the quality of the solution, thus, the use of superficial analogies leads to solutions of low quality while the use of law based analogies lead to solutions of high quality. However, according to Ochonogor (2001) the use of analogies does not guarantee success in problem solving because analogies serve as a guide and could be misled if conditions and operations between the analogy and the concept differ. All the strategies to solve problems will not be of any help if the learner is unable to represent the problem mentally.

2.3 Problem representation by learners

Once a problem is presented, a problem solver is required to initially internalize the problem, that is interpreting the problem and create a mental picture of the problem. The quality of the mental picture that a problem solver forms affects the application of concepts which in turn determines the quality of the solution, thus, problem representation is a key component of problem solving (Greeno, 1980; Jonassen, 2005). Greenbowe (1983) found that the ability to construct and use appropriate problem representations is dependent upon conceptual understanding. This was confirmed by BouJaude and Barakat (2003), who observed that learners, who lack conceptual understanding use incorrect problem solving strategies. Greenbowe (1983) also found that the formal operational level was essential for successful problem solving and this confirms Herron's (1975) findings that a problem solver at concrete level cannot solve problems requiring formal operational reasoning because the schema of learners at the concrete level is capable of creating mental representations of concretes not abstracts. Another factor that affects problem representation hence problem solving proficiency is the level of expertise of the problem solver.

2.4 Level of expertise of the problem solver

The sequence of problem representation of experts and novices is not the same in that experts commence problem solving by representing the problem qualitatively before they represent it quantitatively and novices commence problem solving by representing the problem quantitatively (Chi & Glaser, 1982). Problem representation of experts enables them to produce superior problem representations because qualitative representations contain relationships and other considerations of the problem component which enables experts to see how information is linked (Larkin, 1981). The other advantages of initially representing the problem qualitatively is that it enables the problem solvers to link the information in the problem to their prior knowledge and it helps the problem solvers to create a clear mental picture of the problem which reduces noise on the working memory which in turn reduces memory load. On the other hand novice problem solvers produce inferior problem representations because their ability to recognize relationships between the different components of the problem is inhibited. This limits the problem solvers' ability of understanding the domain. However, representing the problem both quantitatively and qualitatively is essential for successful and efficient problem solving (Ploetzner & Spada, 1998 as cited in Jonassen, 2005). Besides determining the quality of problem representation the level of expertise also determines the type problems that are solved and the promptness with which the problems are solved.

Mason (1994) investigated the difference between expert and novice problem solvers and reported that experts solve algorithmic and conceptual problems promptly compared to novices. This is because experts retrieve the problem solving schema automatically whereas novices retrieve the problem solving schema intentionally and this is time consuming. Another observation made by Mason (1994) is that the frequency at which algorithmic problems and conceptual problems were solved by novice and experts was the same. This is because the participants of the study were undergraduates and professors who had developed algorithmic problem solving schema from previous encounters. The ability to represent a problem accurately is affected by the language used during teaching and in the problem statement.

2.5 Medium of instruction

The language used during teaching may give rise to alternative conceptions (Pedrosa & Dias, 2000). For the problem solver to create a mental picture of the problem, he/she needs first to understand the problem. For this reason the medium of instruction used in presenting the problem determines the quality of problem representation. In Botswana, Prophet (1990) found that the use of English as a medium of instruction for teaching Science hinders the ability of learners to formulate scientific ideas and in South Africa, Physical Science education is severely hampered by poor understanding of the English language (Arnott, Kubeka, Rice & Hall, 1997). Failure to formulate scientific ideas and to comprehend the problem makes it difficult and in some cases impossible for the problem solver to create a mental picture of the problem and this leads to an increase in the searching sequences. Increasing the searching sequence can overload the working memory thereby reducing the ability of the problem solver to formulate a solution.

The proficiency of learners in solving stoichiometry problems in the current study could be affected by their conceptual understanding of stoichiometry and the use of English as a medium of instruction. Learners with high conceptual understanding of stoichiometry and good command of English are likely to achieve better than learners with low conceptual understanding of stoichiometry and poor command of English. Language plays an important role in the teaching of problem solving as does the level of expertise. Problem solving also requires the individual to use his/her working memory.

2.6. Working memory in problem solving

After the problem representation, the problem solver should retrieve information relevant to the problem from the long term memory, temporarily store and manipulate the information in the working memory (Baddeley, 1992a). Danili and Reid (2004) found that as the working memory capacity increases, achievement in Science also increases or as achievement in Science increases the working memory capacity increases. However, “when information load exceeds the working memory capacity achievement in Science will start to decrease” (Johnstone & El-Barina, 1986). This is possible because occurrence of random errors will increase as the workload increases because it is difficult to process many things at once (Camacho & Good, 2006). An increase in random errors leads to a decrease in the quality of solutions. It has to be noted that the working memory is not only overloaded by the quantity of material presented but also by the quality of the information being presented. For example if information is presented in a disorganized manner, the working memory is overloaded and this inhibits linking of pre-existing knowledge to new knowledge which in turn hinders the formulation stage of problem solving thus problem solving is negatively affected.

Karuppiah (2012) investigated the relationship between learners' achievement and working memory capacity in stoichiometry and found a positive correlation between students' achievement in stoichiometry and working memory up to breaking point. This finding was conformed Greenbowe (1983) and Johnstone (1986). However, Staver and Jacks (1988) found that the working memory does not sufficiently influence learners' performance and this could be due to the fact that the participants in the study lacked the schema required to balance chemical equations or that the participants had pre-existing knowledge that was not modified because they were not actively involved in the learning process. The difference between the results reported by Staver and Jacks (1988) and Karuppiah (2012) could be due to the difference in the content that was tested because the study by Staver and Jacks (1988) tested learners on balancing chemical equations and the disadvantage of testing balancing of chemical equations is that learners can memorize the equations if they have frequently encountered them hence they can balance the chemical equations mechanically. On the other hand Karuppiah (2012) tested learners on a wide range of stoichiometry concepts and this placed a variety of demands on the working memory of the learners and this negatively affected problem solving proficiency. Problem solving in stoichiometry requires mathematical skills.

2.7 Mathematical skills and stoichiometry

The relationship between mathematical ability and stoichiometry problem solving is that algebraic problem solving and stoichiometry problem solving involves finding relationship. BouJaoude and Barakat (2003) claim that learners who cannot manipulate numbers readily find it difficult to learn the mole concept and solve problems based on the mole concept. On the contrary Childs and Sheehan (2009) and Aje (2005) found that students with a strong mathematical ability had little difficulty balancing chemical equations and solving gas problems thus indicating that there was a positive relationship between learners' mathematical ability and stoichiometry achievement. Learners with a strong mathematical ability found it easy to balance chemical equations and solve gas problems because they had a sound understanding of ratios which is a prerequisite in learning and solving stoichiometry, and are therefore able to identify stoichiometry relationship in the problem and can transfer their knowledge of algebra to solve stoichiometry problems (Chandrasegaran, Treagust, Waldrip, & Chandrasegaran, 2009).

On the other hand Gabel and Sherwood (1984) found that learners do not fail to solve mole problems because they lack arithmetic but because they lack prior knowledge of the facts used to solve the problems. This finding is supported by Staver and Jacks (1988) and Gabel and Bunce (1994). It is possible that learners who lack prior knowledge fail to solve mole problems because they fail to create a mental representation of the problem. As a result they cannot establish relationships essential to solving the problems. Gabel and Sherwood (1984) also found that learners who fail to solve mole problems managed to solve analogue problems, which could be possible if the learners were familiar with the items used in the analogues because familiar objects enhance the ability of the problem solver to represent the problems and to manipulate the different components of the problem mentally. The strength of the study by Gabel and Sherwood (1984) was that the subjects were randomly sampled from the population which minimized sampling bias and sampling error while the weakness of this study was the high mortality rate (more than one sixth of the original sample was lost) hence this reduced its internal validity.

Contrary to the findings of Gabel and Sherwood (1984) were the findings of Childs and Sheehan (2009) who found that prior knowledge does not affect learners' ability to solve mole problems. This is possible because the participants in the study that was conducted by Childs and Sheehan (2009) were university students who were familiar with the mole concept from high school while the participants in the study conducted by Gabel and Sherwood's (1984) were high school learners who were encountering the mole concept for the first time.

Literature cited above shows that researchers do not concur regarding the effects of mathematical ability on problem solving in stoichiometry. However, this research is not intended to investigate the effects of mathematical ability on solving stoichiometry problems. However, it has to be noted that competency in mathematics will either affect learners' proficiency negatively or positively. Proportional reasoning is a significant aspect of problem solving.

2.8 Proportional reasoning for Problem Solving

Proportional reasoning and mathematical reasoning are related because reasoning in mathematics includes evaluating variables and handling data (Gabel & Sherwood, 1989). Proportional reasoning affects problem solving proficiency (Wheeler & Kass, 1977). Gabel and Sherwood (1983) confirmed this assertion after they investigated the effectiveness of the label-factor method, the use of analogies, diagrams and proportional reasoning of learners of varying proportional ability, verbal and visual preference and mathematical anxiety. The advantage of the study conducted by Gabel and Sherwood (1983) was that sampling error was minimized by random sampling of the schools and the assignment of participants into the four teaching strategies. Additional advantages were the length of the test which increased content validity and the time-series design which minimized maturation and test effects thereby increasing the internal validity of the study.

The results of Gabel and Sherwood (1983) were expanded by Gabel, Sherwood and Enochs (1984) when they investigated the general problem solving skills used by learners in solving mole concept, stoichiometry, gas laws and molality in solving problems. These researchers found that learners with high proportional reasoning abilities use algorithmic reasoning strategies more frequently than learners with low proportional reasoning. The high frequency of the application of algorithmic strategies was possible because the participants were taught proportional reasoning before they reached the plateau period of maturation which promoted the application of rules without thinking or they were not familiar with the content or were taught the subject using traditional teaching methods. Caragaratna (1993) suggests that the use of proportional reasoning fosters the development of critical thinking and the ability to formulate modes of solving stoichiometry problems among learners without resorting to memorization, which can only be realized if the learning environment offers learners a chance to construct knowledge and to formulate problem solving strategies rather than being told what to reproduce.

Page, Guevara and Walton (1989) investigated the effect of instruction that incorporated proportional reasoning within problem solving techniques and found that the post-test mean scores of the experimental group were higher than of the control group. Based on these results, they concluded that proportional reasoning enhances learners' achievement in problem solving. These results were confirmed by Yip Din Yan (1996) whose findings were similar to the findings of the study done by Page, Guevara and Walton (1989). The similarity of the results of these studies was due to the fact that the participants in these studies had reached the plateau period of maturation when they were taught the proportional concept. Metacognition is necessary in every aspect of learning and is valuable in problem solving.

2.9 Metacognition and Problem Solving

During problem solving, learners should control their thinking, a process known as metacognition. Harandi, Eslami, Darehkordi, Deh and Darehkordi (2013) investigated the effect of metacognitive strategies training on problem solving performance and social skills in high school girls and found that the social and problem solving ability of the learners in the treatment group significantly improved compared to learners in the control group. These results corroborated Moneni's (2012) findings that metacognitive strategy training improved the problem solving performance of learners. This may be attributed to the fact that there was a match between the cognitive level of the participants and the cognitive demands of the metacognitive strategies. One of the strengths of the studies conducted by Harandi, Eslami, Darehkordi, Deh and Darehkordi (2013) and Moneni (2012) was that the testing effect was minimized by administering the post-tests after six weeks and by using constructive teaching which gave the participants a chance to explore new ideas and problem solving techniques. However, the results of Harandi, Eslami, Darehkordi, Deh and Darehkordi (2013) cannot be generalized beyond the sample because it was not representative of the ninth grade population since it excluded boys.

On the other hand Yang and Lee (2013) investigated the effect of instruction in cognition and metacognitive ability strategies of ninth grade learners in Taiwan. He found that instruction in cognitive and metacognitive strategies did not have a significant effect on the cognitive abilities of ninth Grade learners. This result was likely due to the fact that traditional teaching methods were employed to teach metacognitive strategies to the experimental. The other possible explanation could be that the participants of this study were below the age of twelve years therefore they were not sufficiently mentally mature to acquire metacognitive skills (Whitebread, Coltman, Pasternak, Sangster, Grau, Bingham, & Demetrious, 2009).

An investigation conducted in an Emirati high school into learners' understanding of stoichiometry, their metacognitive strategies and the influence of metacognitive strategies on learners' understanding of stoichiometry found that there was a positive correlation between students' understanding of stoichiometry and the use of metacognitive strategies (Haidar & Al Naqabi, 2008). Metacognition is one of the attributes of the formal operation level and the existence of a positive correlation in this case indicates that formal operation is required when learners are solving stoichiometry problems. Additionally this study observed that learners use the following metacognitive strategies; awareness of cognition, planning, monitoring, self-appraisal and engagement. Apart from all the known strategies employed in the teaching of stoichiometry, it is necessary to explore alternative conceptions.

2.10 Alternative conceptions in stoichiometry

The language used during teaching (Pedrosa & Dias, 2000), the teaching method, the teacher content knowledge (Lemma, 2013) and the interaction of learners with the physical world before formal science education are some of the factors that give rise to alternative conceptions in stoichiometry. The prevalence of alternative conceptions lowers learners' achievements. Demircioglu, Ayas and Demircioglu (2005) investigated the effects of a new teaching program on conceptual change using a control group and an experimental group and found that the post-test achievement of the experimental group was higher than the post-test achievement of the control group which had many alternative conceptions. The higher achievement of the experimental group was possibly because the prior knowledge of the participants was used as a foundation of conceptual change, the participants were given an opportunity to test their prior knowledge and all this created conceptual conflict which facilitated learning (conceptual change). The control group participants experienced little or no conceptual change probably because their pre-existing knowledge was not elicited and the participants were not given an opportunity to test their ideas because traditional teaching methods were used. This study indicates that the alternative conceptions limit the proficiency of learners and that the teacher-centred methods are not the best methods for conceptual change.

The effect of alternative conceptions on achievement was also investigated by William (2009) who found that alternative conceptions were prevalent among learners and reduced learners' ability to conceptualize necessary chemical processes making their acquisition of knowledge difficult. The participants of this study had alternative conceptions probably because when they were learning this topic, they were given rules and algorithmic procedures instead of discrepant events hence, their pre-existing schema was neither modified nor discarded. The strength of this study was that participants were required to provide an explanation for their prediction and this removed the element of guessing unlike in the study conducted by Demircioglu, Ayas and Demircioglu (2005) where there was the use of multiple choice problems which were prone to guess work. The significance of this study was that it highlights that the prevalence of alternative conceptions reduced the learners' proficiency in solving conceptual problems. Worked-out examples provide learners with some form of reference; therefore worked examples are essential in problem solving.

2.11 Worked-out examples in problem solving

Clark, Nguyen and Sweller (2006) defined worked-out examples as “A step by step demonstration of how to solve a problem”. Worked out-examples are important since they can be used to teach problem solving skills (van Merrienboer, 1997). This was supported by Salden, Aleven, Schwonke and Renkl (2009) when they stated that worked-out examples are useful in teaching problem solving. Worked-out examples were used by Chi, Bassok, Lewis, Reimann and Glaser (1989) when they investigated “How students use learning to solve problems”. These researchers found that successful problem solvers spent more time analyzing worked-out problems, their solutions were based on principles and control their thinking during problem solving. The other researcher who reported on worked-out examples was Okanlawon (2010) who observed that some Chemistry teachers use worked-out examples when teaching learners to identify limiting reagents (problem solving) in chemical reactions. It is expected that the use of worked-out examples lead to conceptual understanding in the former study since there was active learning while in the latter study little or no conceptual understanding occurred there was passive learning.

Besides the way in which worked-out examples are presented to learners the frequency of encountering worked-out examples affect problem solving. Sweller (1994) found a positive correlation between the frequency of encountering worked-out problems and achievement. However, this result does not suggest that the frequency of encountering worked-out problems leads to high achievement nor does it suggest that high achievement leads to a high frequency of encountering worked-out problems. But that there was an association between the frequencies of encountering worked-out problems and achievement. This positive correlation may be attributed to the fact that worked-out problems free learners from performance demands providing them with the opportunity to concentrate on acquiring understanding which enhance problem solving. According to Herron (1990) the disadvantage of worked-out examples is that they do not expose learners to the cognitive processes that are experienced by the author (expert). This was supported by Okanlawon (2010). The other disadvantage of worked problems is that they are not effective if learners lacked prior content knowledge (Kalyuya, Chandler, Luovinen & Sweller, 2001). Having discussed various strategies to solve stoichiometry problems it is necessary to discuss stoichiometry problem solving.

2.12 Misuse of coefficients

Camacho and Good (2006) found that students and learners misuse or ignore coefficients in chemical equations when solving stoichiometry problems. This was possibly because students and learners did not represent problems qualitatively which would enable them to identify relationships between the coefficients before they represent problems quantitatively. The other factor could be that the novices had underdeveloped proportional reasoning abilities. Lemma (2013) concurs with Camacho and Good (2006). When Lemma (2013) found that instead of writing $2H_2O$ learners wrote H_4O_2 and wrote H_4 instead of writing $2H_2$. The participants were probably novices (Grade 9 learners). Algorithmic, conceptual and unidentified strategies can be used to solve stoichiometry problems. After discuss the factors that affect problem solving in general, it is necessary to discuss stoichiometry problem solving.

2.13 Stoichiometry problem solving

2.13.1 View of stoichiometry

Fach, Boer and Parchmann (2007) suggested learners and teachers regard stoichiometry as a difficulty and unmotivating topic. Schmidt and Jigneus (2003) suggested that stoichiometry is difficulty for students to grasp and therefore discouraging. Fiebig and Melle (2001) administered a questionnaire in Germany investigating topics which Chemistry teachers find difficult to teach and found that teachers considered stoichiometry difficulty to teach because there were no suitable teaching methods. Childs and Sheehan (2009) investigated Chemistry topics that students find difficult to learn and found that students indicated that volumetric calculations, concentrations of solutions, writing chemical equations and the mole concepts were among the topics that regard as difficult. Probably teachers and learners find stoichiometry difficulty because of its abstract and quantitative nature.

2.13.2 Importance of solving stoichiometry problems

"The aim of problem solving in stoichiometry in high school is to clarify and reinforce concepts, principles, and laws, to improve learners' competence in strategies and procedures thus facilitating intellectual growth" (Selvaratnam & Canagarama, 2008). This statement is somehow misleading because problem solving that involves writing the formula, substituting numerical values and/or manipulating the equation to arrive at the answer does not leads to intellectual growth or clarification of concepts because the procedure followed is mechanical. On the other hand problem solving which requires learners to show understanding of the concepts lead to intellectual growth.

2.13.3 Algorithmic and conceptual stoichiometry problem solving

Chui (2001) investigated the difference in learners' ability to solve algorithmic and conceptual problems in Chemistry and found that learners who were good at solving both algorithmic and conceptual problems were better at solving conceptual problems than algorithmic problems. Chui (2001) also noted that there is a positive correlation between algorithmic skills and conceptual understanding. The strength of this study was that the participants were asked to either explain their answers or support their answers by calculations. All this eliminated guessing. The other strength of this study was that the learners were tested in a natural environment which reduced reactive effects. However, the sample used in this study had fewer females compared to males inferring that the sample was not representative of the population from which it was drawn from. The limited scope of the test (one problem per topic) comprised its content validity.

Chui's (2001) results were confirmed by Yilmaz, Tuncer and Alp (2007). The high algorithmic and conceptual achievement that was reported by Yilmaz, Tuncer and Alp (2007) may be due to the fact that the learners had practised the topics that were in university selection test hence the tasks were no longer problems but exercises. The other factor that might have contributed to this finding is that the participants may have guessed the answers since the instruments consisted of multiple choice problems or the use on constructive teaching to teach stoichiometry that could have promoted conceptual understanding and reduced alternative conceptions.

The similarity of the results of the two studies mentioned above may be attributed to the samples of these studies that were not representative of their respective populations since they were drawn from one school and two schools respectively.

Contrary to the results of the two studies above were the results reported by BouJaoude and Barakat (2003), Okanlawon (2008) and Stamovlasis, Kamilatos, Papavikonomau and Zarotiadou (2005) who found that algorithmic achievement was higher than conceptual achievement. The difference between the results reported by Stamovlasis et al and the results reported by Yilmaz, Tuncer and Alp (2007) and Chui (2001) may have stemmed from the fact that Chui (2001) and Yilmaz et al (2007) used samples that were non-representative of the populations from which they were drawn from whereas Stamovlasis et al (2005) used a sample that was almost representative of its population. However, BouJaoude and Barakat (2003) who used a sample that was non-representative as Chui (2001) and Yilmaz, Tuncer and Alp (2007) but got different results. The corresponding findings between the results reported by BouJaoude and Barakat (2003) and the result of Stamovlasis et al (2005) may be because the participants in these studies were all Grade 11 learners. This means that they might have had almost the same experience in solving algorithmic and conceptual problems and were at the same cognitive level. The other problem solving strategies that is reported in literature is unidentified strategies.

Unidentified strategies

Unidentified strategies are strategies that do not have a pattern nor found in textbooks. Several researchers have observed that these strategies are used learners to solve stoichiometry problems. Schmidt (1993) found that learners who use unidentified strategies to solve stoichiometry problems have a high achievement. This was supported by Schmidt and Jigneus (2003) in Sweden. However, Toth and Sebestyen (2009) found that learners used unidentified strategies to solve easy stoichiometry problems and used efficient strategies to solve difficulty problems. The other result these researchers reported was that the achievement of learners who use unidentified strategies was low. The low achievement may be caused by the fact that the learners who use these strategies apply them when they are not applicable (Cai, Mayer, & Grochowski, 1999). The implication of the result reported by Toth and Sebestyen (2009) is the strategies are dependent on the level of difficulty of the problem. The difference between the former result and the latter result may be because in the former two studies volunteers who are normally motivated were used and this made the samples non-representative of their respective population because volunteers. On the other hand Toth and Sebestyen (2009) did not use volunteers. However, results of Schmidt (1993) and Schmidt and Jigneus (2003) would be only possible if the sample was made up of imaginative problem solvers. But, creative problem solvers are rarely found in the population because achievement is a normally distributed variable. The other strategies used to solve stoichiometry problems that are systematic and outlined in textbooks are the mole and proportional methods.

Mole and proportional methods

It was found out that Hungarian learners used the mole and the proportional methods to solve stoichiometry problems and there was significant difference between the achievement of the learners who used the mole and proportional methods by Toth and Sebestyen (2009). This concurred with the finding of Toth and Kiss (2005). On contrary to the two findings mentioned above were Fach, de Boer and Parchmann (2007). Fach, de Boer and

Parchmann (2007) found that achievement of learners who use the mole method was low because they tend to misconstrue the numerator and the denominator hence obtaining incorrect solutions. The difference between the reports of Toth and Sebestyen (2009) and Fach, de Boer and Parchmann (2007) was that the sample of the former was representative of the population because sampling error was minimized by random sampling whereas the sample of the latter was not representative of the population from which it was drawn. This is because participants were selected by teachers and furthermore selected learners who volunteered formed the sample. The other cause of the difference was that Fach et al (2007) used interviews which allowed them to get in-depth information whereas Toth and Sebestyen (2009) used pen and paper test. The disadvantage of pen and paper is that they do not gather much information. Toth and Sebestyen (2009) also disagreed with Gabel and Sherwood (1983) who found that learners who used the label factor method produce results that surpassed the results of learners who used the proportional method.

2. Limiting reagent problems

Regarding low achievement in solving limiting reagent problems, BouJaoude and Barakat (2003) concur with Laugier and Dumon (2000) as well as Huddle and Pillary (1996). However, Laugier and Dumon (2000) attributed the low achievement to the fact that learners assume that all the reactants are used up in a chemical reaction. On the other hand Huddle and Pillary (1996) assert that learners assume that the limiting reagent is the reactant in a chemical reaction with the lowest stoichiometry coefficient. These alternative conceptions are probably because the participants in these studies lacked proportional reasoning or their prior knowledge was ignored when the concept was being taught reported by Okanlawon (2010) hence conceptual change did not occur.

On the contrary Chui (2001), found that the algorithmic and conceptual achievement of learners for the limiting reagent concept was high. This finding may be due to the fact that the conceptual problem was in a pictorial form and consequently learners at concrete and formal levels managed to represent this problem. However, the results of this study cannot be generalized because the not all socio-economic class was represented since the sample was drawn from a top school.

2.13.7 Mole concept

Yilmaz, Tuncer and Alp (2007) also found that learners' conceptual achievement on the problems based on the mole concept was higher than algorithmic achievement. These researchers attributed this result to extensive practice in answering the mole problems.

However, this is only possible if the emphasis was on how to arrive at the solution and not on what is the correct answer. The other factor that does not support this result is that traditional teaching methods are dominating the teaching of Chemistry in Turkey. This result counters the result the result that was previously reported by Potgieter, Rogan and Howie (2005) who found that learners and students had a poor understanding of the mole concept. The disparity between these results may be due to the fact that in Turkey Chemistry is taught as a subject by Chemistry specialty while in South Africa Chemistry is combined with Physics and sometimes not taught by a Physics specialty. This is because there is a shortage of Science teacher in South Africa.

2.13.8 Stoichiometry problem solving in South Africa

While Potgieter, Rogan and Howie (2005) were constructing a Chemistry concept inventory of Grade 12 learners and the University of Pretoria foundation year students, they found that the mole concept, stoichiometry and the limiting reagent concept were poorly understood. These researchers also found that almost 50% of the participants misunderstood the mole concept. This was possible because of the limited time (one hour) that was allocated to teach the mole concept in South Africa. Consequently teachers taught the concept hurriedly. The other possible reason was that pictorial questions were used and the learners and students participated in this study were probably not familiar with solving pictorial problems and an added challenge was the fact that teachers in South Africa lack conceptual understanding of Physical Science (Ramnarian & Fortus, 2013; Rollnick, et al 2008;). The weakness of this study was that it excluded rural learners and that there were more learners from privileged schools than disadvantaged schools when in actual fact learners from privileged schools are fewer than learners from disadvantaged schools in South Africa.

Grade 12 graduates in South Africa lack conceptual understanding of the mole concept, according to Potgieter and Davidowitz (2010) who concur with Potgieter, Rogan and Howie (2005) probably because of the superficial treatment that is given to the mole concept in Grades 10 and 11. Furthermore, the New National Curriculum Statement had a high content density (Umalusi, 2010) consequently promoting a culture of memorization among learners. However, Davidowitz, Chittleborough and Murray (2010) found that the response of learners in formative tests and summative examinations over the years was constantly improving. This is probably an effect of bridging courses that are intended to cater for knowledge gaps created in high schools offered at most universities in South Africa.

In Mpumalanga province, Mphachoe (2009) after analyzing the National Curriculum Statement and Physical Science paper 2 results suggested that Physical Science teachers should assist learners to understand steps involved in working stoichiometry problems and in identifying the goals in stoichiometry problems. This implies that there is a gap between the desired stoichiometry achievement and the actual achievement possibly due to lack of conceptual understanding of stoichiometry or an over-reliance on algorithms among learners. It is too difficult to implement this recommendation because the teachers themselves cannot identify the goals of the questions as well as solving problems logically (Selvaratnam, 2011). Below is a Question 7 from the National Senior Certificate Grade 12 Physical Science Paper 2 of 2012.

Question

A hypothetical reaction is represented by the balanced reaction below

$A (g) + 2B (g) \rightleftharpoons 2C (g)$

3 moles of A (g) and 6 moles of B (g) were mixed in a $5dm^3$ sealed container. When the reaction reached equilibrium at $25^{O}C$, it was found that 4 moles of B (g) was present.

7.2. Show by calculation that the equilibrium concentration of C (g) is 0, $4mol.dm^{-3}$.

7.4. The initial number of moles of B (g) is now increases while the initial number of moles of A (g) remains constant at $25^{o}C$. Calculate the number of moles of B (g) that must be added to the original amount so that the concentration of C (g) is 0.8mol.dm^{-3} at equilibrium, if the equilibrium constant at 25^{o}c is 0.625.

Mphachoe (2012) analyzed 10,5% of ***candidates'*** responses to the above question and found that students in Mpumalanga Province of South Africa could not perform stoichiometric calculations, had poor understanding of ratios, failed to substitute correctly and could not differentiate moles from concentration. However, the reports by Mphachoe (2009; 2012) are not supported by inferential statistics therefore these results cannot be generalized beyond the sample. The disjointed manner in which stoichiometry is taught in high schools in Mpumalanga and the limited time (one hour to teach the mole concept and 6 hours to teach stoichiometric calculations) allocated to teach this topic as well as low conceptual understanding among teachers could have contributed these results.

2.14 Summary of Chapter Two

In this chapter the factors that affect problem solving in general and in stoichiometry this included the level of expertise, the mathematical ability of learners, medium of instruction, teaching methodologies, problem representations, alternative conceptions, worked examples, proportional reasoning and metacognition were discussed. The other aspect of stoichiometry that was discussed in the chapter was literature on stoichiometry problem solving in the world. The literature was from Germany, Sweden, Hungary and Turkey, South Africa and Mpumalanga Province of South Africa were discussed. Also, discussed in this chapter was the categorization of the learners according to their problem solving competence as well as the effect of unidentified, conceptual and algorithmic strategies, the proportional and mole methods on stoichiometry problem solving. The next chapter presents the methodology used to conduct this study.

Chapter Three

Methodology

3.1 Introduction

This chapter presents_the research design, sampling methods well as a discussion of the participants. An in-depth description of the instrument that was used to collect data for this study follows and an explanation on its development is provided. The locations where the data was collected have also been described in detail. Validity and reliability of the instrument as well as analysis of data are presented.

3.2 Research design

A quantitative descriptive research design was used in this study because it enabled the researcher to determine the problem solving proficiency of learners without manipulating any variable. The other reason for using a descriptive research design in this study was that numerical data that was obtained from the achievement test enabled the researcher to describe the stoichiometry problem solving proficiency of Physical Science learners in Highveld Ridge East and West circuits, determine the relationship between algorithmic and conceptual problem solving proficiency and categorize learners according to their problem solving abilities. Numerical data generated from the achievement test also allowed the researcher to find out whether the difference between algorithmic and conceptual problem solving proficiency was statistically significant or insignificant. The numerical data also allowed the researchers to establish if the relationship between algorithmic and conceptual problems solving proficiency was statistically significant or insignificant. An exploratory research design was not used as a research design of this study because it generates qualitative data which cannot be used to determine the strength and direction of the association between algorithmic and conceptual problem solving proficiency. The other reason for not using an exploratory research design was that the aim of this study was to describe algorithmic and conceptual problem solving proficiency rather than to gain insight into algorithmic and conceptual problem solving proficiency or providing an explanation for why problem solving proficiency was high or low.

3.3 Target population

This study was conducted in Highveld Ridge East and West circuits of Mpumalanga Province in South Africa. In these two circuits there were 1684 males and females, Blacks, Whites, Indians and Colored from lower, middle and high income families studying Physical Science in Grade 12. 482 learners out of a total of 1684 learners were studying Physical Science at advantaged schools (former model C) and the rest were studying Physical Science at disadvantaged schools (township). The age range of these learners was between 17-20 years old.

This population was used because it was easily accessible to the researcher and; therefore it was economical on time, logistics and expenses. The other reason for using this population was that Grade12 learners had completed studying stoichiometry and were preparing for their final Matriculation examination. It was also assumed that the learners in this population had acquired problem solving techniques while studying stoichiometry in Grades 10 and 11.

3.4 Sampling

In this study the names of all the former model C high schools in Highveld Ridge East and West circuits were written down and numbered from one to five. Balls of the same shapes and sizes were numbered from one to five. The balls were mixed in a container and one ball was randomly selected from the container. The school with number that corresponded to the number on the ball that were picked was to be a research site. The same was performed with all the disadvantages high schools except that ten balls were used and two balls were randomly selected. The scripts from the three schools were numbered from one to seventy-seven and balls of the same sizes, shapes were also numbered from one to seventy-seven and placed in a container where they were thoroughly mixed. Sixty-one balls were randomly selected from the container. Scripts with numbers that corresponded with the numbers written on the balls formed the sample. This procedure was adopted from Singleton, Straits and Straits (2011). Thus in this study random sampling was used to select participating schools and the participants.

Proportional stratified sampling was used to select the research sites so that all the socio-economic classes in these two circuits were represented in the sample. Random sampling was used to select the research participants because it minimized the chances of over-representing or under-representing the advantaged schools nor the disadvantaged schools as well as the Black, White, Coloured and Indian learners. This produced a sample that was almost representative of the Physical Science Grade 12 learners in Highveld Ridge East and West circuits. The other reason was that results obtained from a sample drawn from the population by random sampling can be extended to the population from which the sample was drawn. The other advantage of using random sampling was that it allowed the researcher to approximate the chance of an event or behaviour occurring in the population (Vogt, Garden, & Haeffele, 2012).

The sample that was formed consisted of twenty three (23) females and thirty-eight (38) male learners with an average age of 17, 5 years. This sample did not include Grade 12 learners who were learning Physical Science in Afrikaans because the researcher cannot read nor write Afrikaans. Another important component of a research is the research instrument.

3.5.1 Research instrument

An achievement test was the research instrument used in this study because it was capable of measuring the current algorithmic and conceptual problem solving proficiency of the learners and higher order thinking skills. An achievement test is an examination that generates information which can be utilized to recognize and group learners (Gay, 1996). In this study an achievement test was also used because the scores obtained from it were used to categorize learners according to their problem solving proficiency and to describe the learners' problem solving proficiency after they were exposed to stoichiometry problem solving in Grades 10 and 11. The other reason for using an achievement test was that the scores from an achievement test were used to assess the ability of the learners to calculate problems accurately, understand and use chemical symbols, communicate using chemical vocabulary, recognize stoichiometric relationships, identify and execute appropriate problem solving strategies as well as to analyze the data.

The achievement test evaluated learners' ability to balance chemical equations, to determine the quantity of reactants used in a chemical reaction and the quantity of products formed in a chemical reaction, to identify limiting reagents and apply the law of conservation of mass to chemical reactions (see annexure 1). The content was derived from the Physical Science National Curriculum Statement Grade 10-12 General Guidelines (June 2006) and some of the questions in this test were adopted from Lythcott (1990), Nurrenbern and Pickering (1987), and Yilmaz, Tuncer & Alp (2007)

The test had six paired problems. The first part of each problem was intended to test learners' proficiency in algorithmic problem solving. Learners were asked to show how they arrived at their answers. Below is an example:

Problem 1.1

Balance the following chemical equation and show how you balanced the equation:

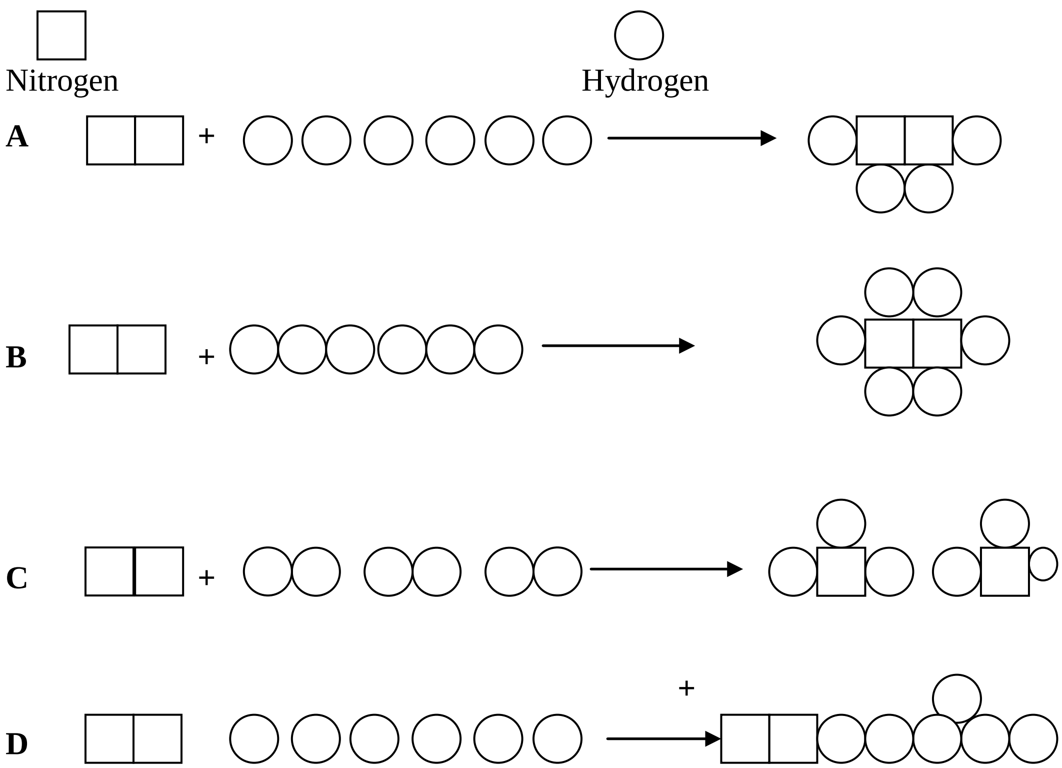
$N_2 (g) + H_2 (g) \longrightarrow NH_3 (g)$ (3)

The second part of each problem was intended to test learners' proficiency in conceptual problem solving through explaining underlying ideas, analyze representation, interpret data and predict outcomes. In this section learners were required to provide the answers and explanations. Below is an example

Problem 1.2

Which of the following diagrams represents a balanced chemical equation of a reaction between nitrogen (N_2) and hydrogen (H_2)? Give a reason for your answer. (3)

KEY



Paired algorithmic and conceptual problems were used in this study because they enabled the researcher to determine if the ability to solve algorithmic problems facilitated conceptual understanding (Naiz & Robinson, 1992), there was a relationship between algorithmic problem solving and conceptual problem solving (BouJaude, Salloum, & Abd-Ei-Khatick, 2004), to identify learners who could solve conceptual problems and who could solve problems algorithmically (Pickering, 1990), to categorize learners into algorithmic and conceptual problem solvers and to expose alternative conceptions (Nakhleh, 1993).

Each algorithmic problem had a maximum score of 3 marks and the maximum possible algorithmic score was 18 marks. The same mark allocation was used for conceptual problems. The maximum possible score of the test was 36 marks and the duration of the test was 60 minutes. Learners were provided with relative atomic masses of the elements and formulae. After a test has been constructed it is paramount to determine if it measures what it is intended to measure, i.e. the validity of the test.

3.5.2 Validity of instrument

The content of the test was derived from the National Curriculum Statement Grade 10 -12 (2006) and questions were selected and set using Bretz, Smith and Nakhleh (2004) framework as cited in Bruck and Towns (2009). See the Table 1 overleaf

Table 1: Classification of test items according to Bretz, Smith and Nakhleh (2004) framework

Question number	**Description in terms of Bretz, Smith and Nakhleh(2004) Framework**
1.1	Algorithmic multi-step
1.2	Analysis of pictorial representation
2.1	Algorithmic microscopic-symbolic conversion
2.2	Explanation of underlying ideas.
3.1	Algorithmic multi-step
3.2	Analysis of pictorial representation
4.1	Algorithmic multi-step
4.2	Explaining underlining ideas
5.1	Algorithmic multi-step
5.2	Explaining underlining ideas
6.1	Algorithmic multi-step
6.2	Analysis of data

After the test was constructed it was sent to a Chemistry lecturer and a Chemistry doctoral student, who was teaching Physical Science at FET phase, in order to determine whether the items in the test were representative of all the parts of the stoichiometry concepts and the problems were algorithmic and conceptual. The instrument was then adjusted in line with their recommendations. Another factor that affects the usefulness of a research instrument is its reliability.

3.5.3 Reliability of the research instrument

In this study the reliability of the test was determined by split-half reliability. The items in the instrument were randomly split into two halves and the scores of the pilot test were used to compute the split-half correlation coefficient which was found to be 0,58. The split-half correlation coefficient was then adjusted using the Spearman-Brown formula and the split-half reliability was 0,73. The purpose of establishing the reliability of the achievement test was to determine whether the same results would be attained if the measuring device was administered more than once under similar situations and to establish the extent to which items assessing the same concept in a test concur (Singleton, Straits, & Straits, 2011; Vogt, Garden, & Haeffele, 2012). The other reasons for using split-half reliability in this study was because it was not possible to test and re-test the same learners because the subjects of the pilot project were not available and splitting the test items into two equal halves minimized the effects of fatigue and test anxiety. The alternative form of reliability that would have been used to determine reliability of the research instrument used in this study was test-retest reliability.

Test-retest reliability was not used to determine reliability of the achievement test because some participants could recall the responses they previously gave and could use the same responses in the subsequent test. This would have inflated the reliability coefficient. After the first administration of the measurement, conceptual change may possibly occur and participants who would have experienced conceptual change would have given responses that were completely different from the responses they had initially given. This would invariably lower the reliability coefficient.

3.6 Pilot study

In this study a pilot study was conducted using four Grade 12 learners from a school that was not selected to participate in this study. After choosing the participants, the researcher explained the importance of the test to the learners, informed them of their right to withdraw from the test at any moment, that the tests results would be used for the purpose of the research only and that they did not have to write their names on the answer scripts but only their age and sex. The test was administered by their Physical Science teacher at their school. This was done to minimize reactive effects. After the test learners, were asked to write comments. The researcher then collected the answer scripts and scored them following the guidelines in Table 2 below

Table 2: Mark allocation of the achievement test

	Algorithmic mark allocation	**Conceptual mark allocation**
0	Incorrect answer and working	Incorrect answer and explanation
1	For correct answer	For correct answer
2	For correct equation/strategy and mathematical manipulation	For an explanation with all the correct aspects
3	Maximum score for each problem	Maximum score for each problem

A pilot study was conducted to find out the reliability of the test, to check if the research was practical and to determine if the results were skewed (Baker, 1994). Participants of the pilot study were learners from a school that was not a site of the research to prevent contamination of the full-scale study. However, conducting a pilot study does not warrant the success of the full-scale study and data collected from a pilot study cannot be used to test the hypothesis (Pear, 2007 as cited in Singleton, Straits, & Straits, 2011). The other weakness of conducting a pilot study is that data obtained from a research instrument that was modified must not be reported (Teijlingen, Rennie, Hundley, & Graham, 2001).

3.7 Procedures

The researcher sought permission to conduct the study from the Circuit Managers of Highveld Ridge East and West circuits (see annexure 3). After being granted the permission the researcher wrote a letter to the Principals of the three schools where the research was conducted seeking permission to conduct the research (see annexure 3) and after being granted permission to conduct the study from the school Principals, the researcher met with Physical Science teachers who were teaching Grade 12 at schools. During the meetings the researcher outlined the aims, importance of the study and emphasized the need to stick to standard procedures of administering a test, the need to inform learners of their right to participate in the study and to completing the consent forms (see annexure 5).

40 scripts of the test (see annexure 1), 40 consent forms and 40 cover letters (see annexure 4) were sent to the three research locations. The assumption was that an average class had 40 learners and all the learners would participant in the study. Before the test was administered each of the three Physical Science teachers gave learners the covering letter, explained the contents of

the letter to the learners and asked them to contact the researcher if they needed confirmation of the contents of the letter and any clarification. This was done because the researcher could not personally explain the contents of the letter to the learners due to work commitments. On the day the learners wrote the test, the teachers gave each learner a copy of the question papers and answer scripts. Participation was voluntary. Non-volunteers were asked to remain silently seated in class while the test was in progress.

The learners were instructed to show how they arrived at their algorithmic solutions, provide explanations for conceptual answers and not to write their names but their sex and age on the answer scripts. At the end of the test the teachers collected the test and answer scripts. The question papers were collected to avoid information contamination because the test was administered on different days at each school. This test was administered on the day learners had a double period for Physical Science lessons during the last week of August 2011. The researcher later on collected all the scripts and scored them using a marking guideline (see annexure 2).

The test was administered during the last week of August 2011 because the schools in these circuits were following two different pacesetters and by the end of August all the schools had presumably taught chemical equilibrium, which offers learners an opportunity to revise stoichiometry concepts. The test was administered at the learners' schools by Physical Science teachers who taught the learners because a descriptive research design does not involve changing the natural environment. During the administration of the test the researcher could not control the lighting and ventilation of the examination venue, the level of noise and the time of the day the test was administered. In order to interpret research data the researcher should process the data first.

3.8 Data analysis

Individual algorithmic and conceptual problem solving scores were summarized in a table (see Annexure 6). The total algorithmic and conceptual scores for each participant were calculated separately and converted into percentages. The percentages were then used to compute descriptive and inferential statistics and categorization of learners. Descriptive statistics was included in data analysis of this study because descriptive statistics portrays data in a form that is effortless to Singleton, Straits, & Straits, 2011).

Descriptive statistics indices reported were the means, standard deviations, minimum and maximum scores, skewness as well as the Pearson coefficient. Algorithmic and conceptual means were the measures of central tendency included in descriptive statistics because they took into report all the data and, are used to compute standard deviations and to compare algorithmic and conceptual proficiency. Algorithmic and conceptual standard deviations were measures of dispersion included in descriptive statistics because they showed the extent to which algorithmic and conceptual scores were distributed around their means and they are more stable. Above all their calculations included every algorithmic and conceptual score. Ranges were not included in descriptive data because if the data has extreme values they could give an incorrect picture of the spread of data (Antonius, 2013). Skewness was included in descriptive data to show if the algorithmic and conceptual scores was symmetrical or asymmetrical

Pearson's moment product coefficient was included in descriptive statistics to describe the strength and direction of the association between algorithmic and conceptual problem solving proficiency. Pearson correlation was also included in descriptive statistics because it takes into account each and every algorithmic and conceptual score, it is the most stable measure of correlation and the algorithmic and conceptual scores were interval measures (Gay, Mills, & Airasian, 2003). Spearman rank coefficient and Phi coefficient were not included in descriptive statistics because algorithmic and conceptual scores were not ordinal measures and nominal measures respectively (Ruane, 2005).

The t-test for paired means was used to determine whether the association between algorithmic and conceptual problem solving proficiency was statistically significant or insignificant. The t-test was also used to establish if the difference between the conceptual and algorithmic means was statistically significant or insignificant. The t-test was used because algorithmic and conceptual problem solving means (paired means) were obtained from one sample, data was expressed as interval scales, problem solving proficiency follows a normal distribution and the participants were randomly selected. In this case Analysis of Variance (AOV) was not appropriate because it is used to compare three or more means and not two means. Descriptive statistics and inferential statistics were computed using Excel 2007 and the results were summarized in tables.

Algorithmic and conceptual solutions were classified as either correct solutions or incorrect solutions. The frequency of correct and incorrect solutions was determined and converted into percentages. The percentages were presented using double bar graph. The same was done for unattempted algorithmic and conceptual problems (see Figure 3). Individual percentages were used to categorize learners according to their algorithmic and conceptual problem solving proficiencies and the results were also presented using bar graphs (see Figure 1 and Figure 2). Bar graphs were used because they show trends hence they are helpful when comparing and contrasting data and people tend to process visual information faster compared to tabulated information. Solutions were analyzed qualitatively to determine the areas that gave learners challenges. A research study is useful if the results may be extended to the population from which the sample was drawn from.

3.9 External and Internal validity

In this study random selection of schools and participants enhanced the extension of the sample results to the population from which the sample was drawn because it minimized selection bias. The ability to generalize sample results to different settings (ecological validity) was enhanced by administering the achievement test at the learners' school using their Physical Science teachers which removed the researcher effect. In this study data was collected cross-sectionally and this eliminated the effects of maturation, testing, and mortality. Finally the scorer effect was minimized by having one scorer which reduced error variance due to disparity in performance caused by variations in the mind frame and wellbeing of the markers.

3.10 Summary

This chapter discussed the research design, the population, the sampling techniques, the sample and the research instrument used in this study. This chapter also presented the procedure followed, how validity and reliability of the instrument were established and how data would be analyzed.

CHAPTER 4

Data analysis

4.1 Introduction

This chapter presents the data that was collected from twenty-three (23) Grade 12 female learners and thirty-eight (38) male learners with an average age of 17.5 years, who were randomly selected from a former model C high school and two disadvantaged high schools in Highveld Ridge East and West circuits. The data was intended to answer the following questions;

(i) What is the relationship between conceptual problem-solving and algorithmic problem-solving proficiency of Grade 12 Physical Science learners?

(ii) How can the problem-solving proficiency of Physical Science learners in stoichiometry be categorized according to problem solving strategies?

(iii) What are the stoichiometry problems that learners are able to solve?

(iv) What are the weaknesses that exist in stoichiometry problem-solving that could be rectified during teaching?

This chapter presented descriptive statistics which would describe the relationship between algorithmic and conceptual problem solving. Also presented is the inferential statistics which would show whether the difference between algorithmic and conceptual problem solving performance (means) and the correlation between algorithmic and conceptual problem solving proficiency was statistically significant or insignificant. Also included in this chapter is data analysis used to categorize learners into either high algorithmic or high conceptual or low algorithmic or high conceptual or high algorithmic or low conceptual or low algorithmic or low conceptual problem solvers, comparison of percentages of correct algorithmic and conceptual solutions, incorrect algorithmic and conceptual solutions, unattempted algorithmic and conceptual solutions as well as weaknesses of the learners in stoichiometry problem solving.

4.2 Descriptive analysis

Descriptive analysis is an essential component of quantitative data analysis because it condenses, summarizes and describes data obtained from empirical evidence (Polit & Beck, 2004). Descriptive statistics indices computed and reported in this study were the means, standard deviations and skewedness values of algorithmic and conceptual problem solving proficiency and the Pearson correlation coefficient between algorithmic and conceptual problem solving proficiency. In this study problem solving proficiency was categorized as low if the mean score was below

50% and as high if the mean score was 50% and above. Low standard deviations would reflect a small variation in the data set (data concentrated around the mean) while a large standard deviation would reflect a large variation in the data set. A skewedness value of 0 would indicate that the data was normal distributed, skewedness values between +1.0 and -1.0 would indicate that data was slightly skewed. A skewedness value greater than +1.0 and less than -1.0 would indicate that data was significantly skewed. Positive skewedness value would indicate that there were more low scores compared to high scores while a negative value would indicate that there were fewer low scores compared to high scores (Antonius, 2013). The possible score for algorithmic problem solving was 18 marks and the possible score for conceptual problem solving was also 18. The actual algorithmic score for each participant was divided by 18 and multiplied by 100 to convert it into a percentage. The same was done with conceptual scores. The percentages were then used to compute descriptive statistics using Microsoft Office Excel 2007 and the results are summarized in Table 3 overleaf

Table 3: Means, standard deviations, skewedness, minimum scores, maximum scores of algorithmic and conceptual stoichiometry problem solving of grade 12 Physical Science learners

	Algorithmic	**Conceptual**
Mean	43.84	19.67
Median	44.4	22.2
Standard Deviation	23.2	10.66
Skewness	-0.07	0.43
Minimum	5.56	0
Maximum	88.9	50
Count	61	61

p = 0.05

Results in table 3 indicated that the maximum algorithmic and conceptual scores were 88,9% and 50,0% respectively while the minimum scores for algorithmic and conceptual scores were 5,56% and 0% respectively. This revealed that the maximum and minimum scores of algorithmic problem solving proficiency were higher than the maximum and minimum scores of conceptual problem solving proficiency. The results in table 3 also revealed that algorithmic problem solving proficiency (43,8%) and conceptual problem solving proficiency were low and that the average algorithmic problem solving proficiency (43.8%) was higher than the average conceptual problem solving proficiency (19.67%). The other finding shown in Table 3 was that the algorithmic and conceptual scores were not concentrated around their respective means. To be more specific algorithmic problem solving proficiencies were more dispersed around the mean (standard deviation = 23.2) compared to conceptual problem solving proficiencies (standard deviation = 10.6), implying that the conceptual mean was more representative of the sample proficiency compared to the algorithmic mean. Table 3 also revealed that both algorithmic proficiency (skewedness = -0.07) and conceptual problem solving proficiency (skewedness = 0,43) slightly deviated from normal distribution curve with algorithmic problem solving proficiency having more low scores than high scores while conceptual problem solving proficiency had more higher scores than lower scores.

4.3 Correlation between algorithmic and conceptual problem solving proficiency

The first objective of this study was to establish the magnitude and the direction of the correlation between algorithmic and conceptual stoichiometric problem solving proficiency among Grade 12

Physical Science learners in Highveld Ridge East and West circuits. A positive Pearson correlation coefficient would indicate that as one variable (either algorithmic or conceptual scores) increases the other variable also increases. On the other hand a negative Pearson correlation coefficient would indicate that as one variable increases the other variable decreases. A Pearson correlation coefficient of ; 0 (zero) would indicate that there is no relationship between variables, between 0.1 and 0.35 a weak relationship between variables, between 0.4 and 0.67 a moderate relationship moderate relationship between variables, between 0.7 and 0.9 a strong relationship between variables and of 1.0 a linear relationship (Weber & Lamb, 1970) . The results of the Microsoft excel 2007 computation of correlation are presented in Table 4 below.

Table 4: Pearson correlation coefficient between algorithmic and conceptual problem solving scores

	Algorithmic	Conceptual
Algorithmic	1	0.18
Conceptual	0.18	1

$p = 0.05$, $n = 61$

The results in Table 4 revealed that as algorithmic problem solving proficiency increases, conceptual problem solving proficiency increases, or as conceptual problem solving proficiency increases algorithmic problem solving proficiency also increases. The other information about the correlation between algorithmic and conceptual problem solving proficiency that was revealed by the results in Table 4 was that the magnitude of the correlation between algorithmic and conceptual problem solving ($r = 0.18$) was weak. To establish if the difference between the algorithmic and conceptual problem solving proficiency as well as the correlation between algorithmic and conceptual problem solving proficiency were statistically significant or insignificant may be deduced by inferential analysis. The t-stat and the t-critical were compared.

4.4 Inferential analysis

The inferential statistics used in this study was the t-test for paired means and t-stat and t-critical are compared. The difference between the means would be statistically significant if the t-stat is greater than t-critical and statistically insignificant if t-stat is less than t-critical. Statistical significance of the Pearson correlation coefficient would be determined by comparing the probability value and the significant level. Pearson correlation coefficient would be statistically significant when the probability value is less than the significant level, and statistically insignificant when the probability value is more than the significant level. The results of the t-test are summarized in table 5 below.

Table 5: A summary of the t-test paired means results

t-Test: Paired Two Sample for Means	**Algorithmic**	**Conceptual**
Mean	43.86	19.67
Variance	538.14	113.74
Observations	61	61
Pearson Correlation	0.18	
Hypothesized mean difference	0	
Df	60	
t Stat	7.94	
P(T<=t) two-tail	5.96E-11	
t Critical two-tail	2.000	

p= 0.05

The results of the t-test for paired means in Table 5 above revealed that the t-stat (7.94) was greater than the t-critical (2,000) which indicates that the difference between the algorithmic problem solving mean and the conceptual problem solving mean was significantly different. The results displayed in Table 5 also indicated that the probability value (5.96E-11) was less than the level of significance of 0.05 which indicated that the association between algorithmic proficiency and conceptual proficiency was not due to chance but real. Individual algorithmic and conceptual percentages were used to categorize learners according to their stoichiometry problem solving proficiency.

4.5 Categorizing learners according to problem solving proficiency

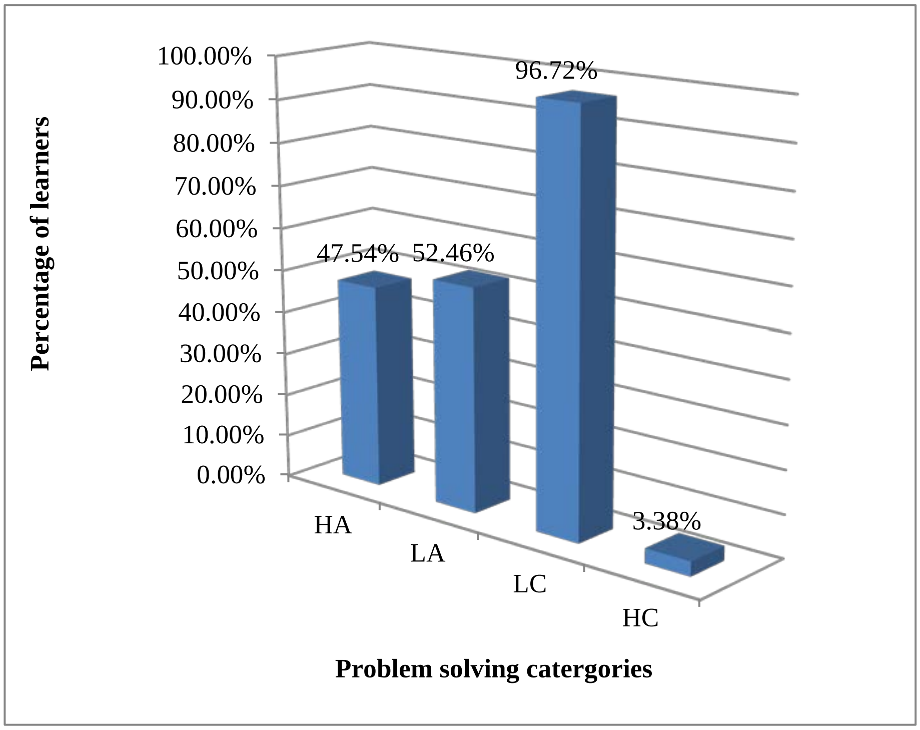
The second objective of this study was to categorize Grade 12 Physical Science learners in Highveld Ridge East and West circuits according to their problem solving proficiencies. Algorithmic and conceptual scores were categorized as illustrated in table 6 below.

Table 6: Problem solving proficiency categories and their descriptions

Category	**Description of category**
Low algorithmic problem solving proficiency (LA)	Algorithmic score less than 50%
High algorithmic problem solving proficiency (HA)	Algorithmic score of 50% and above
Low conceptual problem solving proficiency (LC)	Conceptual score a below 50%
High conceptual problem solving proficiency (HC)	Conceptual score of 50% and above

The number of learners in each category was determined, converted into percentages and presented in Figure 1 below.

Figure 1: Percentage of learners in each problem solving category



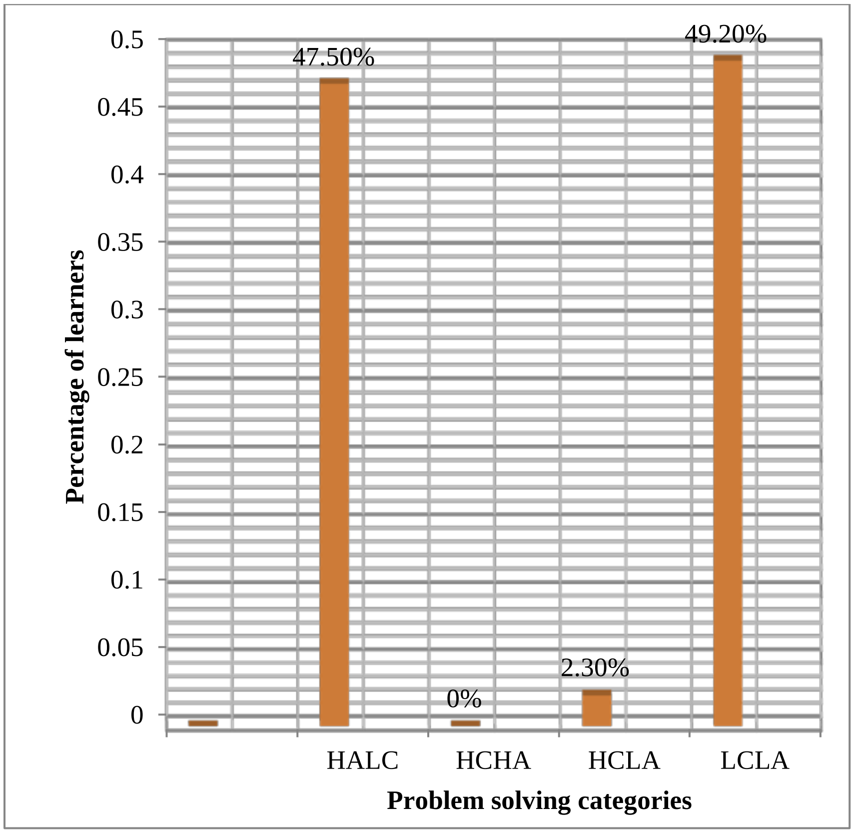
The result displayed in figure 1 indicated that the percentage of learners with high algorithmic proficiency (47,54%) was lower than the percentage of learners with low algorithmic proficiency (52,46%). In other words there was a small variation between the percentages of learners with high and low algorithmic problem solving proficiency. The results displayed in Figure 1 also showed that the percentage of learners with low conceptual proficiency (96,72%) was higher than the percentage of learners with high conceptual problem solving proficiency (3,38%). This means that there was a large variation of conceptual problem solving proficiency among the learners. The other result in shown Figure 1 above was that the percentage of learners with low algorithmic problem solving proficiency (52,46%) was lower than the percentage of learners with low conceptual problem solving proficiency (96,72%) and the percentage of learners with high algorithmic problem solving proficiency (47,54%) was higher than the percentage of learners with high conceptual problem solving proficiency. Lastly, the category with the least percentage of learners was the high conceptual problem solving proficiency. Algorithmic and the conceptual categorizes were paired as illustrated in Table 7 overleaf.

Table 7: Paired algorithmic and conceptual problem solving categories and their descriptions

Category	Description
Low algorithmic proficiency and low conceptual proficiency (LALC)	Less than 50% in both algorithmic and conceptual problem solving.
High algorithmic proficiency and low conceptual proficiency (HALC)	More than 50% and above in algorithmic problem solving and less than 50% in conceptual problem solving
Low algorithmic proficiency and high conceptual proficiency (LAHC)	More than 50% in algorithmic problem solving and more than 50% in conceptual problem solving.
High conceptual proficiency and high algorithmic proficiency (HCHA)	More than 50% in both conceptual and algorithmic problem solving.

The percentages of learners in each paired category are presented in Figure 2 overleaf.

Figure 2: Percentage of learners in each paired problem solving category

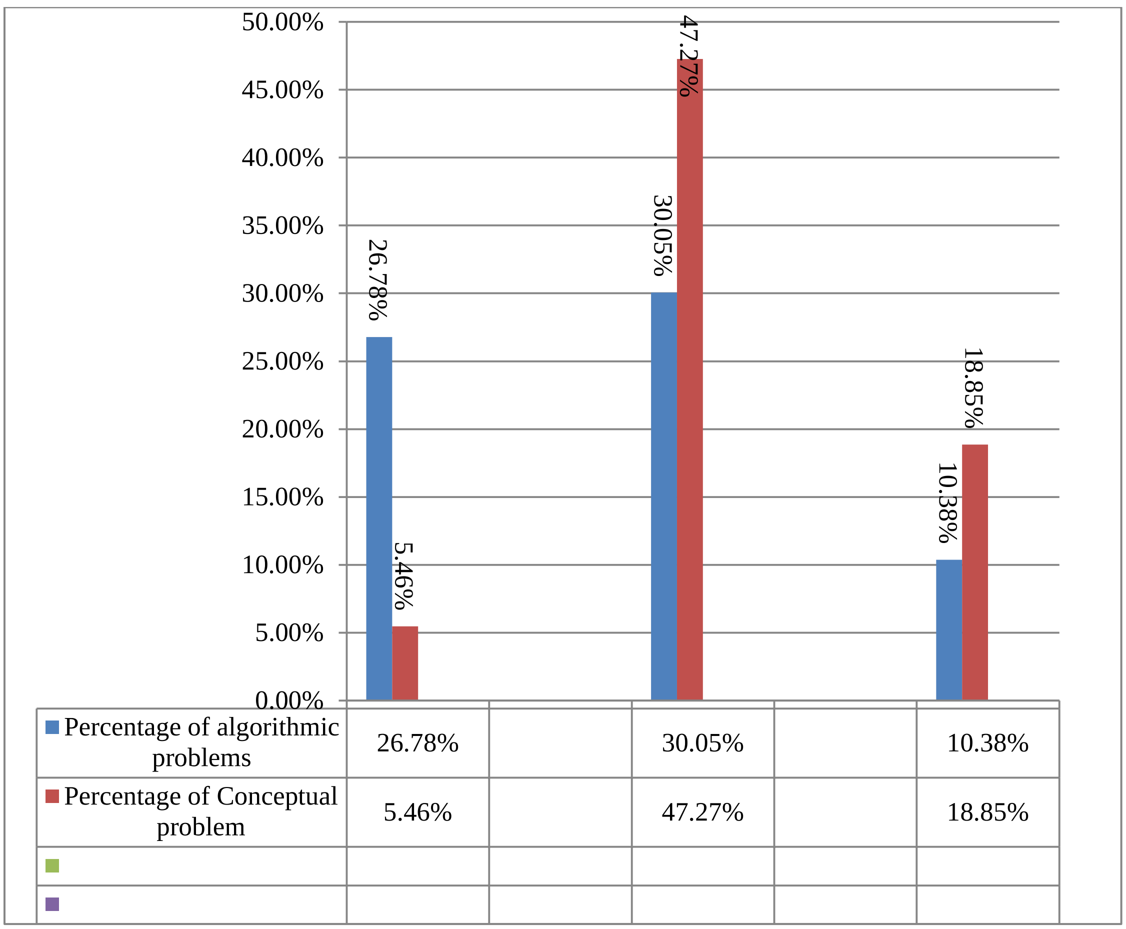


Results displayed in figure 2 revealed that there were no learners with high algorithmic and high conceptual problem solving proficiency and there are few learners with high conceptual and low algorithmic problem solving proficiency (2,30%). Figure 2 also revealed that the percentage of learners with high algorithmic and low conceptual problem solving proficiency (47,50%) was almost equivalent to the percentage of learners with low algorithmic and low conceptual problem solving proficiency (49,20%). The qualities of the solutions provided by the learners as well as the number of problems solved produced were determined and compared.

4.6 Comparing quantity of solutions

The third objective of this study was to compare correct algorithmic and conceptual solutions, incorrect algorithmic and conceptual solutions as well as the number of algorithmic and conceptual problems that were not answered. The frequencies of the correct and incorrect solutions were determined and converted to percentages which are presented in Figure 3 below.

Figure 3: A summary of algorithmic and conceptual solutions and unattempted



Results displayed in Figure 3 above indicated that the highest percentage was for incorrect conceptual problems (47,27%) and the lowest percentage was for correct conceptual solutions (5,46%). Figure 3 also indicated that there were more correct algorithmic solutions (26,78%) than conceptual solutions (5,46%), more incorrect conceptual solutions (42,27%) than incorrect algorithmic solution (30,05%) and more unattempted conceptual problems (18,85%) than algorithmic problems (10.38%). The percentage of incorrect algorithmic solutions (30,05%) was higher than the percentage of correct algorithmic solutions (26,78%) and unattempted algorithmic problems. For conceptual problem solving proficiency the percentage of incorrect solutions was the highest (42,27%), followed by the percentage of unattempted conceptual problems (18,65%) and the lowest percentage was for correct conceptual solutions (5,46%). After categorizing learners and comparing the quality and quantity of their solutions it was necessary to analyze their solutions in an effort to identify their weaknesses.

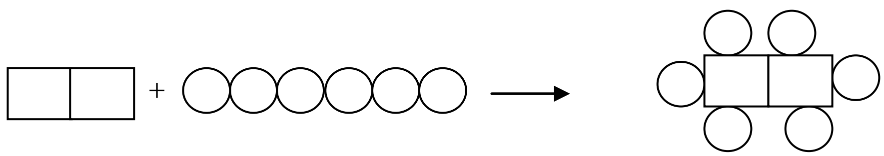
4.7 Stoichiometry problem solving weaknesses

The fourth objective of this study was to determine learners' weaknesses in stoichiometry problem solving. This was achieved by analyzing the solutions that were given by the learners.

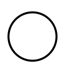
4.7 Qualitative data

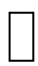
4.7.1 Interpretation of visual chemical diagrams

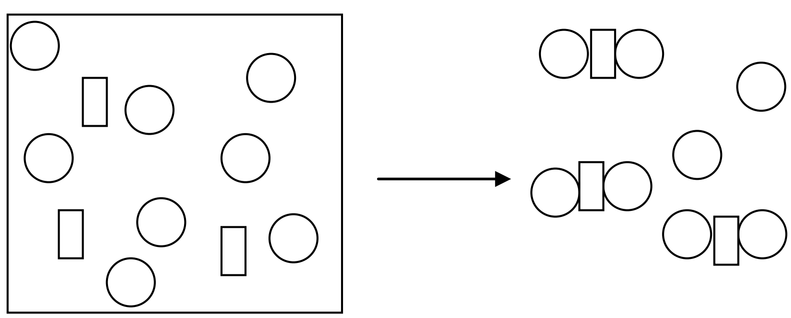
Problem 1.2 was intended to test the ability of learners to change a visual chemical equation into a symbolic equation. An analysis of the solutions provided by the learners revealed that 49.18% of the sample regarded $3H_2$ and $2NH_3$ as the same as 6H and N_2H_6 because they chose option B provided below.



Problem 3.2 required learners to write a balanced equation from a diagram provided below

Element A = 

Element B = 



Below are some of the answers given by learners

(I) $A_8 + B_3 \longrightarrow A_8B_3$

(ii) $4A_2 + 3B \longrightarrow A_2 + 3A_2B$

(iii) $4A_2 + B_3 \longrightarrow 4A_2 + 3B$

26% of the sample provided incorrect chemical formulae of the reactants (A_8 and B_3 instead of 8A and 3B) and 50% provided incorrect chemical formula of the excess product (A_2 instead of 2A). Problem 4.2 required learners to identify the limiting reagent in a chemical reaction from a diagram and 81.9% of the learners failed to identify the limiting reagent and to justify their solution. Problems 1.2, 3.2 and 4.2 were testing the ability of learners to interpret diagrams and it was found that learners have difficulties in interpreting chemical diagrams. Solutions to problems 1.2 and 3.2 showed learners were not proficient in communicating using chemical symbols.

4.7.2 The mole concept

59% of the participants chose option A as their solution to problem 2.2 and justified their solution by stating that gases with equal volumes have the same number of particles according to Avogadro's law. 57.4% of the sample gave an incorrect option (B) as their solution to problem 2.1. The learners arrived at this option after dividing the mass of oxygen given in the problem (8g) by the relative atom mass of oxygen ($16g.mol^{-1}$) instead of the molecular mass of oxygen ($32g.mol^{-1}$). The same mistake was made by learners when solving problem 4.1. When solving problem 5.1, 50% of the participants failed to calculate the number of moles of methane given in the problem statement since they divided the mass of methane by the relative molecular mass of water.

4.7.3 Conservation of mass

Problem 5.2 tested the learners' understanding of the law of conservation of mass. The solutions to this problem revealed that 40% of the sample of this study indicated that the total mass of the reactants was less than the total mass of the products and 8.20% indicated that the mass of the products will be greater than the mass of the reactants. The weakness that was revealed through the analysis of learners' scripts was that learners do not understand the law of conservation of mass.

4.7.4 Summary

This chapter presented descriptive statistics, inferential statistics, and categorization of learners according to their problem solving proficiency, a comparison of percentage of incorrect and correct algorithmic and conceptual solutions as well as a comparison of algorithmic and conceptual problems that were not solved. The results presented in this chapter indicated that there was a weak relationship between conceptual and algorithmic problem solving proficiency, algorithmic proficiency is higher than conceptual proficiency and that there are no learners with high conceptual or high algorithmic proficiency while the majority of learners had low conceptual problem solving proficiency. Some learners have difficulty solving multi-stepped problems, visual problems and creating an accurate problem representation.

Chapter 5

Discussion

5.1 Introduction

This chapter presents a discussion of the weak positive correlation between conceptual problem solving and algorithmic problem solving, the categorization of learners, and comparison of percentages of correct algorithmic and conceptual solutions, incorrect algorithmic and conceptual solutions as well as the number of unattempted algorithmic and conceptual solutions. The chapter also presents learners' weaknesses in solving stoichiometry problems such as writing chemical equations, problem representation and interpretation of visual diagrams. The discussion includes the researchers' suggestions while relating the findings from the results of this study to previous studies. The last section includes the implications of the results, recommendations and the conclusion.

5.2 Relationship between algorithmic and conceptual problem solving proficiency

The results in table 5 (r = 0.18) revealed that there was a weak positive relationship between low algorithmic and low conceptual problem solving proficiency among Physical Science learners in Highveld Ridge East and West circuits. This implies that Grade 12

Physical Science learners with low algorithmic problem solving proficiency also had low conceptual problem solving proficiency. However, this does not mean that low stoichiometric algorithmic problem solving proficiency was caused by low conceptual problem solving proficiency or that the low conceptual problem solving proficiency caused low algorithmic problem solving proficiency learners, instead there was an association between algorithmic and conceptual stoichiometric problem solving proficiency among the learners. A Pearson correlation coefficient of 0.18 also implies that algorithmic problem solving proficiency of the learners in Highveld Ridge East and West circuit cannot be used to predict the learners' conceptual problem solving proficiency. On the other hand conceptual problem solving proficiency of the learners cannot be used to predict the algorithmic problem-solving proficiency.

Squaring the Pearson correlation coefficient between algorithmic problem solving proficiency and conceptual problem solving proficiency ($r = 0.18$) would give a determinant coefficient of 0.032 which meant that the weak association between low algorithmic problem solving proficiency and low conceptual problem solving proficiency was only found in 3,2% of Physical Science learners in Highveld Ridge East and West circuits. The low correlation coefficient and the low number of learners with an association between algorithmic and conceptual problem solving proficiency could be due to the fact that in Highveld Ridge West and East circuits' stoichiometry was taught during the second quarter of Grades 10 and 11 and applied during the second quarter of Grade 12. This probably does not enhance hierarchical organization of stoichiometry information among learners which makes retrieval of the information from the long term memory to the working memory difficulty. The other possible cause of this low correlation could be that traditional teaching and assessment methods were used to teach stoichiometry because some of the Physical Science teachers in these circuits were not specialists in Chemistry but, Physics and Biology specialists. Some teachers may view stoichiometry as algorithms to be taught (Rollick, Bennett, Dharsey, & Ndlovu, 2009).

Compared to previous studies, the direction and the strength of the correlation in this study concur with the findings of Agung and Schwart (2007) and BouJaude and Barakat (2003) who found a positive correlation between algorithmic and conceptual problem solving. However, the magnitude of the Pearson correlation coefficient of this study (r = 0.18) was less than the Pearson correlation coefficient reported by BouJaude and Barakat (2003) (r

= 0.76). A possible explanation for the difference between the Pearson coefficient (r = 0.18) of this study and the Pearson coefficient reported by BouJaude and Barakat (2003) (r = 0.76) is that participants used in the study conducted by BouJaude and Barakat (2003) were from a streamed class, hence they were high performers in Science whereas the participants of this study were high achievers and low achievers. Another possible explanation is that participants in the study conducted by BouJaude and Barakat (2003) had a better understanding of stoichiometry compared to participants in this study because they have been taught Chemistry subject from grade 7. On the other hand in Highveld Ridge East and West circuits learners study Chemistry in Grades 8 and 9 as a component of Natural Science (a combination of Chemistry, Life Science & Physics) and in Grades 10, 11 and 12 as a component of Physical Science (combination of Chemistry and Physics). The other possible cause of the difference between these Pearson correlation coefficients could be that learners in Lebanon were taught Chemistry by teachers who specialized in teaching Chemistry whilst in Highveld Ridge East and West circuits learners may have been taught Chemistry in Grades 8 and 9 by either a Life Science or Physics teacher and in Grades 10, 11 and 12 by a Physics specialist. This is because there is a shortage of qualified Science teachers in South Africa. Finally in the previous study it was reported that the teacher spent some time solving stoichiometry problems which is highly unlikely in Highveld Ridge East and West circuits because teachers had limited time to teach stoichiometry because the Physical Science curriculum has a high work density (Umalusi, 2006). The duration and sequencing of teaching stoichiometry concepts was prescribed by the provincial Department of Education in the form of pacesetters.

The result of this study also refutes Yarroch (1985) who found that there was no correlation between algorithmic problem solving proficiency and conceptual problem solving proficiency. The difference between the correlations of this study and the study that was conducted by Yarroch (1985) could be due to the fact that the problems used in the previous test were limited to chemical equations whereas the problems in the test for this study covered the entire stoichiometry curriculum. Problem solving abilities of students gave rise to the categorization of learners according to their problem solving abilities.

5.3 Categorization of learners

An enhanced result would be high algorithmic, high conceptual problem solving proficiency and a combination of high algorithmic and high conceptual problem solving proficiency. However, the results displayed in Figure 1 revealed that in Highveld Ridge East and West circuits the majority (97,72%) of learners had low conceptual problem solving proficiency. In other words the majority of the learners (97,72%) were incapable of applying rules to unfamiliar situations. This means that stoichiometry problem solving that the learners had previously encountered had not helped them comprehend of stoichiometry concepts. This is contrary to Bowen and Bunce (1997) who suggested that problem solving in stoichiometry leads to comprehension of concepts. Figure 1 also revealed that 47.54% for the learners in Highveld Ridge East and West circuits had high algorithmic problem solving proficiency and 52.46% had low algorithmic problem solving proficiency. This means that almost half of the Physical Science learners in Highveld Ridge East and West circuits are capable of applying a set of operations to solve problems while the other half were incapable of applying a set of operators to solve problems.

This may due because traditional teaching methods which promote competence in algorithmic problem solving at the expense of competence in conceptual problem solving were used to teach stoichiometry (Nakhleh, 1993 ; Stamuolasis, Tsaparlis, Kamilatos, Papavikonomau & Zarotiadou, 2004 & 2005).The high percentage of learners with low conceptual problem solving proficiency may be due to the fact that since teachers are familiar with high school stoichiometry problems hence they tend to demonstrate problem solving quantitatively. This may also mean that the learners lack the ability to formulate a problem solving plan.

The results of this study concur with the findings of Okanlawon (2008) who observed that the percentage of learners with high algorithmic problem solving proficiency was higher than the percentage of learners with high conceptual problem solving proficiency. The similarity between the results of the current study and the previous study may be explained by the fact that the participants in these two studies were of the same age (17-18) and probably at the same cognitive level. The other possible explanation for this similarity may be that traditional teaching methods were used to teach stoichiometry thus algorithmic problem solving was promoted at the expense of conceptual problem solving (Stamuolasis et al 2004 & 2005)

The percentage of conceptual problem solvers in this study was less than the percentage of conceptual problem solvers reported by Okanlawon (2008). The difference in the results of these two studies may be due to the difference in the way learners were categorized. In this study the learners were categorized using overall algorithmic percentages and overall conceptual percentages whereas in the study conducted by Okanlawon (2008) students were categorized by the number of algorithmic problems and the number of conceptual problems they successfully solved. The results reported by Okanlawon (2008) because data was collected by two instruments (an achievement test and speak-aloud) while in this study the data was collected using a single instrument (achievement test).

When algorithmic and conceptual problem solving categories of learners were paired, it was found that the percentage (47,54%) of participants with a combination high algorithmic/low conceptual proficiency was almost the same as the percentage of participants with a combination of low conceptual/low algorithmic proficiency (49,18%), 3.28% of the sample had a combination of high conceptual/low algorithmic abilities, while none of the participants had a combination of high conceptual/high algorithmic proficiency. The fact that there were no learners with a combination of high algorithmic and high conceptual problem solving proficient means that there are no Physical Science learners in Highveld Ridge East and West circuits who can fit the definition of a proficient problem solver that was provided by OECD (2012). According to this scenario there are no Physical Science learners in Highveld Ridge

East and West with all of the following capabilities; recognize associations, determine answers successfully, create clear-cut explanation, comprehend and utilize symbols.

The results of this study differed from Pickering's (1990) and Yilmaz, Tuncer and Alp's (2007) results. The difference between the results reported by Chui (2001) and the results of this study may have stemmed from the fact that in Turkey theory is reinforced by laboratory work while in Highveld Ridge East and West circuits most of the disadvantaged schools do not have laboratories or if they do they are dysfunctional, therefore the learners do not reinforce theory practically. However, the result of this study did not totally contradict Chui's (2001) results because in both studies the percentage of learners with a combination of low algorithmic and high conceptual problem solving proficiency was almost equivalent (3,28% in this study and 3,94% in the previous study). The results of this study also differed from the results of the study conducted Yalmaz, Tuncer and Alp (2007) who found that the majority of the learners were high algorithmic and high conceptual problem solvers. The difference between the results of this study and the study done by Yalmaz et al (2007) could be that the challenges in the instrument (test) were exercises because they were familiar to the participants since they had encountered them preparing for the university entrance test whereas in Highveld Ridge, examination preparation is usually done in Grade 12 hence the challenges in the achievement test were problems.

5.4 A comparison of correct solutions, incorrect solutions and unattempted problems

A comparison was done of the percentages of

(i) correct solutions of algorithmic and conceptual problems

(ii) incorrect algorithmic and conceptual problems

(iii) unattempted algorithmic and conceptual problems were conducted in this study. The best result would be a high percentage of correct algorithmic and conceptual solutions, a low percentage of incorrect algorithmic and conceptual solutions, a low percentage of incorrect solutions and unattempted problems. However, the results presented in Figure 3 in Chapter 4 revealed that the percentage of incorrect solutions was greater than the percentage of perfect solutions. This implies that learners in Highveld Ridge East and West circuits lack content and procedural knowledge. Higher percentage of incorrect solutions can be cause by the learners inability to consider the following questions before answering a problem; “What kind of a problem is this? And “What strategy is useful for this kind of a problem” (Middlecamp & Kean, 1987). Failure to considered these two questions would have render learners unable to relate the new problems to the problems they had previously solved hence unable to retrieve an appropriate algorithm or link concepts.

On comparing correct algorithmic and conceptual solutions, the percentage of correct algorithmic solutions was higher (26.78%) than the percentage of correct conceptual solutions (5.46%). Lythcott (1990) found that the percentage of correct algorithmic solutions was higher than the percentage of correct conceptual solutions and the results of this study confirmed these findings. However, the percentage of correct algorithmic solutions in this study was less than the percentage of correct algorithmic solutions that was reported by Lythcott (1990). This anomaly may be attributed to the fact that learners in the former had extensive practice in answering algorithmic problems therefore the before they were tested while in this study the level of exposure to algorithmic problem solving was not controlled. Another plausible explanation may be that the problems that were given to participants in the study done by Lythcott (1990) were limited to mass problems only whereas in this study mass problems were part of the test.

The results displayed in Figure 3 revealed that 10.38% and 18.85% of the participants of this study did not solve algorithmic and conceptual problems respectively. This indicated that the frequency of solving algorithmic problems in Highveld Ridge East and West circuit was slightly higher than the frequency of solving conceptual problems. This may imply that learners in Highveld Ridge East and West circuits had mastered algorithms more than creative thinking. Another probable explanation for this could be that Physical Science learners in these two circuits were taught to solve stoichiometry problems algorithmically because learners frequently use problem solving strategies that they were taught at school (Fach, de Boer & Parchmann, 2007; Toth & Kiss, 2005). This result concurs with Glazar and Devetak (2002) as well as Mason (1984), who reported that reported that the frequency of solving algorithmic problems was higher than the frequency of solving conceptual problems. This similarity could possibly be attributed to the fact that algorithmic problem solving in all these studies required low order cognitive skills. However, this result shows that Physical Science learners in Highveld Ridge East and West circuits were willing to engage in problem solving (OECD, 2013).

5.5 Weaknesses of learners in solving stoichiometry problems that can be remedied

5.5.1 Visual representations

In problems 1.2, 3.2 and 4.2, the researcher was testing the ability of learners to interpret diagrams and it was found that learners failed to interpret chemical diagrams. However, learners should be familiar with interpreting diagrams from Grade 10 because the National Curriculum Statement (June 2006) explicitly states that learners should be able to:

(i) Balance reactions equations by using models of reactants molecules and rearranging the atoms to form products by conserving atoms.

(ii) Represent molecules at a microscopic level using circles and rearranging the pictures to form the product molecules by conserving atoms.

The problem may be the teachers in these two circuits being familiar with writing, balancing of chemical equations and identification of the limiting reagent they tend to demonstrate problem solving of these concepts quantitatively. Also the teachers may have ignored the prior knowledge of the learners hence minimal learning occurred or the learners failed to transfer knowledge from the familiar (traditional problems) to the unfamiliar.

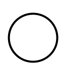
However these results confirm the results that were reported by Gabel (1999), Treagust & Chittleborough, (2001) that novices struggle to interpreting chemical diagrams. These results refute the results that were reported by Gabel and Sherwood (1983) who reported that learners who used the proportional method to solve stoichiometry problems attain lower achievement compared to learners who used diagrams. These results also counter Larkin (1981) who found that qualitative representations contain relationships and other considerations of the problem component which enables experts to see how information is linked respectively.

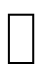
5.5.2 Subscripts and coefficients

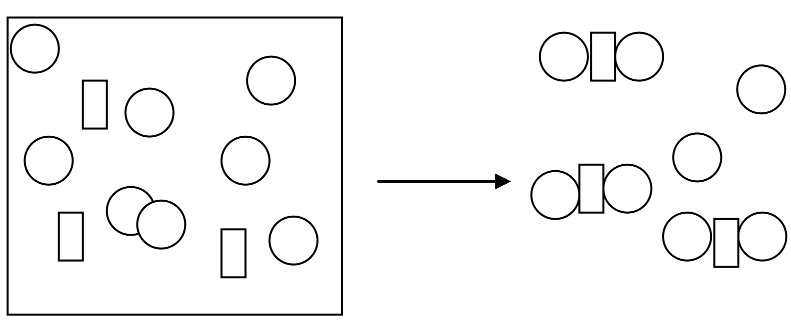
Problems 1.1 and 1.2 tested the learners' ability to write a balanced chemical equation of a reaction between nitrogen and hydrogen. The majority of the participants managed to write a balanced chemical equation for problem 1.1 but failed to show how they arrived at the answer. This shows that the learners in Highveld Ridge East and West had not failed to master an algorithm used to balance chemical equations nor they could not use diagrams to balance equations. This may be an indication that showing how the equation was balanced is a problem. The result above may be due to the fact that the learners had encountered the balanced equation while studying chemical equilibrium and the manufacture of fertilizers (Haber process). However, the majority of the learners failed to answer problem 1.2 which was evaluating the learners' ability to interpret chemical diagrams. This demonstrated that do not understand that the chemical formula H_2 indicates that hydrogen exist naturally as a diatom and the chemical formulae NH_3 means that 3 atoms of hydrogen are chemically combined to one atom of nitrogen. According to the definition of problem solving in OECD, (2012) Physical Science learners in Highveld Ridge East and West circuits were not proficient problem solvers because they did not comprehend chemical symbols and failed to utilize the symbols within the context of a problem.

The other weakness that was exposed by choosing option B of problem 1.2 was that students do not understand that the coefficient before ammonia ($2NH_3$) indicating that there are 2 separate molecules of ammonia and the coefficient before hydrogen ($3H_2$) indicating that there are 3 molecules of hydrogen. In this case learners failed to utilize repertoire to assist them to solving a harder problem Middlecamp & Kean, 1987). The other reason is probably that learners were unfamiliar with diagrammatical chemical equations hence they could not retrieve anything from their long term memory. Nevertheless, this result agrees with Lemma's (2013) findings that 56.5% of students and 6.67% of teachers believed that N_2H_6 is the same as $2NH_3$ and H_4 is the same as $2H_2$. The fact that learners managed to solve problem 1.1 and failed to solve problem 1.2 which was evaluating the same concept may be an indication that problem 1.1 did not to provide academic challenges that improves a learner's comprehension (Van de Walle, 2003).

Problem 3.2 was intended to determine if learners could write balanced chemical equations from a visual diagram shown below.

Element A = 

Element B = 



Below are some of the answers that were given by the participants:

(I) $A_8 + B_3 \longrightarrow A_8B_3$

(ii) $4A_2 + 3B \longrightarrow A_2 + 3A_2B$

(iii) $4A_2 + B_3 \longrightarrow 4A_2 + 3B_3$

The above solutions showed that learners do not understand the use of subscripts, coefficients and cannot write chemical equations. These findings correspond with the findings of Potgieter, Rogan and Howie (2005). Failure of learners to write balanced chemical equations also corresponds with Childs and Sheehan's (2009) findings.

5.5.3 Conservation of atoms

Problem 5.2 tested the learners' understanding of the law of conservation of mass. The weakness that was revealed through the analysis of learners' scripts was that learners do not understand the law of conservation of mass and this partially concurs with Lemma (2013) who reported that 62.5% of the participants thought that the mass of fuel and oxygen was less than the mass of the exhaust gases. Learners thought the mass of the products of combustion is less than the mass of the reactants because they ignore the mass of the gaseous products. On the other hand, learners thought that the mass of products was greater than the mass of reactants and this may be because they ignored the mass of oxygen that reacts with the fuel. The solutions to problem 5.2 showed that the learners had difficulties in abstract thinking. However, combustion is a process which the learners encounter before learning about it. As a result they may have alternative conceptions. The prevalence of the above alternative conceptions among learners might be an indication that when the law of conservation of matter is being taught prior knowledge of learners is being ignored, hence alternative conceptions are hardly discussed; therefore learners do not modify nor discard these alternative conceptions.

5.5.4 The mole concept

Problems 2.1 and 2.2 evaluated the ability of learners to solve gas problems and the average scores were less than 1.5 (half). 59% of the participants chose option A, which states that at standard temperature and pressure gases with the same volume have equal masses, as their solution for problem 2.1. The explanation provided was that gases with equal volumes have the same number of particles according to Avogadro's law. The weakness identified by analyzing solutions to problem 2.1 was that Grade 12 learners in Highveld Ridge East and West circuits thought that molecules, atoms, ions and electrons have the same masses. This could have stemmed from the fact that during learning the learners did not explore the various particles that are referred to in the definition of the mole nor do they understand the meaning of molar mass. The other possible cause of this alternative conception may be that Chemistry textbooks introduce the mole concept incorrectly by attributing its meaning to chemical mass (Furio, Guisasola, & Raticliff, 2000). The above weakness in stoichiometry problem solving that Grade 12 Physical Science learners in Highveld Ridge circuits had was previously reported by Upahi and Olorundare (2012) who established that the majority of students do not have a clear understanding of basic concepts such as the molar volume and mass. Modic (2011) found that students think that two substances with the same masses have the same number of moles.

Problem 5.1 required learners to calculate the relative molecular mass of methane, the number of moles of methane in 20 grams, and then calculate the number of moles of water formed. Instead the learners calculated the relative molecular mass of water (18g) and substituted this value into the equation n = m/M. This indicated that the learners have problems with identifying given data, unknown data and linking them. In other words they were not proficient in understanding the problem and devising a problem solving strategy (Polya, 1957) and recognize the associations between quantities, calculate correctly and efficiently and 30% mathematical manipulation (Ochonogor, 2001; OECD, 2012). Nevertheless, this result concurs with Adigwe (1996) as cited in

Ochonogor (2001) who stated that learners simply substitute numerical values without taking into account relationships. This result also concurs with considering relationship and Staver and Lumpe (1995) found that learners who rely on memorized algorithms fail to recognize relationships between concepts.

5.5.5 Limiting reagent

Problem 4.2 tested the ability of students to identify the limiting reagent from a diagram and to justify their solutions. The average score (0.67 out of 3) was less than the average score of problem 4.1 (1,3) which tested the learners' ability to identify a limiting reagent using an algorithm. The indicated that the learners in Highveld Ridge East and West circuits were better in identifying limiting reagents algorithmically rather than from diagram and that problem 4.1 did not offer the learners academic challenges that improved they way of thinking (OECD, 2003). The other reason may be that participants did not have extensive practice in solving visual limiting reagent problems hence they had to retrieve information that was required to solve the problem from the working memory consensually. This may have overloaded their working memory and ultimately lower their achievement. The other possible cause could be that traditional teaching methods may have been used to teach learners how to identify the limiting reagents as was observed by Okanlawon (2010) in Nigeria. However, there is no empirical evidence in this study to support any of these assertions.

However, the low average score of problem 4.2 corroborates BouJaoude and Barakat's (2003) finding that the majority of learners lacked conceptual understanding of the limiting reagent**.** A possible explanation for the similarity of the findings of these two studies may be the overreliance of learner on algorithmic strategies to identify limiting reagents. The low conceptual problem solving proficiency of the limiting reagent observed in this study contradicts the findings of Chui (2001) despite that in these studies the conceptual problems were presented to the learners in a pictorial form. This difference was possibly due to the fact that the participants in the study conducted by Chui (2001) were more exposed to limiting reagent problems in a pictorial form as compared to participants in this study.

Four participants out of sixty one participants (6.56%) had average scores above 50% when algorithmic and conceptual percentages were combined. This result showed that the overall achievement in stoichiometry is dependent on algorithmic and conceptual problems solving proficiency. This result support Potgieter and

Davidowitz (2010) and Potgieter, Rogan and Howie (2005) claimed that stoichiometry that stoichiometry is poorly mastered by learners. However, this result differs from the marked improvement in stoichiometry achievement that was reported by Davidowitz, Gail and Murray (2010).

5.6 Strengths of the study

The strengths of this study are that data was collected from learners from different socio-economic backgrounds in a relatively short period of time and random sampling enhanced population validity because the sample was almost representative of the population. The other advantage of this study is that the achievement test was administered in the natural environment of the participants therefore reactive effects were minimized.

5.7 Limitations of the study

One of the weaknesses of this study was that conclusions drawn were based on observations made once and the research design (descriptive quantitative) did not eliminated rival explanations. The sample used in this study did not include rural, farm and private; therefore the results of the study cannot be extended to learners in these schools. No other research instrument was used to verify the results of the achievement test. A combination of an achievement test and an interview were used, detailed information of how learners solve stoichiometry problems may have been obtained and the results of the test would have been verified. According to Gall, Gall and Borg (2005) the results of a descriptive survey study cannot be used to infer the cause and effect. It follows that from this study that it cannot be inferred if low algorithmic problem solving proficiency was a result of low conceptual problem solving proficiency or low conceptual problem proficiency was a result of low algorithmic proficiency.

5.8 Implications

From 2008 to 2011 the final Matriculation Physical Science Examination Paper 2 has been evaluating the ability of learners to calculate equilibrium constants. These problems required learners to relate the coefficients in the chemical equations to the number of moles provided or to determine the number of moles formed/used, number of moles at equilibrium, concentration at equilibrium and calculate the equilibrium constant. Relating the coefficients in a balanced chemical equation to the number of moles provided in the question can be done successfully by learners with conceptual understanding of stoichiometry. In addition conceptual understanding of stoichiometry is also required to explain the effect of changing concentration and pressure on chemical equilibrium position. Calculating number of moles formed/used, moles at equilibrium, concentrations at equilibrium and the equilibrium constant can be done successfully if students can solve stoichiometry problems algorithmically. Low algorithmic and conceptual problem solving proficiency observed in this study implies that students in Highveld Ridge East and West circuits are unlikely to successfully solve chemical equilibrium problems.

The skill of writing and balancing chemical equations is normally tested in the Matriculation Examinations in organic chemistry and industrial chemistry. In organic chemistry learners are required to write balanced chemical equations or write structural equations. Low algorithmic and conceptual problem solving proficiency observed in this study implies that Physical Science learners in Highveld Ridge East and West circuits will attain low marks when solving problems that require them to write balanced chemical equations. It has to be noted that calculation equilibrium constant is not affected by the learners' ability to write balanced equations since normally the examiners provide learners with balanced chemical equations. If it happens that one year, the examiners do not provide balanced chemical equations in a stoichiometric or chemical equilibrium problem; the performance of learners in Highveld Ridge West and East circuits is likely to decrease considering their inability to write balanced chemical equations.

5.9 Recommendations

This study has revealed that Grade 12 Physical Science learners have low algorithmic and conceptual proficiency in solving stoichiometry problems. This is despite the fact that the Mpumalanga Department of Education is conducting workshops aimed at improving learners' achievement in Physical Science. However, most of these workshops are trainer and knowledge content centred. It is therefore recommended that the Mpumalanga Department of Education should conduct teacher development programs that are not trainer-centred and lead to improved learner acquisition of knowledge such as Science Teachers Learning from Lesson Analysis (Taylor & Roth, 2010). The strength of this programme is that it improves learners' achievement because teachers who experience this programme probe and engage learners in analyzing records and observations more than teachers who did not experience this programme. By so doing learners are given more chances to relate their information to novel situations. The advantage of probing learners' responses is that alternative conceptions held by learners are exposed and the teacher can then engage the learners in conceptual change and it increases problem solving (Ge & Land, 2003).

The other roles of Mpumalanga Department of Education in improving proficiency in stoichiometry problem solving is to provide schools with textbooks with multiple representations of the information, models and laboratories. The advantage of providing learners with models is that the use of models gives learners a chance to test their predictions, learners at concrete and formal cognitive levels are accommodated. It is further recommended that the Mpumalanga Department of Education should include conceptual problems in the cluster, regional and provincial tests and examinations. This will give learners the opportunity to practice relating their knowledge to unfamiliar situations. The responsibility of improving proficiency in stoichiometry does not only lie on the Mpumalanga Department of Education but, also with Physical Science teachers.

Physical Science teachers are familiar with most problems they use to teach stoichiometry problem solving. It is therefore recommended that they should desist from demonstrating problem solving in a linear way (Wilson, Fernandez, & Hadway, 1993), but rather in show learners fractional solutions that have to be examined to discover routes that are capable of leading to the result. It is also suggested that when teaching stoichiometry teachers should use “Progressive teaching methods, like problem-based learning, inquiry-based learning, individual and group projects that foster deeper understanding and prepare learners to apply their knowledge in novel situations” (Easton, 2012 as cited in OECD, 2003). The use of problem based learning has been suggested because it is a teaching method that enhances deeper understanding of material (Akinlogu and Tandaolgon, 2007; Bilgin, Senocak & Misozbilir, 2008; Samaranjeeet, Kamisash, & Siti, 2005). One of the advantages of problem based instruction is that it is learner-centred therefore learners actively construct knowledge.

The advantage of group project is that learners are given an opportunity to use their prior knowledge which exposes their alternative conceptions. The group members will then, explore (debate and verify) the alternative conceptions which lead to conceptual change hence learners will have less alternative conceptions (Basil, 1989). The other advantage of group projects is that learners assist each other to rephrase the problem, represent the problem, see their poorly formulated ideas being more precisely formulated by their peers and integrate their ideas visually (De Corite, Greer, & Oerschaffel, 1996 as cited in Malouff, 2008). All this facilitates learners’ understanding of the concepts, problems and the execution of problem solving. Finally, group projects develops learners higher order cognitive skills such as predicting, metacognition analyzing and evaluating which are required during problem solving (Malouff, 2008).

The other recommendation is that Physical Science teachers in Highveld Ridge East and West circuits should provide their learners with extensive practice in stoichiometry problem solving because practice enhances retrieval of information and ultimately reduces the work load on the working memory when solving problems. Also at school level stoichiometry problem solving achievement can be improved by exposing learners to submicro-diagrams and physical models.

The low proficiency in algorithmic and conceptual stoichiometry problem solving that has been observed in this study confirms the report published by Mphachoe (2009) after moderating the National Curriculum Statement Examination Physical Science Paper 2 in Mpumalanga province. In Mpumalanga Province, learners are taught to writing and balancing chemical equations in Grade 10, quantitative chemistry in Grade 11 and these concepts are applied in Grade 12. It is recommended that these concepts be taught one after another as in the Cambridge IGCSE syllabus to enable learners to organize their information hierarchically and recognize the connections between these concepts.

Considering that basing conclusions on one observation is one of the weaknesses of a cross sectional design, it is recommended that the study should be repeated using a longitudinal design and the achievement test to be coupled with a think aloud interview. Lastly it is recommended that Highveld Ridge East and West circuits should conduct content enrichment workshops on stoichiometry and problem solving.

5.10 Conclusion

From this study it can be concluded that Physical Science learners in Highveld Ridge East and West circuits had low algorithmic and conceptual problem solving proficiency in stoichiometry. However, the achievement of conceptual problem solving is lower than the achievement of algorithmic problem solving. The relationship between algorithmic and conceptual problem solving achievement is positive and weak and for students to pass stoichiometry they should be good in solving both algorithmic and conceptual problems. Learners in these two circuits have difficulties in solving multi-stepped problems, interpreting visual diagrams and chemical equations and understanding the law of conservation of mass.

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Annexure 1

Appendix 1

Stoichiometry test

Task	Stoichiometry test	**Duration**	60 minutes
Grade	11 & 12	**Examiner**	TIGERE
EDWIN			
Total	52		

Instructions and information

1. Answer all questions.
2. Number your answers correctly according to the numbering system used in this questionnaire.
3. Give a reason or show your working on the space provided.
4. Do not write your name on your answer script. Write the name of your school, your Grade, location of your school (Low density or High density)

RELATIVE ATOMIC MASSES

C = 12	O = 16	N = 14
Cl = 35.5	S = 32	H = 1

FORMULA

C = m/v   n = m/M $\frac{n_a}{n_b} = \frac{C_aV_a}{C_bV_b}$

CONSTANTS

Volume of mole of a gas at STP =22,4dm^3

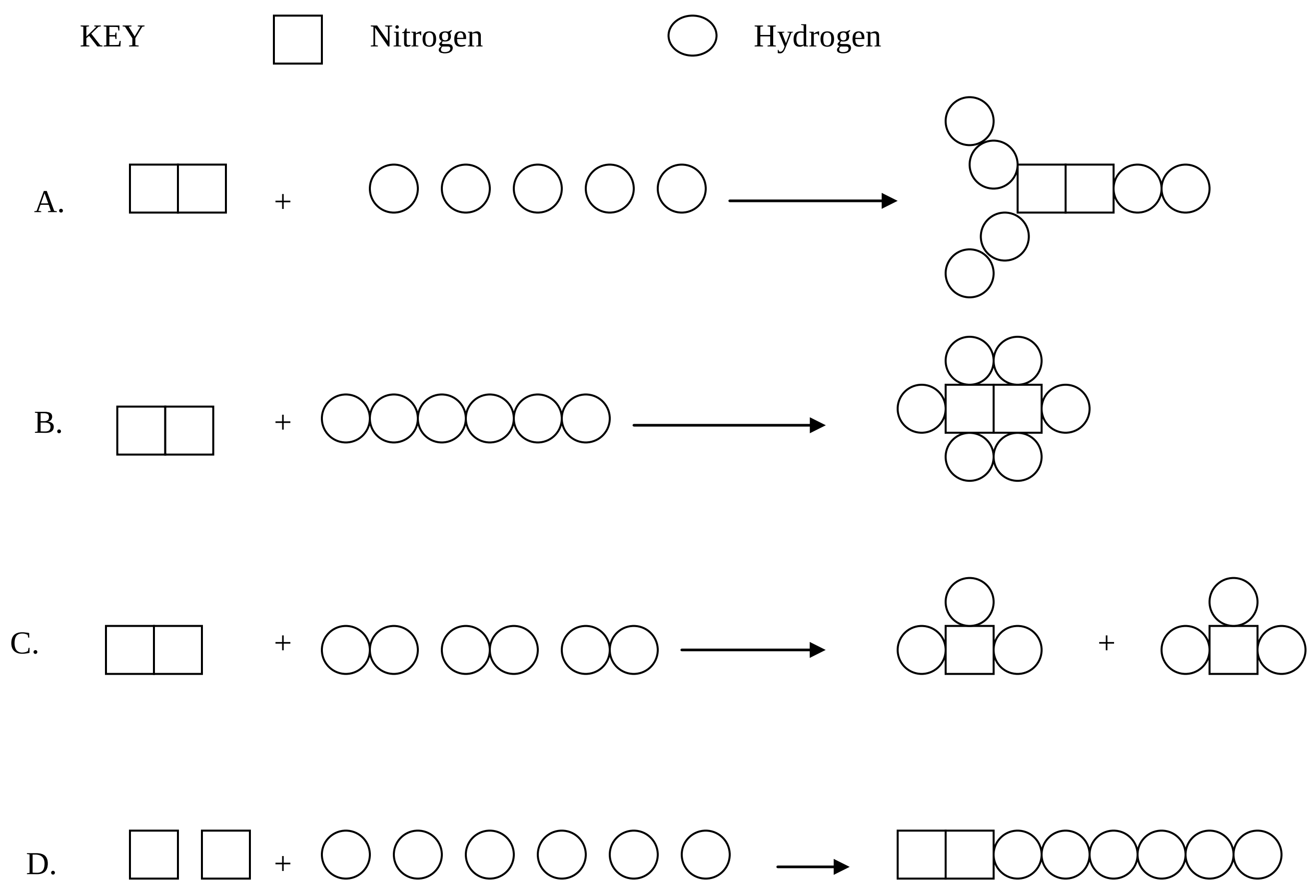
Avogadro's constant = 6, 02 x 10^{23}

QUESTION 1

1.1 Balance the following chemical equation and show how you balanced the equation:

$N_{2\,(g)} + H_{2\,(g)} \longrightarrow NH_{3\,(g)}$ (2)

1.2 Which of the following diagrams represents a balanced chemical equation of a reaction between nitrogen (N_2) and hydrogen (H_2)? Give a reason for your answer. (2)



QUESTION 2

2.1 Which one of the following contains equal number of atoms as in 8 grams of oxygen (O_2)? Show how you have arrived at your answer above.

A. 0, 4 moles N_2 gas at STP

B. 11.2 litres of CO gas at STP

C. 1.2 grams of carbon

D. 5.6 litres of Cl_2 at STP

.

2.2. Gases X and Y occupy the same volume at volume at standard pressure and temperature. Which one of the following is true for gases X and Y? Explain your answer.

A. They have equal masses

B. They have equal molecular masses

C. They are the same gases

D. They contain equal number of atoms.

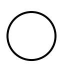
QUESTION 3

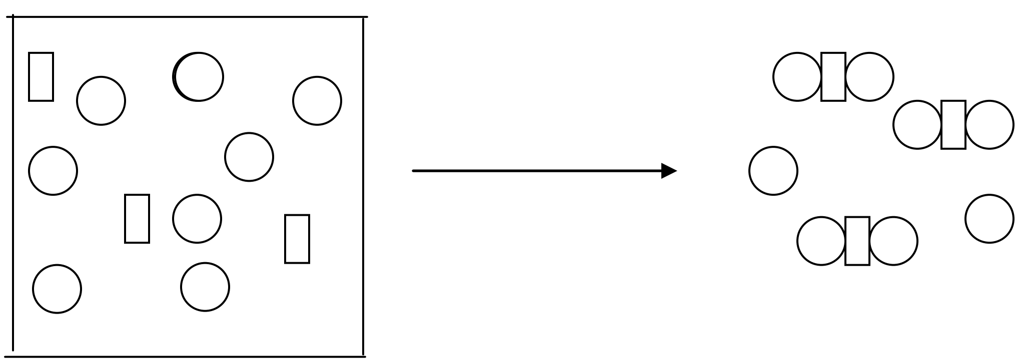
3.1 The equation below shows the reaction between hydrogen and oxygen;

$2H_{2\ (g)} + O_{2\ (g)} \longrightarrow 2H_2O_{\ (g)}$

A mixture has 2 moles of H_2 and 2 moles of O_2. What is the limiting reagent. Show how you have arrived at your answer.

3.2 The diagram below represents a chemical reaction between element A and B

A =  B = 



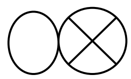
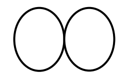
Write a balanced equation for the above reaction. Show your working

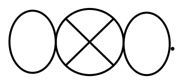
QUESTION 4

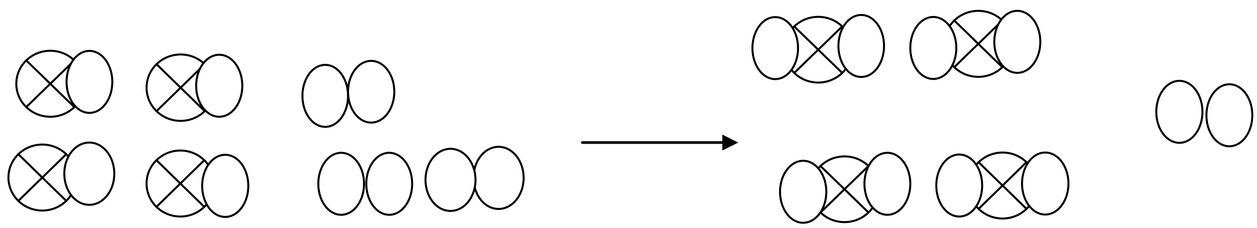
4.1 The balanced chemical equation below shows a reaction between ammonia oxygen.

$4NH_{3\,(g)} + 5O_{2\,(g)} \longrightarrow 4NO_{(g)} + 6H_2O_{(l)}$

If 750g of ammonia and 750g of oxygen are reacted, which reagent will be the limiting reagent? Show how you arrived at your answer.

4.2 Four molecules of  are mixed with three molecules of 

and they react to form . This reaction is represented below.



Which molecule is the limiting reagent in the reaction above? Explain how you arrived at your answer.

QUESTION 5

5.1 When methane is burnt in oxygen, the reaction produces carbon dioxide, water and heat. Below is an equation for this reaction.

$CH_{4\,(g)} + 2O_{2\,(g)} \longrightarrow CO_{2\,(g)} + 2H_2O_{(l)}$

How many grams of water will be produced if 20g of methane are burnt in excess oxygen? Show your working.

5.2.1 If 15g of coal is burnt in excess oxygen. What will be the relationship between the mass of the reactants and the mass of the products? Explain your answer.

QUESTION 6

6.1 70 cm^3 of sodium hydroxide solution of concentration 0, 18 mol dm^{-3} reacted completely with 30 cm^3 of a solution of sulphuric acid.

$$2NaOH_{(aq)} + H_2SO_{4\,(aq)} \longrightarrow Na_2SO_{4\,(aq)} + 2H_20_{(l)}$$

What is the concentration of the sulphuric acid used? Show your working.

6.2.1 Hydrochloric acid solution (HCl) is titrated by sodium hydroxide solution (NaOH). It was found out that 20ml of hydrochloric acid of concentration of 0,1moldm^{-3} is neutralized by X ml of sodium hydroxide solution of concentration 0.1moldm^{-3}.If the same 0.1mol.dm^{-3} of sodium hydroxide is used to titrate to 10ml of 1mol.dm^{-3} of trioxonitrate (V) solution (HNO_3), Yml of sodium hydroxide solution is needed. What is the relationship between X and Y

Appendix 2

Memorandum

1.1 Step 1

$N_2 + H_2 \longrightarrow NH_3$

Step 2

Left side	Right side
H = 2	H = 3
N = 2	H = 1 (1 mark)

Step Balancing the left side and the right side

Left side	Right side
H = 3 x 2	H = 2 x 3
N = 1x 2	H = 2 x 1 (1 mark)

1.2 Answer C (1 mark)

Explanation

The number of atoms on the left side is equal to the number of atoms on the right side (1 mark) and on the left side the diatomic nature of hydrogen and nitrogen is shown (1mark).

2.1 Answer D (1 mark)

Working

n= m/M

= 8/(16 x 2) = 0.25 moles

Number of moles in 0.25 moles

$0.25 \times 6.02 \times 10^{23} = 1.505 \times 10^{23}$ (1mark)

$5.6/ 22,4 \times 6.02 \times 10^{23} = 1.505 \times 10^{23}$ (1 mark)

2.2 Answer D (1mark)

Explanation

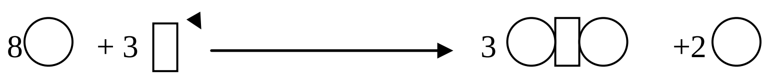
The volume of a gas is proportional to the number of moles (1mark) and the number of number of particles is proportional to the number of moles if the gas is an ideal gas(1 mark)

3.1 Answer Hydrogen (1 mark)

Working

	Hydrogen	: Oxygen
Molar ratios from the equation	2	: 1
	2 given mole	:2 mole of the given moles (1mark)

Therefore there will be 1 mole of oxygen in excess.(1mark)

3.2  (1 mark for left side & 1 mark for right side)

8 A + 3B 3A_2B + 2B (1 mark)

4.1 numbers of moles present

	NH_3	O_2
	n = m/M	n = m/M
	= 750/17	= 750/32
	= 44.12 moles	= 23.44 moles (1mark)

From the equation 4 moles of NH_3: 5 moles of O_2

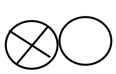
4moles : 5moles

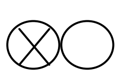
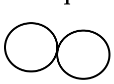
44.12moles : x moles

(44.12 x 5) = 4x

X = 55.15 moles of O_2 needed which are not available (1 mark)

Therefore oxygen is the limiting reagent (1mark)

4.2 **Answer**  (1 mark)

The equation indicates that all the  molecules are used up in the reaction and 

one molecule of is left. (2 marks)

5.1 Number of moles of methane present n = m/M

= 20/(12 +4)

= 1.25 moles (1 mark)

From the equation

1 mole of CH_4 produces 2 moles of H_2O

1.2 x 2 = 2.5 moles (1 mark)

2.5 moles x 18 = 45g (1 mark)

5.2 Mass of reactant is equal to mass of products (1 mark)

Explanation

Matter is not destroyed nor created during a chemical reaction. (2 marks)

6.1 na/nb = CaVa/CbVb (1mark)

½ = x*30/(0.18 *70) (1mark)

X = 0.21 mol.dm3 (1mark)

6.2 X and Y are equal

$HCl + NaOH \longrightarrow NaCl + H_2O$ (1 mark)

$HNO3 + NaOH \longrightarrow NaNO_3 + H_2O$ (1 mark)

Molar ratios of the reactants are the same in all the cases. (1 mark)

Annexure 3 Permission letter

Highveld Park High School
Private Bag X12950
Secunda
2302

28 March 2011

The Circuit Managers
Highveld Ridge East and West Circuits
Private Bag X 235
Evander
2301

Dear Sir

Re- Permission to conduct a Masters in Mathematics, Science and Technology Education research

The undersigned is a Physical Science Educator at as well as a part-time student of Unisa studying the above mentioned qualification. His studies require him to conduct a research and have chosen to conduct the research in some of the schools in your Circuits. Schools in your circuits were chosen for no other reason but for convience.

The title of the research is "Evaluating problem solving proficiency of Grade 12 Physical Science in solving stoichiometry problems in Highveld Ridge East and West. The undersigned is asking for permission to conduct his research in some of your schools. The contact details of the undersigned are as follows:

Cellphone number	0767417000
Work place number	(017) 634 1119
Fax	(017) 634 2303
Email address	tigere@gmail.co.za

Your cooperation is appreciated.

Your truly

Tigere Edwin

(Researcher)

Cc; School Principals and Physical Science educators

Annexure 4: Covering letter

Highveld Park High School
Private Bag X12950
Secunda
2302

28 March 2011

Dear learners

Re- Masters in Mathematics, Science and Technology Education stoichiometry problem solving research

The undersigned is conducting a research as part of his Masters in Mathematics, Technology and Science Education with the University of South Africa and your school has been chosen to be one of the research sites. The title of the research is "**EVALUATING PROBLEM SOLVING PROFICIENCIES OF GRADE 12 PHYSICAL SCIENCE LEARNERS IN HIGHVELD RIDGE EAST AND WEST CIRCUITS WHEN SOLVING STOICHIOMETRY PROBLEMS".**

The aims of this study are as follows:

1. To determine the relationship between proficiency in conceptual and algorithmic problem solving strategies.
2. To categorize grade 12 Physical Science learners in Highveld Ridge East and West according to their problem solving proficiency.
3. To compare the percentage of correct solutions, no answers and incorrect answers between algorithmic and conceptual problem solving.
4. To identify weaknesses in stoichiometry problem solving that could be rectified during the teaching of the topic.

The importance of this is to help teachers and the Department of Education to see where learners have difficulties, hence they can devise ways and means to improve your and the future learners' competency in solving stoichiometry.

It has to be noted that participation in this study is not compulsory, learners can withdraw from writing the test whenever they feel like, information obtained from your script will not be used for any other purposes (not part of CASS MARK) and your name will not appear in any part of this study. The undersigned is requesting you to participate in this research and if you choose to participate fill in the consent form is attached to the test.

For further clarification you can contact the researcher on 0767417000.

Your cooperation is appreciated.

Yours truly

Tigere Edwin

Annexure 5 Consent form

I …………………………………………..voluntarily agree to participate in the research entitled "Evaluating problem solving proficiency of Grade 12 learners studying Physical Science in Highveld Ridge East and West in solving stoichiometry problems. I have given Edwin Tigere the permission to use data from my script in his research on conditions that the data will be used in his study only without mentioning my name.

……………………	…………………………	…………………….
Name of learner	Signature of learner	Date

Annexure 6: Individual algorithmic and conceptual problem solving scores and problem solving categories

Script number	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2	Sum algorithmic	Sum conceptual	Algorithmic percentage	Conceptual percentage	Algorithmic category	Conceptual category	Paired category
15	2	0	1	2	3	2	3	0	0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
60	2	0	2	3	0		3		2	0	3	0	12	3	66.7	16.7	HA	LC	HALC
13	2	0	1	2	3	2	3	0	0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
12	2	0	0	2	3	2	3	0	0	0	3	0	11	4	61.1	22.2	HA	LC	HALC
28	3	1	0	0	0	0							3	1	16.7	5.56	LA	LC	LALC
27	3	2	0	2	0	0	1	0	0				4	4	22.2	22.2	LA	LC	LALC
59	2	0	0	1	0		1		1	0	3	0	7	1	38.9	5.56	LA	LC	LALC
22	2	2	3	0	3	3	3	0	3	0	2	0	16	5	88.9	27.8	HA	LC	HALC
23	2	2			0	0							2	2	11.1	11.1	LA	LC	LALC
53	2	0	2	3	1	2	3		0		3	0	11	5	57.9	27.8	HA	LC	HALC
55	1	3	2	2	1	1	1		0	0	2	0	7	6	38.9	33.3	LA	LC	LALC
41	2	2			1	0	0	0	0	0			3	2	16.7	11.1	LA	LC	LALC
16	2	0	1	2	3	0	3	0	0	0	3	0	12	3	66.7	16.7	HA	LC	HALC
17	2	0	1	2	3	2	3		0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
18	2	1	1	2	3	2	2		0	0	3	0	11	5	61.1	27.8	HA	LC	HALC
21	3	1	0	0	3	0	0	0	3	0	2		11	1	61.1	5.56	HA	LC	HALC
56	2	0	2	0	3	1	3	0	0	0	3	0	13	1	72.2	5.56	HA	LC	HALC
47	2	1	1	2	3	1	1	0	0	0	3	0	10	4	55.6	22.2	HA	LC	HALC
64	2	0	2	2	1	2	2		0	0	3	0	10	4	55.6	22.2	HA	LC	HALC
61	2	0	2	3	0	2	3		3	0	3	0	13	5	72.2	27.8	HA	LC	HALC
48	2	1	1	2	3	1	1	0	0	0	3	0	10	4	55.6	22.2	HA	LC	HALC
45	2	1				1			0	3	0		2	5	11.1	27.8	LA	LC	LALC
29	2	2	0	1	0	1		2	0	1	0	0	2	6	11.1	33.3	LA	LC	LALC
31	3	1	1	0	1	2	0	3	3	0			8	6	44.4	33.3	LA	LC	LALC
65	2	0	0	0	0	2	1	1	3	2	0		6	5	33.3	27.8	LA	LC	LALC
39	2	1	2		0	3	0	0	0		0	0	4	4	22.2	22.2	LA	LC	LALC
9	2	0	3	1	3	2	1	0	3	0	3	0	15	3	83.3	16.7	HA	LC	HALC
42	2	0	0	1	1	0	1	0		0	0	0	4	1	22.2	5.56	LA	LC	LALC
20	2	1		1	1	0	0		3	0	2		8	2	44.4	11.1	LA	LC	LALC
51	2	0	2	2	3	1	3		0	0	1	0	11	3	61.1	16.7	HA	LC	HALC
71	2	2	0	1	3	0	0	0	3		3	0	11	3	61.1	16.7	HA	LC	HALC

Script number	1.1	1.2	2.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	6.1	6.2	Sum algorithmic	Sum conceptual	Algorithmic percentage	Conceptual percentage	Algorithmic category	Conceptual category	Paired category
14	2	0	1	2	3	2	3	0	0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
3	2	1		2	3	2	0		0	0	0	0	5	5	27.8	27.8	LA	LC	LALC
6	2	2	0	3	0	2	1		0	0	0	0	3	7	16.7	38.9	LA	LC	LALC
10	2	1	1	2	3	2	3		0	0	3	0	12	5	66.7	27.8	HA	LC	HALC
5	3	1	0	0	0		0	0	0	3			3	4	16.7	22.7	LA	LC	LALC
24	2	0	0		0	0							2	0	11.1	0	LA	LC	LALC
30	2	0		0	3	1	0	3	0		3		8	4	44.4	22.2	LA	LC	LALC
62	2	1	1	2	3	1	2		0	0			8	4	44.4	22.2	LA	LC	LALC
57	2	0	1	2	3	2	3		0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
7	2	0	1	2	3	2	3		0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
11	2	0	1	2	3	2	3		0	0	3	0	12	4	66.7	22.2	HA	LC	HALC
37	2				0	3	2	3	0	3	2		6	9	33.3	50	LA	HC	LAHC
74	3	0	0	1	1	1	0	0			0	0	4	2	22.2	11.1	LA	LC	LALC
75	2	1	0	0	1	0	1	0		0	0		4	1	22.2	5.56	LA	LC	LALC
49	2	0	1	2	3	1	1		0	0	3	0	10	3	55.6	16.7	HA	LC	HALC
4	2	0	1	2	3	2	3	0	1	0	0	0	10	4	55.6	22.2	HA	LC	HALC
1	2	1											2	1	11.1	5.56	LA	LC	LALC
43	1	0	0	0	0	0	0		0	0			1	0	5.56	0	LA	LC	LALC
54	2	0	0	1	0	1	0	0	0	0	0	1	2	3	11.1	16.7	LA	LC	LALC
50	2	0	2	2	2	1	3	0	0	0	3	0	12	3	66.7	16.7	HA	LC	HALC
35	3	0	0	0	0	0	1	0	0	0	0	0	4	0	22.2	0	LA	LC	LALC
19	2	0	1	2	3	1	2		0	0	3	0	11	3	61.1	16.7	HA	LC	HALC
25	3	1	1	1	3	0	3	1	3	0	2	0	15	3	83.3	16.7	HA	LC	HALC
36	3	0	0	0	1	0	0	1			0	0	4	1	22.2	5.56	LA	LC	LALC
26	3	1	0	1	0	0	1	1	0	0	0	0	4	3	22.2	16.7	LA	LC	LALC
52	2	0	1	2	3	1	3	0	0	0	0	0	9	3	50	16.7	LA	LC	LALC