



Assessing the relationship between practical activities and students' problem-solving skills in stoichiometry

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ABSTRACT

Stoichiometry is one of the major topics that have proven to be difficult for students to understand and perform well in. Much research has presented different teaching methodologies in which the concepts can best be taught and various hands-on activities, however, availability of resources and students' attitudes towards the topic still remain the main hindering factors. This study aims to assess the correlation between practical activities done at high school and the problem-solving skills of first-year university chemistry students in stoichiometry. Results showed that students struggled with the mathematical, analytical and reasoning problem-solving skills. There was not much correlation between the number of practical experiments done at high school and students' performance in the stoichiometry questionnaire, but lecturers reported that the students' performance improved after a semester including practical activities at university. The overall perception towards practical activities was positive, and the students also showed that they were not happy with how the practical chemistry concepts were taught and the amount of practical activities they did at high school. In view of these findings, the study recommends that students be given more hands-on activities to help them better understand chemistry concepts and that teachers should use different teaching methodologies that actively involve students in the learning process. The study further recommends that under-resourced schools be given necessary apparatus for them to be able to perform various practicals with students, and that students be given necessary support as they transition from high school to university so they can cope with academic requirements and improve their overall chemistry performance.

Keywords: Stoichiometry, practical activities, problem-solving skills, perceptions, hands-on activities

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LIST OF ABBREVIATIONS

ATP – Annual teaching plan

CAPS – Curriculum and Assessment Policy Statement

ELM – Experiential Learning Model

KELM – Kolb’s Experiential Learning Model

MI – Multiple Intelligence

NWU – North-West University

PCK – Pedagogical Content Knowledge

POA – Program of Assessment

POGIL – Process Orientated Guided Inquiry Learning

TSPCK – Topic Specific Pedagogical Content Knowledge

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Chapter 1: Overview of the study

1.1. Introduction

Chemistry is one of the sciences necessary for sustainable development since its knowledge is helpful for the manufacturing of fertilisers, insecticides, food processing and storage, management of natural resources, provision of food and health facilities, and environmental protection for a favourable living environment (Ogbeba & Ajayi, 2016). A chemical reaction must occur for all of the above products to form. A chemical reaction occurs once reactants form products, how they are balanced and the amount in which they react is determined using stoichiometry calculations.

Stoichiometry measures the relationship between the number of moles and mass of various products and reactants in a chemical reaction. Therefore, learners must understand the chemical reaction and the relationship between the ratio of the reactants and products in order to accurately solve stoichiometry problems. Problem-solving requires students to utilise multiple steps and requires good problem-solving skills and strategies (Selvaratnam & Mavuso, 2010). Common problem-solving skills that students use in stoichiometry are analytical, mathematical, and representational problem-solving skills. Tigere (2014) who studied the problem-solving proficiency of Grade 12 Physical Science students when solving stoichiometry problems in the Mpumalanga Province, South Africa, reported that students' ability to solve stoichiometry problems is key to their high school success in chemical equilibrium, acid-base, and chemistry problems. The development of problem-solving skills in stoichiometry is important for success in solving problems related to the topic (Gulacar *et al.*, 2020).

Much research has indicated that students seem to struggle to respond to stoichiometry questions and has emphasised the need to implement new teaching methodologies. However, it is also essential to identify skills that learners lack when solving stoichiometry problems, the attitudes they have towards practical activities and the methods implemented when teaching, and their prior knowledge before implementing a teaching approach. The study of Ogbeba and Ajayi (2016), comparing the achievement and retention of senior secondary students in chemistry with and without hands-on activities, found that students achieved higher grades using hands-on activities than demonstrations. However, the study did not indicate the problem-solving skills that the methodology assists students to improve and did not indicate

alternative methods for schools that do not have resources to implement hands-on activities such as Phet simulators or virtual labs which have been proven to be effective in improving students' understanding in science (Puntambekar *et al.*, 2021; Winkelmann *et al.*, 2020; Wu *et al.*, 2021).

There should be a link between teaching methods used by teachers to the resources available at schools and students' problem-solving abilities. This could help teachers to correctly identify alternative teaching approaches that are best suited for each learner's learning style and to ensure that students are not affected by lack of resources in schools. However, sufficient resources should still be made available in schools for teachers to be able to implement different teaching methods and to also perform practicals that help to increase the conceptual understanding of the students. An alternative to traditional laboratory experiments is the use of small or microscale kits, which are more affordable, use smaller amounts of chemicals, and can be used even in schools where there are no laboratories (Mafumiko, 2008; Ifepe & Anekwe, 2022).

BouJaoude and Barakat (2003) looked at students' strategies for solving problems in stoichiometry and their relationships to conceptual understanding and learning approaches. They discovered that some students wrote down formulas and plugged-in numbers from the problems without appreciating the chemical systems they represented. This indicates that students who do not have the necessary reasoning, analytical and mathematical skills to solve problems, struggle to understand concepts and have a negative attitude towards problem-solving (Drummond & Selvaratnam, 2008, 2009).

This study aims to assess the impact of practical activities on students' problem-solving abilities. The findings of studies done by Mji and Makgato (2006), Oginni *et al.* (2013), Ogbeba and Ajayi (2016), have shown that lack of practical activities causes learners not to fully understand stoichiometry concepts and thus perform poorly. In order to ascertain the reasons behind student failure in stoichiometry, this study investigated the two domains of learning about stoichiometry and practical activities. This was done using a questionnaire that consists of three sections covering the affected domains. The domains of learning assessed are the *affective domain (attitudes)* and the *cognitive domain (knowledge)*. The first domain covers the attitudes that students have towards practical assessment, whether they see it necessary to increase their knowledge content or not. The second domain covers the knowledge that the

students have and if they have understood the stoichiometry concepts they were taught at high school with or without the use of practical tasks and assessment.

Furthermore, this study also evaluated the problem-solving skills in which the students exhibit gaps, with a focus on reasoning, mathematical, analytical, and representational skills, using a questionnaire based on the chosen stoichiometry concepts. Moreover, this study looked at how problem-solving skills are applied by the sampled students to solve stoichiometry problems based on standard solutions, acid-base titrations, limiting reactants, and so on, where students are required to balance equations and use given information to calculate the concentrations of unknown substances. Solving stoichiometry calculations is impossible without a correctly balanced and well-represented equation, hence representation of students' skills was also be evaluated.

In addition to the use of a questionnaire, this study looked to gain more insight into the gaps and difficulties displayed by the students by holding one-on-one interviews with the lecturers and practical assistants (technicians) who worked closely with the students during their first semester.

1.2. Background of the problem

The political transition in South Africa in 1994 resulted in transformation in all government departments, and various policies concerned with how these departments were managed. The Department of Education underwent a transition that resulted in a gradual transformation of the education system. The education system was changed to cater for all the races that were marginalized during the apartheid era. Education policies applied to all races; Black and White learners attend the same schools, and are guided by the same policies, including policies regarding medium of instruction (De Wet & Wolhuter, 2009).

Even though black and white children can attend the same schools, it is important to note that not all black families can afford to pay fees for their children in either private or former Model C schools, and most children from rural areas attend non-fee-paying schools which are designated quintile 1, 2 and 3, and they receive a government funding. The socioeconomic standing of the neighbourhood where the schools are located is the basis for the quintile classification (Ogbonnaya & Awuna, 2019). School quintile is a ranking system of schools into

one of five quintiles where Quintile 1 represents the less resourced schools and Quintile 5 schools with more resources (White & Van Dyk, 2019).

In the same study by Ogbonnaya and Awuna (2019), the findings were that students from better resourced schools (Quintiles 4-5) performed better than students from poor schools (Quintiles 1-3), this indicates that schools should transition from having lack of resources. Transition of the national system is, however, a responsibility of not only the government but also that of research foundations as well as higher education organizations and Non-Government Organisations (NGOs) (Mitter, 2000; Volmink & Van der Elst, 2019). It also involves the learners, parents and community members through school governing bodies that are able to identify limitations and challenges firsthand at various schools (Cross *et al.*, 2002). The limitations and challenges that students from poor schools' face need to be looked into. The current study aims to evaluate whether lack of available resources in schools impacts how learners understand stoichiometry concepts.

Content gaps that students in grade 12 have are identified by teachers and subject specialists after final examinations and published in a National Subject Diagnostic Report (DBE, 2023). The National Subject Diagnostic Report is a report that highlights the strengths and weaknesses of students who sit for each national examination each year. It serves as a guide to teachers so that they know the common mistakes students made in the previous year's national examination. The report further suggests ways teachers can assist students in improving their weaker areas.

In 2019, for instance, The National Diagnostic report (DBE, 2019) found that students writing Grade 12 often still poorly understand Grade 11 stoichiometry work. The report further urged teachers that Grade 11 work should be included in classwork, homework, and tests in Grade 12 to increase students' achievement in stoichiometric concepts. This is in line with the study by Molaakgosi (2017), who found that revising key concepts from Grades 10 and 11 significantly improved students' performance in Grade 12. However, Molaakgosi (2017) further noted in the chemistry common tests that students had difficulties with basic mathematics and scientific skills needed to pass Physical Sciences. This implies that even though revision improves the average performance of students, it does not enhance their problem-solving abilities and conceptual knowledge.

From an assessment of the national performance of students in Grade 12 over the past years, there is evidence that students are struggling to pass physical sciences as pass percentages at 30% achievement in 2019, 2020, 2021, 2022 and 2023 were 75.5%, 61.5%, 69%, 74.6% and 76.2%, respectively. It is important to note that even though the pass percentages are high, they include students who have achieved the minimum 30% requirement for a pass in Physical sciences while pass percentages for students who obtained 40% and above for the above years are 51.7%, 42.4%, 44.8%, 49.7%, and 51.1%. The National Diagnostic Report (accessible at www.education.gov.za) for 2022 noted that learners who wrote the final Physical Sciences Chemistry P2 exam had a gap in their stoichiometry concepts. The findings were that students had poor understanding of stoichiometry and are very uncertain when choosing formulae for solving questions. It was once again a problem in the 2023 Diagnostic report and the same suggestions that students need to have more exposure to the topic was emphasized again.

Hafsah *et al.* (2014) found that for instructors to develop students' problem-solving skills in stoichiometry, teachers must first develop students' knowledge and skills base. They further stated that the students are incapable of solving true problems without conceptual knowledge and that heavy emphasis should be placed on conceptual understanding of stoichiometry topics, followed by completing drills and class or home exercises. The same findings were evident in the study by BouJaoude and Barakat (2003). They found many of their student participants to have a partial conceptual understanding of stoichiometry concepts like simple formulas for finding the molar mass, the number of moles, and limiting reagent. Furthermore, they stressed the need to ensure that students understand concepts and the conceptual foundations of formulas.

Learners have different learning needs within each classroom environment, and differences among students are explained in Gardner's multiple intelligence theory (2011). As a result, there is a need for diversified methods of learning that will enhance active participation and improve academic performance of all learners. Teachers often use either a teacher-centred approach or a learner-centred approach; where the teacher is focused on transmitting information to the learners using the first approach and learners are active participants in the latter approach (Kemp, 2013). Findings of the study by Lake (2010) indicated that some teachers use these approaches interchangeably, depending on the subject taught. One teacher

in a focus group when the above research was performed indicated that they resorted to learner-centred teaching when the subject does not have too many rules to be applied. Another teacher said that the learner-centred approach is more challenging with subjects such as English and Mathematics as learners often do not know how to tackle the tasks at hand. However, both of these methods have limitations. The teacher-centred approach robs learners of the opportunity to fully participate and gain confidence through active participation. On the other hand, lack of resources may make the learner-centred approach challenging; and some learners might waste time in the classroom when they misbehave when interaction is required (Polly *et al.*, 2014).

1.3. Significance of study

Stoichiometry is one of the most basic, central, and yet abstract topics in chemistry. It requires students to understand both the qualitative and quantitative aspects to solve theoretical and practical aspects. It requires teachers to develop methodologies and engage in practical activities to arouse students' interest in chemistry. Ogbeba and Ajayi (2016) used hands-on activities to show that new methods can yield better results in stoichiometry than traditional teaching methods. However, the availability of resources and innovative ideas in implementing better teaching approaches are still a concern for most schools. Each year evidence of underperformance in chemistry is evident, which indicates a need to change how chemistry is taught to assist learners in building more conceptual knowledge and problem-solving skills.

Moreover, the lack of resources may limit how students can apply their practical knowledge in solving theoretical stoichiometry concepts and apply these skills further when moving to higher levels of learning such as colleges and universities. Several research studies have shown gaps in how students respond to stoichiometry questions, and they emphasize the need to implement the new teaching methodologies. Hence, it is crucial to identify which problem-solving skills learners lack when solving stoichiometry problems before implementing alternative teaching approaches.

1.4. The aim of the study

The study aims to investigate the link between practical activities involving stoichiometry and students' problem-solving ability.

1.5. Research objectives

The objectives of the study are to determine:

1. Which problem-solving abilities (i.e., analytical skills, reasoning skills, mathematical skills, or representation skills) students present gaps in when answering stoichiometric questions (i.e., limiting reactants, excess reactants, acid-base titrations, standard solutions, and mole ratio),
2. The stoichiometry practicals that are done at high school and whether they help students to understand those concepts better,
3. The perceptions that students have towards practical work and its importance in assisting them in understanding stoichiometric concepts,
4. If there is an achievement gap between students from urban and students from rural or farm schools,
5. If gender influences achievement in stoichiometry concepts.

1.6. Research sub-questions

The research attempted to meet the objectives by answering the following questions:

1. In which problem-solving abilities do students exhibit a gap (for example, analytical skills, reasoning skills, mathematical skills, or representation skills) in balancing chemical equations, identifying limiting and excess reactants, working with acid-base titrations, standard solutions, and mole ratio calculations?
2. What stoichiometry practicals are expected to be done at school, in what concepts did students receive practical training at the high school level and has it helped them better understand those concepts?
3. What perception do the students have regarding practical learning and its importance?
4. Is there a difference in the performance of students from well-resourced (generally urban) schools and students from under-resourced (typically rural) schools?
5. Is there a difference in achievement between female and male students in the chosen stoichiometry concepts?

1.7. Research hypotheses

To assist to answer the research questions, the following null hypotheses were formulated:

- a. There is no correlation between practical activities and students' problem-solving abilities in stoichiometry concepts. (Research question 2)

- b. Students' have a positive perception about practicals and practical assessment. (Research question 3)
- c. There is no correlation between the type of school attended (i.e., rural, farm, or urban) with students' problem-solving abilities in stoichiometry concepts. (Research question 4)
- d. There is no difference between the achievement of male and female learners with regards to stoichiometry skills. (Research question 5).

1.8. Scope of the study

The study was limited to first year students enrolled in the BSc-extended and BSc mainstream chemistry programs registered at North-West University (Mafikeng Campus). Additionally, interviews with lecturers and laboratory assistants/technicians from the North-West university who have worked directly with the students were held.

1.9. Definition of key concepts used in the thesis

1.9.1. Hands-on activities

A teaching method whereby students are actively involved in their learning and class activities through the use of their hands mainly as the teacher guides the students through the various activities (Ajayi, 2017).

1.9.2 Perceptions

The method by which living things organise and interpret sensation to create a meaningful world experience (Pickens, 2005)

1.9.3 Practical activities

Tafa (2012) stated that practical activities can be classified into *exercises* (which help develop practical skills of students); *experiences* (which help students feel and interact with apparatus); *demonstrations* (which help to assist students in the development of scientific arguments); and lastly *investigations* (which assist students to develop their understanding of scientific processes and concepts). It is used interchangeably with practical work in this study as they are the same.

1.9.4 Problem-solving skills

Problem-solving skills can be defined as the process of finding the best solution to an enigma or making a decision that is subject to limitations (Mourtos *et al.*, 2004).

1.9.5 Stoichiometry

Stoichiometry is the study of the relationships between reactants and/or products in a chemical reaction (Ajayi, 2017).

Chapter 2: Literature review

2.1. Introduction

This chapter is divided into two main sections: theoretical and conceptual framework. The first part of the theoretical framework discusses the phenomena and theories investigated. The second part reviews the conceptual framework and the gaps that the current study seeks to address.

A theoretical framework is important because it helps a researcher to perform the research within the confines of existing theories, thereby allowing them to make a meaningful contribution to the current body of knowledge (Adom *et al.*, 2018). The literature review helps a researcher get a global view of the phenomena and then narrows it down to help the researcher focus on the specific concept (conceptual framework) and the direction the researcher can take for their particular study. Furthermore, it guides the researcher in a way that will help him avoid reinventing the wheel. Moreover, it shows the researcher options on how the research study can be structured, thereby giving the foundation for the research methodology (Sajeevanie, 2021).

2.2. Theoretical background

In this sub-section, the Multiple Intelligence Theory (MI) and Kolb's Experiential Learning Model (KELM) are discussed and related to the context of the current research study. The two theories were chosen because, in this current study, we want to highlight that there is more than one-way students learn (MI), and learning is best achieved through experiences that learners use to derive their meaning and understanding of concepts (KELM). Furthermore, pragmatism will also be briefly reviewed as it is the chosen paradigm for this study.

2.2.1. Multiple intelligence theory

Loh-Hagan (2020) said intelligence is accumulated knowledge and that an intelligent person is smart and classified people into three different intelligence groups as high, average, and low. However, the Multiple Intelligences (MI) theory gives a different view about intelligence, stating that there are different types of intelligence. The MI theory was developed in the late 1970s and early 1980s by a psychologist, Howard Gardner. According to this theory, people possess eight or more bits of intelligence that interrelate and are autonomous. These varying

bits of intelligence can be applied individually or in a group to solve problems or create products beneficial to their societies. A summary is given in Table 2.1 of all the eight identified bits of intelligence.

Table 2.1. Gardner's eight bits of intelligence*.

Intelligence type	Definition
Linguistic	This intelligence is concerned with language and communication, one's ability to analyse information and use that information further to create products involving oral and written language such as speeches, books, and memos.
Logical-mathematical	An individual's ability to develop equations and proofs, make calculations, and solve abstract problems.
Spatial	An ability to recognise and manipulate large-scale and fine-grained spatial images.
Musical	An ability to produce, remember and make meaning of different sound patterns.
Naturalistic	An ability to identify and distinguish among different plants, animals, and weather formations found in the natural world.
Bodily-kinesthetic	An ability to use one's body to create products or solve problems.
Interpersonal	An ability to recognise and understand other people's moods, desires, motivations, and intentions.
Intrapersonal	An ability to recognise and understand their moods, desires, motivations, and intentions.

*Adapted from Davis *et al.* (2012, pp. 6-7).

Davis *et al.* (2012) analysed the MI theory and concluded that it differs from other psychological approaches to intelligence in that its approach is interdisciplinary, which allows for the consideration of the varying capacities and faculties possessed by people. The author further states that the theory has garnered considerable attention, far more in educational circles than in the corridors of standard psychological testing and experimentation. Furthermore, Davis highlights that the MI theory is consistent and relevant because several educational experiments are built on its foundations, many of which have claimed success.

Gardner and Hatch (1989) defined intelligence as the ability to solve problems. The theory emphasises that there are different ways in which learners prefer to learn, which in turn will assist the study in suggesting proper methodology to help learners in problem-solving gaps to be identified in the study. A similar view in that student diversity increases each year is found in the study by Batty and Reilly (2023). This theory suggests that educators should recognise and teach a broader range of talents and skills that students have (Timmins, 1996) and the same statement is found in Arum *et al.* (2018). Gardner (1999) states that only linguistic and logical-mathematical intelligence have been viewed as being most valuable and are therefore tested for in schools.

An individual's mental capacity to solve problems and create a product is affected by several factors. According to Armstrong (2009), growth of intelligence is affected by three main factors:

- Biological endowments such as hereditary or genetic factors. In addition, there might be injuries to the brain before, during, and after birth.
- One's life history, including experiences with parents, teachers, peers, friends, and others who awaken various bits of intelligence, keeps the individual from developing or actively repressing the experiences.
- Cultural and historical background, such as the time and place in which an individual was born and raised and the nature and state of cultural or historical developments in different domains.

Only the intelligence types associated with stoichiometry and students' problem-solving ability are discussed below.

Linguistic intelligence

Linguistic intelligence is defined as the capacity to use language, whether native or other languages, to express oneself and understand others (Ali *et al.*, 2023). It is also the capacity to use language effectively orally or in writing (Armstrong, 2009; Gardner, 2011). This suggests that linguistic intelligence includes the ability to convince others orally or through written words and to pick up on other languages quickly. The authors further state that this intelligence can manipulate the way language is structured and sounds, the meanings of language, and how language is used. Some of the uses of language include rhetoric (where others are convinced

to take a specific course of action using language), mnemonics (whereby language is used to remember information), explanation (where language is used to inform others), and metalanguage (where language is used to learn the language itself). Armstrong (2009) and Ali *et al.* (2023) stated that people with high linguistic intelligence think in words and love reading, writing, telling stories or speaking publicly, and playing word games.

In the classroom, linguistic intelligence is most emphasised, and the MI theory states that this is unfair to learners because all other types of intelligence are often neglected. Lazear (1992) advocates for teachers to learn how each learner finds it easier to understand and then create an 'intelligence profile' so that each can be fairly assessed in the classroom. The author recommends the following assessment methods: learner portfolios, independent projects, student journals, and assigning creative tasks. However, the practicality of this approach may be challenging in countries with limited learning resources, such as South Africa and most African countries. Armstrong (2009) proposed teaching activities and materials for linguistic intelligence learners in the classroom, such as lectures, discussions, word games, storytelling, choral reading, journal writing, books, tape recorders, typewriters, stamp sets, and books on tape.

Logical-mathematical intelligence

Gardner (2009) defines logical-mathematical intelligence as the ability to study and solve problems logically and analytically, conduct mathematical operations, and perform scientific investigations. Logical-mathematical intelligence can also be interpreted as the ability to think in numbers, calculate, draw conclusions, build logical correlations, generate hypotheses, solve problems, think critically, understand abstract symbols such as numbers and geometric shapes, and connect disparate pieces of data. People with high logical-mathematical intelligence think by reasoning, love experimenting, questioning, figuring out logical puzzles and calculating. Thus, it can be assumed that individuals with logical-mathematical intelligence possess several elements of abilities such as organising, analysing, solving problems logically, and deductive reasoning.

Furthermore, logical-mathematical intelligent individuals quickly calculate mathematical problems, notice patterns, and want to see things in a logical sequence (Armstrong, 2009). The author further proposed teaching activities and materials for logical-mathematical intelligence

learners in the classroom to involve mental calculations, brain teasers, science experiments, number games, problem-solving, critical thinking, and math manipulatives.

Both linguistic and logical-mathematical bits of intelligence are essential for this study as students with such intelligence are better equipped to solve stoichiometry practical problems by applying their intelligence accordingly when answering questions. Stoichiometry requires students to read statements and make conclusions by identifying all given variables and unknown variables. From there, they use mathematical intelligence to properly manipulate equations to calculate unknown variables. When balancing equations, mathematical skills are also required from students; thus, these two bits of intelligence are most applicable to this study.

2.2.2. Kolb's experiential learning model

According to Kolb (1984, cited by Rizk, 2011), experiential learning is a process that creates knowledge through experience transformation. Ajayi (2017) said of Kolb's theory of learning that the transformation of experiences and activities creates knowledge, and a cycle model of learning is presented. Ajayi further stated that stoichiometry is best understood through active learning and practical activities as it enhances the retention abilities of learners. Turesky (2005) said that it is a vital skill to learn from experience.

This thesis agrees with the notion because stoichiometry is not only theoretical but has practical concepts that need to be treated and taught accordingly. Turesky (2005) also noted that the cycle consists of four stages and that concrete learning is achieved when a student goes through all learning cycles. Yet, some people tend to emphasise one part of the cycle more, which does not result in a concrete learning experience. Therefore, one cycle stage is ineffective as a learning procedure on its own, thus increasing the emphasis that all cycles are essential for concrete learning (McLeod, 2010).

David Kolb's Experiential Learning Model (ELM) cycle is summarised in Figure 2.1 below.

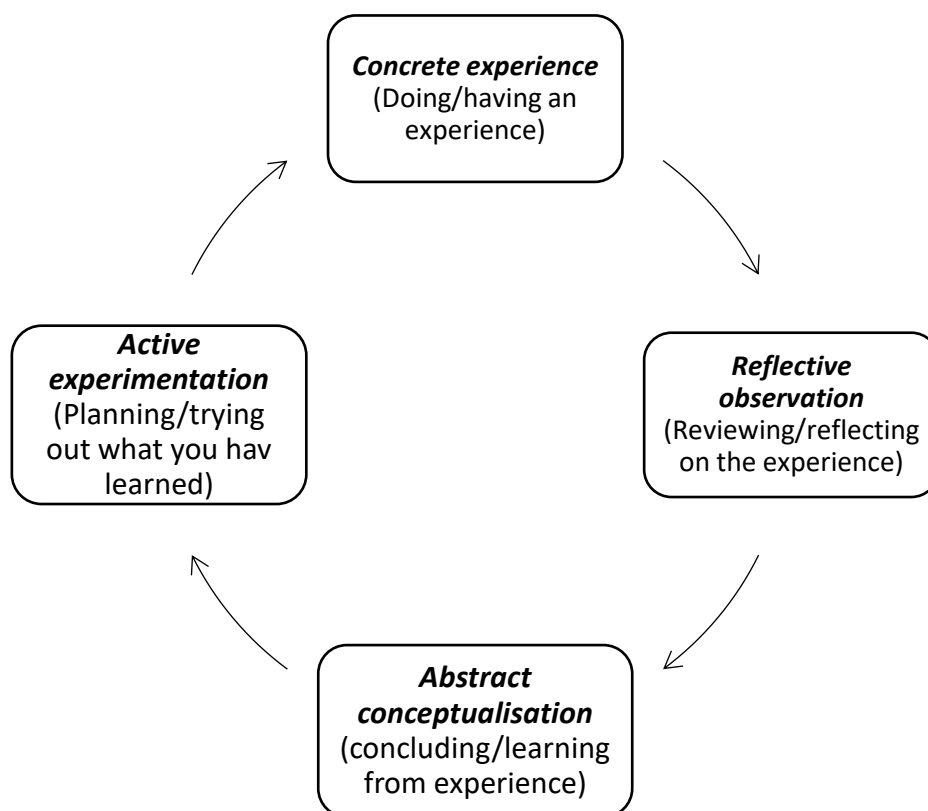


Figure 2.1: Kolb's Experiential Learning Model (ELM). Source: Adapted from Loo (2004, p. 2).

Learning is a process where experiences such as practicals are transformed into knowledge (Turesky, 2005), and learning preferences are different for each student. Kolb identified four learning styles: assimilators, convergers, accommodators, and divergers. These learning styles have various strengths and weaknesses but also bring something fundamental to the study. Learners are not the same and have different ways best suited for learning, which aligns with Gardner's MI theory. If we do not consider students' diverse learning styles, we subject them to a single method that might not suit their differences. Although the focus of this study is not on identifying students' learning styles but on their problem-solving abilities, understanding these learning styles is important for this study to be able to categorise students in a longitudinal study that could follow from the findings of this current study. Below is a brief explanation of each learning style.

Accommodators

Kolb (1985, cited by Loo, 2004) describes accommodators as students who learn best from experiences that involve hands-on activities. Winarso and Toheri (2021) define

accommodators as students who prefer to absorb information from direct experience and process it through active experimenting.

Assimilators

The assimilator approaches learning through conceptualisation and observations to process content (Ajayi, 2017; Winarso & Toheri, 2021). Assimilators favour the logical soundness of a theory over practical value ideas in general. Readings, lectures, examining analytical models, and having time to think things through are all preferred activities for people with this personality type (McLeod, 2010). Learners in this category are not best suited for practical learning or hands-on activities as they find the practical value of theories to be less important than the theoretical background.

Convergers

Ajayi (2017) described convergers as students who learn better when provided with practical applications of concepts and theories. The converger prefers to process knowledge through active exploration, and their strengths lie in problem-solving, decision-making, and the practical application of ideas (Winarso & Toheri, 2021). Convergers prefer to deal with hands-on tasks. They are therefore best suited for practical learning approaches than the traditional teaching methods.

Divergers

Divergers prefer to learn through Concrete Experience and then Reflective Observation to understand the content, and they excel at looking at existing circumstances from various perspectives (Winarso & Toheri, 2021). In other words, they learn better when allowed to observe and make conclusions about their observations (Ajayi, 2017). These people perform better in situations requiring them to develop new ideas and brainstorm, achievable through practical learning methodology.

Kolb's experiential learning theory is necessary for this study. It emphasises the importance of learning by doing or experience, allowing learners to observe, think, and draw conclusions about scientific concepts. It is best suited for practical stoichiometry concepts so learners can build their conceptual knowledge.

2.2.3 Chapter summary

The two theories anchor two main points, in that learners cannot be confined to one teaching method as it does not cater for their difference in their intelligences. The second point is that active learning and hands-on activities enhance the chances of students to better understand and retain content knowledge. The highlights from these theories are that teachers must acknowledge different learners' strengths and that we should also give them an opportunity to draw understanding from experiences as they interact with different apparatus. The teaching methods that can allow for these conditions to be met is the practical teaching method or hands-on activities, which in turn require schools to have resources for proper implementation. Studies by Ajayi (2017) and Ajayi and Ogbeba (2017) have shown that there is an improvement in students' performances when hands-on activities and simulations (Wu *et al.*, 2021; Mohafa *et al.*, 2022) are used. Additionally, multiple intelligences that students' have can be catered for through experiential learning as it can cater for about all learning styles that different students have.

2.3. Conceptual framework

This section of the study brings in the concepts that apply to this study. The concepts to be discussed are in line with the objectives listed above and are related to practical activities and problem-solving abilities, the practicals that high school learners perform according to the Curriculum and Assessment Policy Statement (CAPS) in conjunction with the Annual Teaching Plan (ATP) in Physical Sciences Grades 10-12; the effect of gender on student achievement in stoichiometry; student perceptions on practical activities; and factors that influence student achievement in stoichiometry such as resources. Furthermore, the domains of learning are reviewed at the end of this section.

2.3.1. Practical activities and problem-solving abilities

The objectives of practical work/practical activities are to enhance students' comprehension, foster their problem-solving abilities, and help them comprehend the nature of science through experimentation (Shana & Abulibdeh, 2020). The aim of practical work also stated in Hofstein and Lunetta (2004, cited by Köller *et al.*, 2015) is to enhance practical scientific skills and problem-solving abilities, to improve scientific habits of thought, to increase comprehension of the fundamentals of the nature of science and to increase interest and motivation in science. Tafa (2012) found that without valuable practical experiences in the laboratory, science cannot

be meaningful to students. In addition to this, Tafa (2012) also found that practical activities can be classified into *exercises* (which help develop practical skills of students); *experiences* (which help students feel and interact with apparatus); *demonstrations* (which help to assist students in the development of scientific arguments); and lastly *investigations* (which assist students to develop their understanding of scientific processes and concepts).

According to these classifications, practical activities are therefore not only limited to laboratory experiments but include all activities where students interact physically by doing or by observing science processes. One of the recommendations found in the study of Oginni *et al.*, (2013) was that the government should increase their efforts and funding to ensure that schools that offer chemistry have enough resources and appropriate laboratories to enhance chemistry learning. This is because practicals and laboratory use had significantly improved students' attitudes towards chemistry and their overall achievement are found in studies done by Hofstein and Mamlok-Naaman (2007), Witteck *et al.* (2007), McDonnell *et al.* (2007), and Shana and Abulibdeh (2020).

The importance of laboratory experiments has been repeatedly emphasized over the years, and researchers have also found that proper use of laboratory exercises can improve students' problem-solving abilities and higher-order cognitive skills (Hofstein and Lunetta, 2004; Zoller & Pushkin, 2007). Hill *et al.* (2008) stated that effective teachers are aware of students' problem-solving abilities/skills, thus the current study aims to investigate the gaps in students' problem-solving skills when solving stoichiometry problems.

Problem-solving skills can be defined as the process of finding the best solution to an enigma or making a decision that is subject to limitations (Mourtos *et al.*, 2004). Additionally, they also differentiated between problem-solving and exercise solving, which can be confused as the same thing. The authors highlighted that *problem-solving* is a method for finding the best response to an unknown and that *exercise solving* entails a procedure to find the one true solution based on given data. They also indicated that students who are exercise solvers struggle to solve questions that contain new information because they rely solely on answers and questions they have seen before. Problems can further be categorised as conceptual and quantitative.

A conceptual problem requires proper understanding of the concept being asked in order to obtain the correct answer, and a quantitative problem requires the use of correct formula and to work through the question using calculations to obtain the correct answer (Bilgin *et al.*, 2009). Conceptual and algorithmic understanding should be integrated and tested when teaching a chemistry topic, which may make the topic more interesting to students (Nakhleh, 1993).

Problem solving requires a good strategy to obtain correct results and many authors have suggested steps to solve problems. Additionally, quantitative problems require students to be able to use two or more equations in one question to solve the problem (Selvaratnam & Frazer, 1982; Selvaratnam & Mavuso, 2010). Woods *et al.* (1997, cited by Mourtos *et al.*, 2004) indicated the following steps in problem-solving that students should follow when solving questions:

- Step 1: *Define the problem* – this is where the student determines what the question is asking and also looks into the given data to solve the question.
- Step 2: *Explore the problem* – This is where students should explore any issues and approaches to the problem.
- Step 3: *Plan the solution* - The student can now identify the available equations, laws and principles that can be applied. The student should also evaluate if there is any hidden information that they should first find that will help them to solve the problem.
- Step 4: *Implementation*.
- Step 5: *Check the solution*: The student must verify all calculations and equations used, while also verifying the appropriate units to the answers. Units are an important part of chemistry.
- Step 6: *Reflection and evaluation*: The student must always check if their answers make sense and if they are reasonable. It is important to know “why” you performed a calculation and why you used a certain law, theory, principle, and/or equation.

Selvaratnam (1990) indicated the following problem-solving strategy to solving quantitative questions:

- Step 1: Identify and give explicit symbols for the data and the goal and organize them.

- Step 2: Select the starting equation.
- Step 3: Proceed step by step to derive the answer.
- Step 4: Calculate using the starting equation.
- Step 5: Check, review, and learn from the solution.

These steps are important for students to follow to solve problems correctly. However, students normally select random equations incorrectly and use the given data without appreciation of units and correct substitution according to Drummond (2018), who stated that this is called the “*Spray and pray approach*”.

Shana and Abulibdeh (2020) evaluated the impact of practical work on students’ achievement and one of their recommendations was that schools should be equipped with the necessary resources for more practical work to be done at schools. This recommendation was based on their findings where students who performed practicals prior to writing tests had performed better than the students taught using the normal traditional method. The study, however, did not highlight as to which problem-solving skills the learners struggled with when answering questions and which skills were gained by learners during each practical performed. The study also did not use schools from disadvantaged areas and only used two private schools; however, it was noted by the researcher that factors such as resources and apparatus do affect the implementation of practical activities.

Mohafa *et al.* (2022) studied the effect of simulations on students’ performance in chemistry. In the study, they found that simulations reduce the gap created by traditional teaching methods where learners struggle to make their understanding of concepts and mental representations of models. Furthermore, they found that simulations decrease the gap between prior knowledge and new chemistry concepts. The results indicated that learners taught using simulations performed better than those in the control group, which indicates that practical activities enhance student understanding of chemistry concepts.

Another alternative to traditional laboratory experiments is the use of small or microscale kits, which are more affordable, use smaller amounts of chemicals, and can be used even in schools where there are no laboratories. The use of these kits has been found to improve students’ interest and understanding of chemistry concepts (Abdullah *et al.*, 2008, 2009; Ifepe &

Anekwe, 2022; Katz, 2022; Mafumiko, 2008; Pesim, 2014). These kits can be made available at schools that offer science subjects but do not have laboratories as they assist teachers to be able to enhance student understanding according to these studies. The use of microscale kits not only assists schools without resources, but also reduces the environmental impact of chemical wastes as they use reduced amounts of chemicals during practicals (Abdullah *et al.*, 2008).

Mandina (2018) evaluated the effects of two types of problem-solving strategies on the overall performance of students in stoichiometry. The study used a pre-and post-test to assess the effectiveness of two proposed problem-solving strategies by Selvaratnam and Fraser (1982, cited by Mandina, 2018) and Ashmore *et al.* (1979, cited by Mandina, 2018) against the lecture method (narrative). Their study sampled eight schools, half of which were taught using the suggested strategies and they chose and found that the Ashmore, Frazer, and Casey model was more effective than the latter in teaching stoichiometry concepts over the lecture method. There are many other studies (Banu, 2011; Ajayi, 2017; Ajayi & Ogbeba, 2017; Alamina, 2019; Mohafa *et al.*, 2022; Ruterana, 2023) that have indicated that the lecture method does not fully improve learner achievement in stoichiometry. More research is needed on various methods that can be used in conjunction with alternative resources that under-resourced schools can use as it is well-researched that resources are a substantial hindering factor in methodology implementations and student achievement (Lake 2010; Tafa 2012; Shana & Abulibdeh, 2020; Ruterana 2023).

Stoichiometry calculations mainly involve using the number of moles of one substance to calculate the number of moles of another substance in a chemical reaction (Gulacar *et al.*, 2013). It is also important for students to understand that the limiting reactant is the substance that is used to determine the amount of product that is to be formed. Figure 2.2 indicates a flow chart that is followed during stoichiometric calculations:

concepts and processes, as noted in the study by Shana and Abulibdeh, (2020) or use different methods to increase their knowledge like hands-on activities (Ogbeba & Ajayi, 2016; Ajayi, 2017) or a virtual lab simulator such as Phet (Wu *et al.*, 2021; Mohafa *et al.*, 2022).

Additionally, İncebacak and Ersoy (2016) found that students struggle to solve problems that are not routine questions they are used to and Mourtos *et al.* (2004) indicated that exercise solvers cannot solve questions without hints or that they are familiar with, thus the questionnaire included questions that do not have hints and that require students to use their analytical skills and reasoning skills to solve other questions. Students must be able to take skills and concepts that they learn in class and apply them to a variety of questions to show that they have understood the concepts.

2.3.2. Curriculum and Assessment Policy Statement for Physical Sciences Grade 10 – 12

This section will focus on the stoichiometry practical and topics that require stoichiometric calculations covered in grades 10-12 as they appear on the CAPS document and ATP (Table 2.2). Maharajh *et al.* (2016, p. 372) stated that the recently implemented Curriculum and Assessment Policy Statement (CAPS)

“was an important step in achieving educational reforms, especially between former resourced and under-resourced schools. CAPS typically brings about significant changes in the methods of assessments, time that learners have to spend in the classroom from grade R-12 and new teaching approaches”.

The CAPS curriculum is concerned with the following (Department of Education, 2011, p. 66, as cited by Krishna, 2013); 1. Gathering and collection of evidence of achievement; 2. Evaluating evidence; 3. Recording findings of the evaluation; and 4. The use of the gathered information to understand and assist a learner’s development with the aim of helping improve the learning and teaching process. One of the general aims of the CAPS document is to *“facilitate the transition of learners from institutions to the workplace”* (Department of Basic Education, 2011). However, with the lack of hands-on activities done at school and experiments, science learners will struggle to adapt into the science field.

The CAPS document is divided into sections (see Annexure A) with specific information on the content to be taught per grade each year. On the CAPS document, Section 2.5 is an overview of practical work. In the overview, an emphasis was made that practical work must be

integrated with theory to strengthen the concepts being taught and in section 3 of the document, informal assessment activities are outlined. The downside of informal activities is that they are optional, and there is no time allocation for the informal work, which puts the teacher under pressure with no formal time allocation or apparatus handed out to aid the teacher in implementation. The CAPS document could allocate time for formal and recommended informal practical activities as well as for theory teaching, as this can assist in increasing students content knowledge. Furthermore, Section 2.7 of the CAPS document is an overview of formal and recommended informal assessments. The section states that there are two formal experiments for Grades 10-11, one of which is Physics and the other Chemistry. For Grade 12, it is said that there are only three formal experiments and one or two of which are Chemistry.

The ratio of the number of experiments done annually to the number of practical topics shows that there are few practicals compared to the content. Practical concepts related to stoichiometry could be assessed in the laboratory and also taught differently from theoretical concepts across all grades. Some of the topics, like calculating the number of moles, are repetitive and theoretical but could also be taught using PhET and other simulations for learners to increase their conceptual knowledge, as evidence that simulations can improve learners understanding and pass rate is found in studies done by Wu *et al.* (2021); Obaya *et al.* (2021); Inaya and Masrurah (2021); and Salame and Makki (2021). For each practical topic, the researcher will indicate whether there has been a formal practical on the topic according to the Program of Assessment (PoA) for the last three years and the possibility of problem-solving skills needed for each topic.

Table 2.2 highlights stoichiometry content covered by students from grades 10-12 and the formal practical activities allocated to each concept. Formal activities are activities that are compulsory in each grade while informal activities are recommended but not compulsory as they do not have any effect on the students' term marks. According to the CAPS (2011) document, informal assessment tasks are classified as any homework, class work, practical investigations, and tests given to students while formal assessments are control tests, yearly examinations, experiments and/or projects that are used to assess students and allocate marks that appear in their report cards. This is important for the current study because it will indicate the number of practicals that learners are expected to perform according to their Program of Assessment (POA) as it addresses one of the research questions in the study. The POA for grades 10-12 for 2022-2023 is available in annexures B and C.

Table 2.2. Annual Teaching Plan (ATP) content for Grades 10-12.

Topic	Content	Formal practical	Problem-solving skills needed
Grade 10			
Chemical change	1. Water of crystallisation	None	1. Analytical 2. Mathematical 3. Representational
Reactions in aqueous solutions.	2. Precipitation reactions, ions are an aqueous solution and chemical reaction types.	None	1. Analytical 2. Representational 3. Mathematical
Grade 11			
Chemical change	1. Limiting reagents and excess reagents.	None.	1. Analytical 2. Mathematical
	2. volume relationships in gaseous reactions.	None	1. Analytical 2. Mathematical
	3. percentage purity	None	1. Analytical 2. Mathematical 3. Representational
Grade 12			
Chemical change	1. Limiting reagents and excess reagents.	None	1. Analytical 2. Mathematical 3. Reasoning skills
	2. chemical equilibrium	None	1. Analytical 2. Mathematical 3. Reasoning skills 4. Representational skills
	3. acids and bases (titrations, reactions, pH, salt hydrolysis)	Titration experiment (one)	1. Analytical skills 2. Mathematical 3. Reasoning skills 4. Representational skills

Topic	Content	Formal practical	Problem-solving skills needed
	4. standard solution	None	1. Analytical skills 2. Mathematical 3. Reasoning skills 4. Representational skills

According to Table 2.2, there is only one prescribed formal practical activity for all stoichiometry concepts listed above which is done in grade 12 and also indicated in the CAPS document (page 128 of the FET Physical Sciences CAPS). Additionally, according to the Program of Assessment for Grades 10-12 for year 2022-2023 (see Annexures B and C), no stoichiometry-related practical was done across grades 10-12. The ATP does indicate resources to enhance learning of the said concepts, but without resources and time allocated just as the formal practicals for the said experiments it becomes a challenge for teachers.

George (2017) studied the availability of laboratory resources for teaching and learning chemistry in Lesotho secondary schools and found that about 70% of the students in Grade 12 had performed an average of four practicals per year, and only two schools from the sampled learners had more. This means that from Grades 10-12, learners perform an average of 12 practicals before they get into university, and not all of those are Chemistry-related. George (2017) also found that 90% of the schools had laboratories, however, they did not have the necessary apparatus to perform experiments and practicals were not formally scheduled which limits how effective the practicals are taught to students. However, the study did not evaluate the impact of the lack of practical work on the students' problem-solving abilities and assess if the students did any alternatives to hands-on practical work as the teachers might have used alternative methods such as virtual laboratories. This gap will be addressed in the current study by using a questionnaire to see if the number of practicals done by learners at high school has an impact on how they answer and understand stoichiometry and if the students were exposed to any alternative teaching methods.

2.3.3. The effect of gender on student achievement

Ajayi and Ogbeba (2017), who evaluated the difference in gender achievement in Nigeria, found no correlation between gender and overall achievement in stoichiometry. They

recommended that hands-on activities are not gender-specific and should be implemented to improve overall stoichiometry achievement. The study done by Ajayi (2017) noted a concern in how girls perform as compared to boys. However, he noted that from a sample of 292 students where 134 of them were females that there was no difference in their stoichiometry test scores.

Later, in another study conducted with Ogbeba the same findings were found (Ajayi & Ogbeba, 2017). A different result was found by Adigwe (2013), who found that males performed better than females and Arum *et al.* (2018) had similar findings where they found that male students had a greater logical-mathematical intelligence than females. Mandina (2018) also found a difference in how males performed compared to females. These findings were tested in the current study as well.

2.3.4. Student perceptions on practical activities

Studies that investigated the effect of different hands-on activities/practicals in chemistry on perceptions and attitudes students have towards the subject, found that the activities improved the students' perceptions and attitudes towards chemistry (Abdullah *et al.*, 2008; Townsend 2012; Türk, 2005). In a study by McDonnell *et al.* (2007), the perception that students had towards laboratory work was positive, and one of the findings from the students was that they enjoyed spending time in the lab. The study also noted that the ideas and techniques for using particular instruments or conducting particular experiments were better understood by the students. Domin (2007) also had a positive response where the researcher noted that the majority of the students felt that the problem-based laboratory was a good learning environment. Students' positive attitude towards chemistry practicals can also be increased by the use of microscale experiments as they also increase their general understanding of concepts (Abdullah *et al.*, 2008; 2009).

Townsend (2012) also found that there was a discernible improvement in science attitudes with relation to preferred subject and understanding of science in grade 5 learners who performed practical activities. The researcher further emphasised the importance of laboratory activities to motivate students and deepen their grasp of science in fifth grade and stated that evidence that this is true was not only in survey findings but also in remarks made by students. Another way to increase students' positive attitude towards chemistry and science as a whole is by teaching the subject using different teaching methodology as compared to the standard lecture

method. Mamombe *et al.* (2021) noted that using *Process Oriented Guided Inquiry Learning (POGIL)* the attitude and overall performance of students improved significantly.

In this study, students' perceptions towards practical activities were investigated using a Likert scale questionnaire to determine if students believe that practical work is helpful for their learning (importance), if students think they should have more practicals (number of practical activities), how often they would like to have practicals (frequency), and their overall satisfaction with the practicals they have done at high school (satisfaction). The study also looked at whether students had done any alternative approaches to practicals during the covid-19 pandemic such as simulations at their previous high schools and whether their respective schools did have laboratories.

2.3.5. Factors that influence student achievement in stoichiometry

According to Gardner, intelligence is a biological trait that is influenced by one's surroundings, including their culture, community, and other people (Arum *et al.*, 2018), hence it is important to investigate how these factors impact how students perform in chemistry. Studies indicate several factors that influence how students perform in stoichiometry and Chemistry as a whole and impact curriculum implementation. Maharajh *et al.* (2016) and Kaundjwa (2015) found that lack of resources is a massive problem in schools and affects curriculum implementation; therefore, it is essential to indicate the resources that directly impact chemistry education. Additionally, Yangambi (2023) found similar results and stated that school resources are a vital factor that determines quality learning. Van der Nest (2012, cited by Maharajh *et al.*, 2016) categorised resources into three groups: *human resources*, *material resources* and *cultural resources*. They further explained that human resources are teachers and the content knowledge they gain throughout their professional development. Material resources are textbooks, laboratory apparatus, and other resources that can be incorporated into improving teaching and learning. Lastly, cultural resources include time, the language of instruction, and other tools or concepts. Each of these aspects are discussed, however, this study is mainly focused on how practical work affects student achievement in stoichiometry, and this is more related to material resources, thus the factor that is discussed extensively in this section is material resources.

Human resources

Improvement of the performance of students in chemistry and science related subjects requires that teachers be well-equipped with knowledge of the subject; and how to ensure that all the students fully understand what is required from them. This can be summed up in the concept

of pedagogical content knowledge (PCK), which is in-depth knowledge about the content to be taught normally possessed by teachers (Buma et al., 2024; Rollnick & Mavhunga, 2017; Shulman, 1986;). PCK includes the understanding of what makes topics to be considered difficult or easy and the different ways to address common misconceptions found in each topic (Shulman, 1986). Park and Oliver (2008) stated that PCK is the transformation of knowledge into more understandable forms for students, which is a shift from what teachers understand to how best to teach what they understand. Topic-Specific Pedagogical Content Knowledge (TSPCK) enables teachers to create a bridge between content of specific topics and students' understanding (Mavhunga & Rollnick 2013). This requires the adoption of adequate and effective methods of teaching that will result in an improvement of the academic performance and content retention of chemistry students.

Professional development can be defined as learning opportunities that help teachers have to improve their teaching approaches and increase their subject knowledge. It can be in different forms such as teacher training workshops, mentoring, and lesson studies (Buma et al., 2024). Teachers should be trained accordingly to help them achieve the desired results and improve how they teach. In a study by Chetty (2015), where teachers were trained for a period of three months on how to teach high school students Physical Science; most participants indicated that they had never had any formal training to prepare them for teaching the subject, and they had limited understanding of the theory thereof. Mudau (2013) performed a study in Johannesburg and the findings highlighted that classroom interaction in Physical Science puts the learner at a disadvantage. This was indicated by the students' experiencing limitations in their problem-solving skills, while the teachers believed they were doing an excellent job. Thus, there is a need for more professional teacher development that will assist teachers in changing their approaches, which allows students to be actively involved in their learning process.

Cultural resources

As indicated above, cultural resources are related to factors such as the time and language of instruction. Students must be proficient in English to analyse stoichiometry problems correctly if English is the medium of instruction. According to Norris and Philips (2003), comprehension of science cannot be attained without the ability to read, comprehend, and write effectively about the subject being studied. Students who struggle with their English communication skills may find it challenging to function well not only in English but also in other academic subjects

(Aina *et al.*, 2013). This aspect will not be evaluated by the current study and therefore will not be extensively discussed.

Material resources

According to the study by Mji and Makgato (2006: p. 8), some of the factors impacting Mathematics and Science performance were laboratory use and lack of available laboratory equipment. One of the perceptions of the students evaluated in their sample was that:

“I think it would be better if when they teach science and physics that they should show us when they ask about sulphuric acid, I don't know what sulphuric acid is, it will just be an abstract thing, that name, when they tell you that when you mix this and that gives you that, you don't know what that is”.

This indicates that students do not understand science without hands-on activities and exposure to different apparatus they are being taught about. Mohafa *et al.* (2022) found that students who were taught using simulations performed better than those who were taught using the traditional method (narration), and simulations helped learners to better understand the stoichiometry concepts. Ajayi (2017) also found that hands-on activities boosted learner performance in chemistry. Lack of resources impacts students' achievement and transition to tertiary institutions (Maila & Ross, 2018). Kaundjwa (2015) found that Namibia's shortage of necessary teaching aids and laboratory equipment caused students to struggle to conceptualise chemistry content. In conclusion, many of the above researchers have found the same result in their research, that students taught using traditional methods perform lower than the students who were taught using different methodologies.

Under-resourced schools significantly impact the overall experience of students' learning and understanding of chemistry concepts, as the subject has many practical concepts that can be better understood through active participation. It was noted by Van Der Berg (2008) that there is a difference in how well-resourced schools perform compared to under-resourced schools and that White and Indian schools were found to perform better than Black schools. This highlights the importance of equipping schools equally to allow learners in rural schools, primarily black, to have a fair chance of competing academically. Many other studies (Modisaotsile, 2012; Du Plessis & Mestry, 2019; Makhechane & Qhobela, 2019) agree that resources are key to improving chemistry results. They also highlighted that schools must be

given the resources needed for teachers to implement different teaching strategies to enhance learners' learning experience and improve their overall performance.

Findings of an explorative study in three high schools in the Western Cape, South Africa indicated that each school experienced unique challenges primarily due to existing and historic inequality in South Africa (Schoeman, 2018). The challenges ranged from socio-economic limitations to bullying and drug abuse, factors indicative of the learners' mental state. In the same study, learners', and teachers' views regarding learner preparedness for life after Grade 12 differed; learners indicated that they still lacked important life skills such as time management, self-discipline, and responsibility. They also suggested that the method of presentation of subjects needed much improvement, and also the need for adequate infrastructure for demonstrations. Additionally, results in the study done by Kim and Hong (2018) showed that in general, school characteristics had a greater impact on cognitive success and the attitude that learners have towards their learning and subjects, which could affect their overall performance.

Thus, this study evaluated the impact of resources on first-year students' achievement scores by looking at the high schools attended by the participants, and whether they had laboratories, computer laboratories or libraries. The need for adequate resources in schools that offer science subjects is emphasized to help improve how science subjects are taught.

2.3.6. Domains of learning

Teachers should know about domains of learning and build their lessons in such a way that they cater to these domains (Wilson, 2016). Once students are actively involved in their learning and perform different hands-on activities, the students are more likely to improve their attitudes towards science education and in turn, improve how they perform in the subject (Kim & Hong, 2018). Similar findings are found in the study by Ekundayo (2012) where it was found that availability of school physical facilities and the conduciveness of the school learning environment have been said to be potent factors influencing students' achievement. The three domains of learning include the cognitive domain which focuses on students' knowledge, the psychomotor domain which focuses on movement/doing, and the affective domain which includes students' attitudes (Wilson, 2016). These domains are discussed briefly below.

Cognitive domain

Commonly known as the *thinking domain*, it is the domain that measures how a student acquires and utilizes knowledge (Ramalingam *et al.*, 2014). They also stated that this domain, similarly to Bloom's taxonomy focuses on skills such as knowledge, understanding, application, analysis, synthesis, and evaluation. Bloom's taxonomy is a model used to categorise thinking into the skills listed previously. However, the cognitive domain mainly is concerned with the development of mental skills and understanding of knowledge. Hoque (2016: pp.47-48) stated that "*Bloom's objectives is used to define how well a skill or competency is learned or mastered*" and "*the cognitive domain involves the development of our mental skills and the acquisition of knowledge*". The author further explained the six skills under cognitive domain in comparison to Bloom's taxonomy as follows (Table 2.3):

Table 2.3. Comparison between cognitive domain and Bloom's taxonomy of six cognitive skills.

	<i>Cognitive domain</i>	<i>Bloom's Taxonomy</i>
1. <i>Knowledge</i>	The skill students use to recall data and concepts learned.	Students are able to define/explain concepts.
2. <i>Comprehension</i>	The skill to understand the meaning what is known.	Students are able to work through assign problems and make examples of what they learned.
3. <i>Application</i>	The ability to use what you know in a different way.	Students can correctly identify methods needed to solve problems and can use those methods.
4. <i>Analysis</i>	The skill to differentiate between facts and opinions.	Students can explain their solutions and choices.
5. <i>Synthesis</i>	Being able to integrate different concepts to form their own understanding of concepts.	Students can use their knowledge in new/different problems
6. <i>Evaluation</i>	Ability to come up with conclusions based on what they learned and understand the importance of concepts.	Students are able to create different ways to solve a problem and choose a correct approach suited for a specific problem.

The cognitive domain is considered to be the core of the domains of learning (Ramalingam *et al.*, 2014). Thus, the development of learning skills should be aligned with the above cognitive skills. Learning processes in this domain include processing of information, formulating understanding, application of knowledge, problem-solving and research (Hoque, 2016).

Affective domain

This domain is mainly concerned with the feelings and emotions of students (Wilson, 2016). Learning is not only about cognitive abilities, but can also be measured in terms of attitudes, behaviours, and physical skills (Hoque, 2016). This domain can assist researchers in measuring the motivation, discipline, and willingness of students to learn. Additionally, the domain is categorised by the following stages: Receiving; Responding; Valuing; Organizing; and Characterization. This domain is important for effective learning, as it has been linked with the difference in learning outputs between students where motivation and goals are related (Dumas, 2020). Students' negative behaviours that have a huge impact on their overall attitude towards learning and their performance include being late, constantly being absent from school, and not following the school code of conduct (Ben-David *et al.*, 2010). The authors further argued that if this domain of learning is not properly assessed, it affects the cognitive domain.

Psychomotor domain

This domain assesses the student's ability to perform tasks accurately and with understanding, which can be assessed using laboratory exercises, art performances, and/or physical education (Hoque, 2016). Ramalingam *et al.* (2014) described stages of the psychomotor domain as action (motion), coordination (synchronized motion), formation (body movement), and production (verbal and non-verbal movement). Availability of school resources and how the learning environment of the school is operated have been found to affect students' achievement in the affective and the psychomotor domain (Ben-David *et al.*, 2010), thus the current study argues that limited resources influence students' overall achievement in stoichiometry. Yangambi (2023) stated that physical resources provide conducive environment for students to learn.

2.3.7. Chapter Summary

Studies have shown that there may be an improvement in students' performances when hands-on activities and simulations are used (Ajayi, 2017; Ajayi & Ogbaba, 2017; Mohafa *et al.*, 2022). Even though this study is similar to the above-mentioned studies, it aims to find the correlation between practical activities and students' problem-solving abilities in stoichiometry. The difference between this study and similar published studies is that this study sought to provide insight into the problem-solving skills that learners exhibit gaps in and also give insight into students' perceptions of practical activities using a Likert-scale questionnaire.

This study also highlighted the number of prescribed practical activities found in the Program of Assessment (PoA) developed by the Department of Education each year for grades 10-12

for Physical Sciences but the focus was on the comparison to stoichiometry content. Additionally, the researcher highlighted the stoichiometry practical concepts on the Curriculum and Assessment Policy Statement (CAPS) document, many of which are not done as practical work by students to enhance their conceptual understanding. This was intended to establish whether stoichiometry practical concepts are given as much attention as they need and are assessed appropriately. The impact of school type will also be tested in this study, and learners were asked to indicate if their respective schools had necessary resources for practical activities and any other methodology listed by different authors like Ajayi and Ogbeba (2017) and Mohafa *et al.* (2022) that can assist students to improve their overall performance in chemistry. Another difference is that this current study tested if there is a correlation between gender and achievement in students, which the study did not test for.

Furthermore, many studies suggest different teaching methods that teachers can use to improve overall learning experiences by learners. These include hands-on activities (Ajayi, 2017), simulations (Mohafa *et al.*, 2022), frequent laboratory use (Oginni *et al.*, 2013) and different problem-solving strategies (Mandina, 2018). These studies further echo the sentiments that schools must be equipped with the necessary resources as these methods have been proven to improve learners' achievement in stoichiometry.

Therefore, the study investigated whether there is a difference in how first-year learners from well-resourced schools perform compared to learners from under-resourced schools. This should then assist in increasing efforts from the Department of Education to ensure that science schools are given the necessary resources to help learners better understand chemistry concepts. The limitation to this insight, however, is that the researcher will not be able to elaborate on the actual extent of available resources from the schools that each learner comes from, the assumption will be based on the location of each school (Rural and Urban areas) and the quintile each school falls under. In closing, domains of learning should be incorporated into how students are assessed. The current focus has been on students' cognitive skills in many high schools however, the two other domains do have an impact on the cognitive domain if they are neglected (Ben-David, 2010).

Chapter 3: Research Methodology

This chapter discusses the methodology and research design behind this mixed methods study. As previously outlined, the purpose of this study is to investigate the link between practical activities and students' problem-solving abilities in stoichiometry. To do that, this study employed the use of a stoichiometry questionnaire to evaluate the gaps that students have in the chosen stoichiometry concepts. Additionally, the study seeks to answer the following research question "What perceptions do the students have regarding practical learning and its importance?", to do this, a Likert-scale questionnaire will be used to analyze the perceptions of the students. This data will give us an idea of whether students understand the importance of practical activities to increase their scientific knowledge. Furthermore, qualitative data through the use of interviews was used to determine key observations made by lecturers and laboratory technicians while working closely with the students that might strengthen the findings of this study and also shed light on any other gaps that the students might have.

3.1. Research paradigm

A paradigm represents and guides the beliefs and values of a discipline, and the way problems, are resolved (Schwandt, 2001). A paradigm is mainly determined by the ontology of a study, type of data the research will seek to examine and how the data is collected. In this study, the researcher generated quantitative data through the analysis of a stoichiometry questionnaire and qualitative data through interviews held with staff members of the North-West University. However, it is important to note that the main data source of this study is quantitative data that were gathered and the qualitative data from the interview served as a reinforcement to the quantitative data. Three paradigms were thus identified, being *positivism*, *constructivism*, and *pragmatism*.

A positivist paradigm mainly uses quantitative methodology, experimenting with experimental and control groups, and giving pre- and post-tests to measure correlations (Taylor & Medina, 2011). This paradigm will not be suited for this study as it will not employ a pre-and post- test design and also has both qualitative and quantitative data. Constructivism is a paradigm that mainly uses qualitative methodology and does not cater for the mixed method theme of the current study. Thus, the paradigm that is best suited for a mixed method study is pragmatism.

The research design is a randomised cross-sectional survey design using a questionnaire to obtain geographical information about the students and test their knowledge in stoichiometry. Randomised cross-sectional survey design is usually associated with exploratory and descriptive designs examining several groups of people simultaneously (Fouché *et al.*, 2011). Cross-sectional studies are shorter and less expensive, and they can be used to uncover correlations that can be examined in a longitudinal study. This study seeks to investigate the correlation between practical activities involving stoichiometry and students' problem-solving abilities. Therefore, the study's results can be used in a longitudinal study to explore ways to close the gaps that students might exhibit and determine if the current alternative methods used for practical activities are effective. Furthermore, interviews were held after the questionnaire was administered to gain more insight into the gaps that the students had in their first year of university.

3.1.1. Pragmatism

The key idea is that every scientific study follows a particular paradigm, or perspective, when conducting its investigation. To maintain clear and unambiguous communication with a study, the researcher must decide within which paradigm he or she is working, be highly familiar with the nature of his or her chosen paradigm, and explicitly state this in his or her research report (De Vos, 2011). Thus, it was important to review the paradigm used in the current study.

The chosen method for this study is mixed methods because the study is implementing the use of both qualitative and quantitative methods, thus it needs a paradigm that can accommodate both methods. Constructivism, transformation, pragmatism, and positivism are the four widely accepted worldviews, and only the pragmatic and transformative worldviews are thought to work well with mixed methods research (Hall, 2013). Positivism is not well-suited for mixed methods research because it is strongly associated with quantitative research and constructivism with qualitative research, thus the chosen paradigm for this study is pragmatism.

Pragmatism comes from the Greek word '*pragma*' which means action. It is a philosophical worldview that arises out of actions, situations, and consequences rather than antecedent conditions. It embraces multiple methods and encourages researchers to use any methodological and philosophical approach that best answers the research questions (Kaushik & Walsh, 2019). As a paradigm, pragmatism aims to solve practical problems and thus it is best suited for this study. Biesta (2010) stated that the pragmatic view of knowledge is that it is best obtained through action and reaction, which supports the theme of the current study that

stoichiometry concepts need to have more practical work to increase student understanding. Kivunja and Kuyini (2017) stated that pragmatism was formed as a result of the argument that a worldview cannot be determined through a single scientific methodology, thus it was important to develop a paradigm that allows for the use of multiple scientific methods.

3.2. Research approach

A mixed-method research approach was used for the research. Research using mixed methods involves the simultaneous or sequential gathering of both quantitative and qualitative data, prioritizing the collection of the data, and integrating the data at one or more stages of the research process (Schaefer, 2017). In this study, the researcher used a questionnaire and later interviewed staff members who have worked with the sampled students. Questionnaires are “*documents containing questions and other items intended to collect information for analysis*” (Delpont & Roestenburg, 2011, p. 186). The questionnaires were key to determine the correlation between practical assessment and students’ problem-solving abilities, and thus the data from the questionnaires was given main priority in this study. The results from the questionnaire were also used to get an insight into the problem-solving skills that the students struggle with when solving questions based on stoichiometry, and the perceptions (attitudes) that students have towards practical work.

Furthermore, the researcher uncovered key observations that the lecturers and laboratory technicians had during the first semester while working with the sampled group of students. Observations can be expressed numerically and manipulated to describe and explain the phenomenon they reflect (Sukamolson, 2007); thus the researcher engaged with staff members who worked closely with the students, to uncover additional gaps that the students had, and a summary is given in the results section. The researcher held one-on-one interviews with the lecturers and laboratory assistants who worked with the students and evaluated their observations. The qualitative data obtained from the interviews gave the study more insight on the gaps that the students had coming into university.

3.3. Study population

The participants in this study included first-year extended-BSc and first-year mainstream BSc Chemistry students in the chemistry department from the Faculty of Natural and Agricultural Science at NWU (Mafikeng Campus), South Africa. The criterion for selecting students was

that they must be doing first-year Chemistry in either the mainstream module (NCHE111) or the extended module (NCHE171). The students took part voluntarily, and informed consent was obtained. Additionally, staff members from the North-West University were interviewed by the researcher. These included the lecturers and laboratory technicians who had direct contact with the students. The criterion for selecting staff members was that they must have worked with the students in the laboratory or have lectured them during first semester. The staff members took part voluntarily and formal invitations were sent to each participant.

3.4. Sampling techniques

A stratified sampling technique was used to determine the sample size of participants for this study. The stratified sampling technique first divides the population into subgroups or strata, and a random sample is taken from each subgroup based on students who are willing participate in the study. The sample was divided into first-year BSc mainstream Chemistry students (Group A) and BSc extended Chemistry students (Group B). Group A had about 190 students while group B had 310, giving a total population of 500 students according to the lecturers who taught the students chemistry. The researcher then arranged with the respective lecturers to go into a scheduled class to explain the purpose of the study to the students who were present on the chosen day, and all the students who agreed voluntarily to participate were the ones who took part.

The total number of students who participated in the study was 338 (68% of 500), with 130 (68% of 190) from group A and 208 (67% of 310) from group B. These numbers indicate that this was a good sample, and according to stratified sampling, a good sample would include a sample of 267 students as derived from similar calculations in the study by Israel (1992). The sample size at $\pm 5\%$, with precision levels and a confidence level of 95%, and $P=0.5$ was calculated as follows from groups A and B:

$$\text{Group A} = 190 \times \frac{267}{500} = 101 \text{ participants from 1}^{\text{st}} \text{ year Chemistry mainstream}$$

$$\text{Group B} = 310 \times \frac{267}{500} = 166 \text{ participants from BSc Extended Chemistry}$$

$$\text{Total} = 267 \text{ participants (Sample size)}$$

Additionally, purposeful sampling was used to select the staff members who were interviewed after they had worked with the students for a full semester. Three staff members were identified and interviewed by the researcher.

3.5. Method of data collection

A questionnaire was used, consisting of three sections, whereby section A asked about demographic information of the participants, section B was based on student's perceptions of the importance of practical work, how frequently they should have practicals and their satisfaction with regards to practicals. Lastly, section C consisted of stoichiometry questions that evaluate students' problem-solving skills. Section C tested students on stoichiometric aspects that require them to use different problem-solving skills and some practical concepts that might need students to have performed a practical to understand and build conceptual knowledge of the topic. The stoichiometry concepts include writing and balancing chemical equations, standard solutions, titration, limiting and excess reactants, and mole ratio calculations, all part of stoichiometry calculations. This questionnaire was administered towards the end of the first semester (Dates: 9th and 31st May) 2023.

Furthermore, one-on-one interviews with lecturers and laboratory technicians (Dates: 12th, 18th, and 26th September 2023) were held to gain more insight into the shortcomings and gaps that the students had during chemistry theory lectures and in the laboratory during practical assessment and performing practicals in general. The interviews were recorded using a recording device and analysed to reinforce the findings of the questionnaire. Formal interview invitations were sent to the possible participants in advance.

3.5.1. Research instruments

A stoichiometry Test, Likert scale questionnaire, as well as interview question were used to assess the students and interview staff members from the North-West University were developed by the researcher. The questionnaire had three sections (A - C) that cover questions on demographic information, perceptions towards practical work and assessment, and problem-solving skills respectively. The concepts assessed in the test included: representing and balancing of chemical equations, limiting and excess reactants, mole ratio calculations, and acid-base reactions and titrations. These topics assess the student's ability to analyse questions, represent equations and apply mathematical skills to solve questions. The content used in the

questionnaire was guided by the Revised Annual Teaching Plans (ATP's) and the Curriculum and Assessment Policy Statement (CAPS) for Physical Sciences in grades 10-12 that were utilised in the years 2019 to 2022 and are available on the Department of education website (www.education.gov.za). These documents indicate the content that was covered and thus help in knowing the content removed during the covid-19 outbreak. The questionnaire is given in Table 3.1.

Table 3.1. Questionnaire.

	
CHEMISTRY QUESTIONNAIRE	
Topic students'	: Assessing the relationship between practical activities and problem-solving skills in stoichiometry
Instructions: 1. This question paper consists of three sections, answer all the questions. 2. Follow the instructions for all questions carefully. 3. You can use a non-programmable scientific calculator. 4. Do not use your phone during the test. 5. Write neatly and legibly. 6. Write down your answers on the provided question paper.	
This question paper consists of 10 pages and two data sheets.	

Section A – General information

Please pick an alias that can be used for research purposes:

Alias (**Not your real name**) :

a. Demographic information:

Province :

BSc extended or mainstream :

Gender (Male/Female) :

Name of High School :

b. Mark each answer as yes if it relates to you or no if it does not: (N.B: Use X or a tick)

Questions:	Yes	No
1. Did your teacher do demonstrations for practicals due to COVID-19?		
2. Did you watch online videos for prescribed practical assessments at school?		
3. Did you get a chance to read through your experiment manuals at high school?		
4. Has your teacher ever used PhET simulations?		
5. Does your school have a laboratory?		
6. Does your school have a computer lab?		
7. Did your school have all the apparatus/material needed during practicals?		
8. Did you have access to Wi-Fi at school?		
9. Did your school have a library?		
10. Can you operate a computer and type a practical report?		
11. Did you perform a practical based on limiting reactant at high school?		
12. Did you perform an acid-base titration practical at high school?		
13. Did you prepare a standard solution in the laboratory at high school?		
14. Have you ever performed a laboratory practical before coming to university?		

c. Has your teacher ever used any other alternative teaching aid in a chemistry class (Yes/no)? If yes, briefly explain.

.....

Section B – Likert scale perception questions.

The likert scale will use numbers from 1-5, 1 being strongly disagree and 5 being strongly agree.

Part 1

1. The importance of practical assessment.

The following questions are perception (view) questions to determine your views towards the importance of practical assessment. There are no right or wrong answers. The following scale will be used, mark with an **X** on each scale you agree with.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree/disagree	Agree	Strongly agree

Codes: **1-** Strongly disagree; **2-** Disagree; **3-** Neither agree/disagree; **4-** Agree; **5-** Strongly agree

Question:	Perceptions:	Codes:				
		1	2	3	4	5
1.	Practical assessment is not important for understanding of practical chemistry concepts.					
2.	Practical assessment increases the amount of work a student does and causes fatigue.					
3.	Practical assessment does not help increase students' problem-solving skills.					
4.	The practical work received helped me to better understand chemistry concepts.					
5.	The alternative methods to hands on practicals (e.g. video sessions for practicals, online classes) assisted you in understanding practical content.					
6.	Practical assessments at high schools should be increased.					
7.	Practicals are easy to understand.					

8.	Practicals are boring and unnecessary.					
9.	The teacher allowed us to independently solve problems in each science practical.					
10.	I am able to write a full science report after a practical lesson.					

Part 2

2. Satisfaction scale questionnaire:

The following questions will be used to determine your satisfaction with the practical work you did at high school. Consider your own experience when you answer the questions. The following scale will be used, mark with an **X** on each scale you agree with.

1	2	3	4	5
Very unsatisfied	Unsatisfied	Neutral	Satisfied	Very satisfied

Codes: **1-** Very unsatisfied; **2-**Unsatisfied; **3-** Neutral; **4-** Satisfied; **5-** Very satisfied.

Question:	Perceptions:	Codes:				
		1	2	3	4	5
1.	How satisfied are you with the number of practical activities done at high school?					
2.	How satisfied are you with how practical concepts are taught at high school?					
3.	How satisfied are you with the teaching methodologies used at high school in chemistry?					
4.	How satisfied are you with the number of hands-on activities done in chemistry classes at high school?					
5.	How satisfied are you with the alternative teaching methods that were used due to covid-19 regulations during practicals?					

Part 3

3. Frequency Likert scale:

The following questions are perception questions used to determine the views that students have on how often they should have practicals and practical assessments. The following scale will be used, mark with an **X** on each scale you agree with for each question.

1	2	3	4	5
Never	Once a month	Once per term	Every second week	Every practical topic

Codes: **1-** Never; **2-** Once a month; **3-** One per term; **4-** Every second week; **5-** Every practical topic

Question:	Perceptions	Codes				
		1	2	3	4	5
1.	How often should students perform practicals tasks?					
2.	How often did you visit the science laboratory at high school?					
3.	How often did you have practical lessons at high school?					
4.	How often were you allowed to perform experiments on your own at high school?					
5.	How often did you visit the school library?					
6.	How often should students have practical assessment?					

How many chemistry practicals did you perform in the laboratory in **Grade 12**:

.....

Section C – Questionnaire

The following questionnaire will test your representational skills, reasoning skills, analytical skills, and mathematical skills in stoichiometry.

1. Representational questions

1.1 Shown below are three elements and a picture of an atom of each:

Oxygen 	Carbon 	Sulphur 
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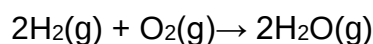
Complete the following table (Use the above atoms for illustrations):

Name of compound	Chemical Formula	Picture illustration of the compound
Carbon dioxide	1.1.1	1.1.2
Sulphur trioxide	1.1.3	1.1.4

1.2. Below are the representation of an oxygen and a hydrogen atom:

Oxygen 	Hydrogen 
---	---

Use the above atoms to illustrate the following reaction:



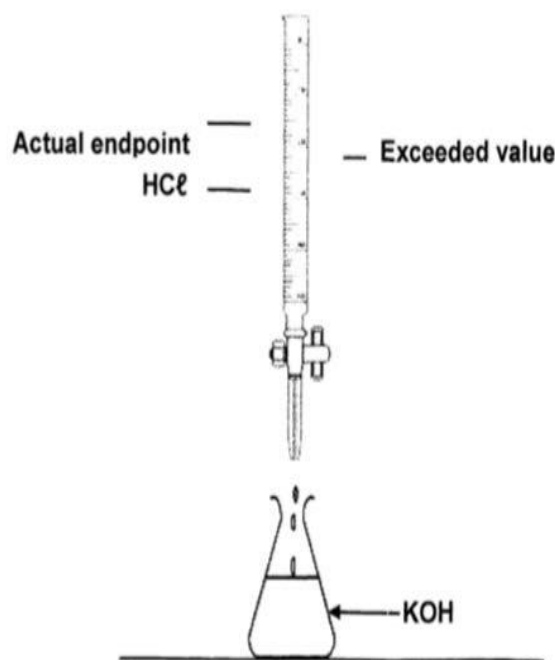
2. Conceptual questions

For each question there are four possible answers, A, B, C, and D. Choose the one you consider to be correct and record your choice **by circling** in pencil or pen on the Answer Sheet. Some questions will require you to give a **reason** for your answer, you are allowed to explain or use a calculation to support your answer.

- Which one of the following does not represent a balanced equation?
 - $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$
 - $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$
 - $2\text{Al} + 3\text{O}_2 \rightarrow \text{Al}_2\text{O}_3$
 - $\text{Mg}(\text{OH})_2 + 2\text{HCl} \rightarrow \text{MgCl}_2 + 2\text{H}_2\text{O}$
- Which one of the following represents the ionisation reaction of an acid?
 - $\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$
 - $\text{H}_2\text{SO}_4 \rightarrow \text{H}^{2+} + \text{SO}_4^{2-}$
 - $\text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$
 - $\text{ZnO} \rightarrow \text{Zn}^{2+} + \text{O}^{2-}$
- The number of moles contained in 2g hydrogen gas is:
 - 2 mol
 - 1.5 mol

- C. 1 mol
- D. 0.11 mol

4. In a titration involving HCl and KOH, as shown below, a learner accidentally exceeds the endpoint.



Which one of the following is correct for the solution now in the conical flask?

- A. $[H^+] > [OH^-]$ and $pH > 7$
- B. $[H^+] < [OH^-]$ and $pH > 7$
- C. $[H^+] < [OH^-]$ and $pH < 7$
- D. $[H^+] > [OH^-]$ and $pH < 7$

Explain your answer above.

.....

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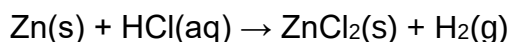
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5. The compound $NaHCO_3$ is commonly known as baking soda. A recipe requires 1600 g of baking soda, mixed with other ingredients, to bake a cake. What is the number of moles of baking soda?

- A. 0.019 mol
- B. 0.031 mol
- C. 84 mol
- D. 19 mol

6. 8g of Zinc reacts completely with excess hydrochloric acid at **STP** to form hydrogen gas.



6.1 Balance the equation above.

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6.2 What is the amount of HCl that reacted?

- A. 0.22 mol
- B. 0.25 mol
- C. 0.06 mol
- D. 0.12 mol

6.3 How much volume of hydrogen was produced at **STP**?

- A. 8 dm³
- B. 5.4 dm³
- C. 2.76 dm³
- D. 22.4 dm³

7. 20.0 cm³ of a sulphuric acid (H₂SO₄) solution was titrated with a standardized solution of 0.05 mol.dm⁻³ (0.05 M) potassium hydroxide (KOH). Using phenolphthalein indicator for the titration, the acid required 36.0 cm³ of the alkali for neutralization.

7.1 Write down a balanced chemical reaction for the above reaction.

.....

7.2 What is the number of moles of the base?

- A. 1.8x10⁻³ mol
- B. 0.05 mol
- C. 1.8 mol
- D. 1.0x10⁻³ mol

7.3 What is the concentration of the acid?

- A. 0.18 M
- B. 0.09 M
- C. 0.045 M
- D. 9x10⁻⁴ M

8. Show using calculations, how you would prepare a **standard solution** with 0.2 mol.dm⁻³ MgCl₂ in a volumetric flask that has a volume of 250cm³.

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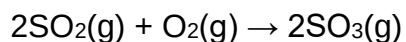
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9. 2 mol of Oxygen is mixed with 3 mol of Sulphur dioxide to form sulphur trioxide during the following reaction:



9.1 Which substance is the excess reactant? Give a reason for your answer.

- A. SO_2
- B. SO_3
- C. O_2
- D. None is in excess.

.....
.....
.....

9.2 What is the maximum mass of sulphur trioxide that can be formed?

- A. 192 g
- B. 320 g
- C. 80 g
- D. 240g

9.3 What is the amount of excess reactant that did not react?

- A. 1.5 mol
- B. 2 mol
- C. 1 mol
- D. 0.5 mol

THE END.

INFORMATION SHEETS

TABLE 1: PHYSICAL CONSTANTS/TABEL 1: FISIIESE KONSTANTES

NAME/NAAM	SYMBOL/SIMBOOL	VALUE/WAARDE
Avogadro's constant <i>Avogadro-konstante</i>	N_A	$6,02 \times 10^{23} \text{ mol}^{-1}$
Molar gas constant <i>Molêre gaskonstante</i>	R	$8,31 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
Standard pressure <i>Standaarddruk</i>	p^θ	$1,013 \times 10^5 \text{ Pa}$
Molar gas volume at STP <i>Molêre gasvolume by STD</i>	V_m	$22,4 \text{ dm}^3 \cdot \text{mol}^{-1}$
Standard temperature <i>Standaardtemperatuur</i>	T^θ	273 K

TABLE 2: FORMULAE/TABEL 2: FORMULES

$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$	$pV = nRT$
$n = \frac{m}{M}$	$n = \frac{N}{N_A}$
$n = \frac{V}{V_m}$	$c = \frac{n}{V} \quad \text{OR/OF} \quad c = \frac{m}{MV}$

Additionally, one-on-one recorded interviews were held with lecturers and laboratory technicians who worked directly with the students. The questions helped the researcher gain insight on the gaps the students had in their theory and practical work done in the laboratory. Semi-structured interviews were chosen for their flexibility in allowing for follow-up questions on points of interest raised by participants while keeping on topic (Creswell & Plano Clark, 2011). The interview questions are shown in Table 3.2.

Table 3.2. Interview questions.

Interview questions:

The interview will begin by the interviewer introducing himself and explaining the objectives of the interview. The interviewer will then explain to the interviewee that their confidentiality will be maintained, and that they should not use their real names in the interview.

Objectives

The objectives of the interview are to determine the observations of the staff members with regards to...

- a) the attitudes that students have towards practical work,
- b) the attitudes that students have towards writing of practical reports,
- c) how students have coped with coming into university,
- d) how students respond to chemistry concepts such as limiting reagents, standard solutions, titrations, and mole ratio calculations,
- e) and the gaps that the students presented in theory lessons and in the laboratory.

Opening questions

- I. If you had to describe your role to someone who does not know what you do, how would you describe it?
- II. What do you love about your job the most?
- III. What are the common challenges that you face in your position?
- IV. How do you overcome those challenges mentioned?
- V. How would you describe your overall experience working with students?

Lecturer questions

- I. Which stoichiometry concepts did you cover with the students?
- II. What are the challenges that the students had during mole concept calculations?
- III. What are the challenges that the students had when calculating amount of product formed when the limiting reactant is not known?
- IV. What challenges did students have when performing acid-base titration calculations?
- V. From the results of the questionnaires, I have noted that learners struggled to balance equations and use reaction ratio's correctly to find unknown amount of

	substance, how have your students responded to this aspect of stoichiometry in first semester?
VI.	What other challenges did the students have that I have not asked about?
VII.	How did you assist them to overcome these mistakes?
<u>Laboratory related questions (For technicians and lecturers):</u>	
I.	How would you describe the attitude students have in the laboratory?
II.	How would you describe the effort made by students when writing their practical reports?
III.	How would you describe the overall attendance of students during practical lessons?
IV.	Which practicals have you performed with the students during the first semester?
V.	How often did the students need assistance during practical activities?
VI.	What common challenges did students have when performing titrations?
VII.	In the questionnaire that the students wrote, the majority of the students did not manage to calculate the mass needed to prepare a standard solution, what challenges did you note from the students with this concept?
VIII.	What are the common challenges (or mistakes) that students have when dealing with laboratory equipment?
IX.	How did you help them to overcome the challenges you have mentioned?
X.	Is there anything you would like to add that I left out?
End of interview.	

3.5.2. Data collection procedure

The study used self-administered or individually administered questionnaires to ensure that the researcher was available in case any problems or questions arose. Technicians from the Chemistry Department helped to invigilate the task, in order to ensure neutrality. Covid-19 restrictions had no effect on the administration of the test, since it was administered in 2023 after the restrictions had been lifted. The stoichiometry questionnaire was divided into three sections that included participants' demographic information, a Likert scale to determine students' perceptions on practical activities and practical assessment, and to determine if students had done practical activities in high school on the concepts to be assessed in the questionnaire and if they did any alternative methods for practicals on the concepts due to Covid-19. The last section assessed the chosen practical stoichiometry concepts and tested their problem-solving skills.

Students used aliases in their responses so as to capture their views with their preferred names and not their actual names to avoid any ethical issues that might arise. It is important to note

that the researcher is not involved in the regular teaching of any students, so there was no conflict of interest, and there were no consequences to the module marks of students who chose to participate or not. During the questionnaire completion, the researcher explained that participation is voluntary while clarifying the objectives of the study and significance to the university and Department of Education. The students willingly participated, and all signed a consent form prior to participating.

During the second semester (Dates: 26th, 12th, and 18th September 2023), interviews with lecturers and laboratory technicians who worked with the learners were held and recorded using a recording device, this gave the researcher more insight and evidence of the gaps that students presented in chemistry throughout their first semester in theory and their practical work due to lack of practical assessment and tasks. The interviews were held successfully, and the interview answers were recorded using a recording device. Each participant willingly participated in the interview.

3.5.3. Data analysis method

Data analysis is a phenomenon of consolidating raw data to extract valuable information to interpret the findings appropriately. Data analysis is correctly done once a quantitative analysis is chosen, and since we are testing hypotheses, inferential statistics is the current quantitative branch. Under inferential statistics, the study made predictions about the experiment's outcome (hypothesis) and tested whether our inferences are true or false. The correlation between the data obtained and the hypothesis being tested was evaluated using a Pearson correlation coefficient. The data obtained from the questionnaires was also analysed using a t-test to compare the performance of males and females. A t-test is used to determine whether or not the means from two different samples differ beyond what would be expected due to sample-to-sample variation, thus it helped the study to determine if there is a performance difference between males and females. Furthermore, the study used a Likert scale questionnaire to analyse learners' perceptions concerning practical work. A Likert scale ranks responses from candidates and gives a probable conclusion based on quantitative results obtained from candidate responses, and the average responses on each question was used to determine the perceptions of the students. In addition to the quantitative data, the interview responses were recorded using a recording device and analysed following the set questions in the provided interview questions (Table 3.2). the findings will be summarised in the discussion section.

In summary, the data obtained in the study was analysed using:

- Averages and standard deviation on chemistry scores;
- T-tests for differences between groups;
- Pearson product correlation coefficients for correlation testing; and
- Listening to the recorded interviews and analysing responses.

3.5.4. Validity and reliability

In the context of validity, we refer to the truth, accuracy, authenticity, genuineness, and soundness of an instrument used to measure a certain aspect. Reliability refers to a dependable, consistent, and that can be used to measure the same thing more than once and have the same outcomes (Delpont & Roestenburg, 2011). We have to ensure that the test conditions are fair, that each student was given the same set of questions based on concepts they have covered before and that it is not too difficult or too easy. Furthermore, to ensure that there is no bias, all students from the chosen study population were assessed with the same questionnaire and under the same conditions. The use of invigilators ensured that the questionnaire was answered individually and truthfully and that all students were given enough time to attempt the questions.

The validity and reliability of the content in the questionnaires was ensured by external moderation of the questionnaire by two chemistry lecturers from the North-West university to ensure that the questions were standardised and accurately asked. The lecturers checked the questionnaire and validated content relevance together with the marking guideline (Annexure D) and made recommendations that were implemented before the administration of the questionnaire. Furthermore, the questionnaire contained only questions on each stoichiometric concept that was taught in Grades 11-12 as per the CAPS document for physical sciences and the revised ATP from 2019-2023. The questionnaire had standardised instructions, and the scoring procedure (memorandum) was the same for all students.

3.5.5. Ethical consideration

Ethical consideration, clearance (Annexure E), and consent (Annexure F) to conduct the research were asked from the North-West University ethical clearance committee at FNAS (chemistry department). The study participants were given full disclosure on the nature of the study to allow them to make informed decisions on whether to participate and reminded that participation is voluntary. In addition, a participation consent form was attached to the front

page of the questionnaire and each student was required to fill out the consent form to ensure that they were aware that their participation was voluntary and that they agree to participate. Furthermore, the participants were not asked to write their names or any personal information however, their gender, name of their previous high school, and province were required for research purposes only.

Chapter 4: Results and Discussions

In this chapter, the data from the questionnaires and interviews is presented. The chapter will begin with a demographic analysis of the participants in the study in terms of the number of participants, gender, type of school and province where the participants attended school obtained from section A of the questionnaire. The questionnaire used in this study evaluated the students' ability to analyse a question (analytical skills), support their answers with reasons (reasoning skills), represent reactants and products with a balanced chemical reaction (representational skills), and their ability to use stoichiometry ratios and solve questions using given equations (mathematical skills).

To answer the research questions which were posed in Section 1.6, the chapter will then analyze the test scores that the students obtained and identify which content areas presented the most difficulty to the students. Responses were also analyzed to identify the common misconceptions that the students had. The interviews with staff members also used to add further insights to answer research question 1.

An analysis of the information about previous laboratory experience, and information on perceptions and satisfaction with practical work will then be analyzed in order to answer research questions 2 and 3. In addition hypotheses a and b from Section 1.7 will be used to provide further information to answer these questions.

The results of the questionnaires in conjunction with tests of hypotheses c and d posed in Section 1.7 will be evaluated in order to answer research questions 4 and 5. The chapter will then close off with a summary of all aspects highlighted.

4.1. Analysis of questionnaires

4.1.1. Demographic analysis

From the stratified sampling technique, it was calculated that the required sample size was 267 participants, luckily, the students responded very well to the invitation to write the questionnaire. The total number who participated, from the extended and the mainstream

classes, was 338, which is a very good sample as it exceeded the minimum required sample as per stratified sampling. The sample is illustrated using Figure 4.1 and later summarised in terms of provinces that the type of schools' students attended.

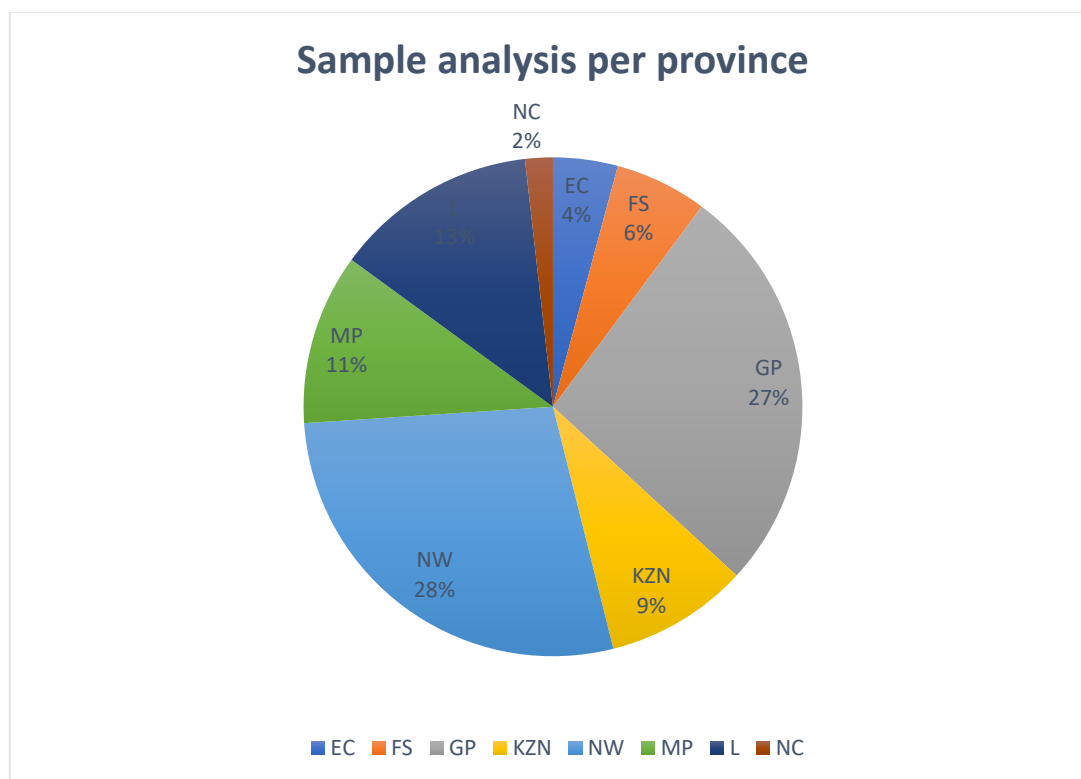


Figure 4.1. Analysis of the sample overall province allocation

In the mainstream chemistry class, there were 130 participants, 69 females and 61 males while the participants and the BSc extended sample had 208 participants, with 123 being females and 85 being males from different schools and provinces. There were no students who had attended school outside South Africa. A summary of the pie chart above in terms of number of students per province is given in Table 4.1 below:

Table 4.1. Number of students per province in the whole sample

Province	Total number of students
Eastern Cape (EC)	14
Free State (FS)	20
Gauteng Province (GP)	89
Kwa-Zulu Natal (KZN)	31
North-West (NW)	93

Mpumalanga (MP)	37
Limpopo (L)	44
Northern Cape (NC)	8
Western Cape (WC)	0

The analysis of the provinces where the participants attended school showed that the sample contained students who came from different education and socio-economic backgrounds. Schools in South Africa are classified into 5 Quintiles, from the poorest (Quintile 1) to the least poor (Quintile 5) school (White & Van Dyk, 2019). Private institutions normally are not allocated to quintiles, but some are denoted zero since they do not receive any government funding. In reality, many of the private schools are the most well-resourced, and fit more comfortably with Quintile 5. Additionally, these schools are ranked based on the unemployment rate and the literacy rate of the individuals in the community, thus schools in lower quintiles are schools that are located in areas where poverty and unemployment is high (White and Van Dyk, 2019). Further research is needed on how these schools help to improve the standard of living in these areas, and how the lack of resources, proper teaching and other factors contribute to these unfortunate statistics.

In the mainstream sample, 43 of the female participants came from school quintiles 1-3, and 21 came from higher quintile schools, with 3 from private institutions. Only 11 of the male participants were from higher quintile schools while 47 were from lower quintile schools. It is important to note that not all participants provided information necessary for this analysis. However, it is only a small fraction of the participants who did not indicate the information. One of the limitations of the study was that it was not possible to obtain an equal number of participants from each school type, however, all quintiles were represented.

The extended sample contained a further 73 female students from lower quintile schools, 41 from higher quintile schools and 4 students from private institutions. The male sample had 58 students from lower quintile schools, 20 from higher quintile schools and 2 from private schools.

The demographic data is summarised per school quintile in Table 4.2:

Table 4.2. Analysis of demographic data of students

Stream	Gender	Quintile 1-3	Quintile 4-5	Private/other	No response	Total
Mainstream	Female	43 (62%)	21 (30%)	3 (4%)	2 (3%)	69
	Male	47 (77%)	11 (18%)	0	3 (5%)	61
Extended	Female	73 (59%)	41 (33%)	4 (3%)	5 (4%)	123
	Male	58 (68%)	20 (24%)	2 (2%)	5 (6%)	85
Total		221 (65%)	93 (28%)	9 (3%)	15 (4%)	338

A slightly higher percentage of extended students (37%) than of mainstream students (31%) attended Quintile 4-5 or private schools, from which better matric results would generally be expected. This is interesting to note because students generally enter the extended stream due to their Mathematics and/or Physical Sciences matric results being at 40%, whereas 50% is the entry requirement for the mainstream degree.

4.1.2. Test score analysis

The test scores for each group will be analysed in this section. The section will begin with analysing the overall scores of the students who participated using a bar graph, then a part analysis of the gender groups in both the mainstream and extended sample. According to the graph (Figure 4.2), more students obtained marks between 40-49 with less students having obtained marks from 50-100%. The combined results are thus:

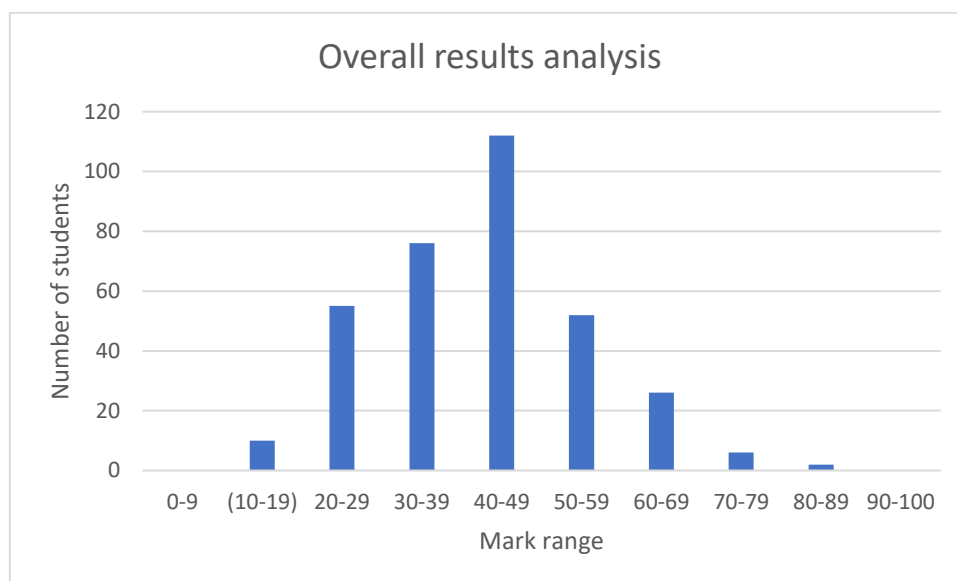


Figure 4.2. Overall score analysis of students.

A further analysis of the test scores in terms of all the concepts that were included in the questionnaire is indicated in Table 4.3.

Table 4.3. Analysis of performance per concept in questionnaire.

	Concepts	Question	Percentage
Balancing equations and mole ratio calculations	Recognise balanced equations	1	90
	Ionisation of an acid	2	42
	Moles of diatomic molecules	3	15
	Mole calculation	5	85
	Balance equation	6.1	93
	Calculate amount	6.2	52
	Calculate volume of gas produced	6.3	34
	Write balanced equation	7.1	8
Acid-base titration	pH	4	32
	Number of moles	7.2	22
	Concentration of acid	7.3	27
Standard solution	Preparation of standard solution	8	4
Limiting reagent	Excess reagent	9.1	46
	Amount of product formed	9.2	38
	Calculate amount in excess	9.3	23

The gaps and misconceptions for each question will be analysed in section 4.1.3, as it can be noted that some concepts the students struggled to answer correctly.

A further analysis of the student performance for each gender per sample is given in Figures 4.3 to 4.6. In terms of BSc mainstream results, the female student test scores out of 100% are given in Figure 4.3 below. The mainstream female sample had 69 students who participated in the study and were given random numbers (1-69) for analysis purposes. In Figure 4.3, the results are congested in the 20-49 percentage range, with only 20 students (33%) able to obtain a 50% or higher test mark.

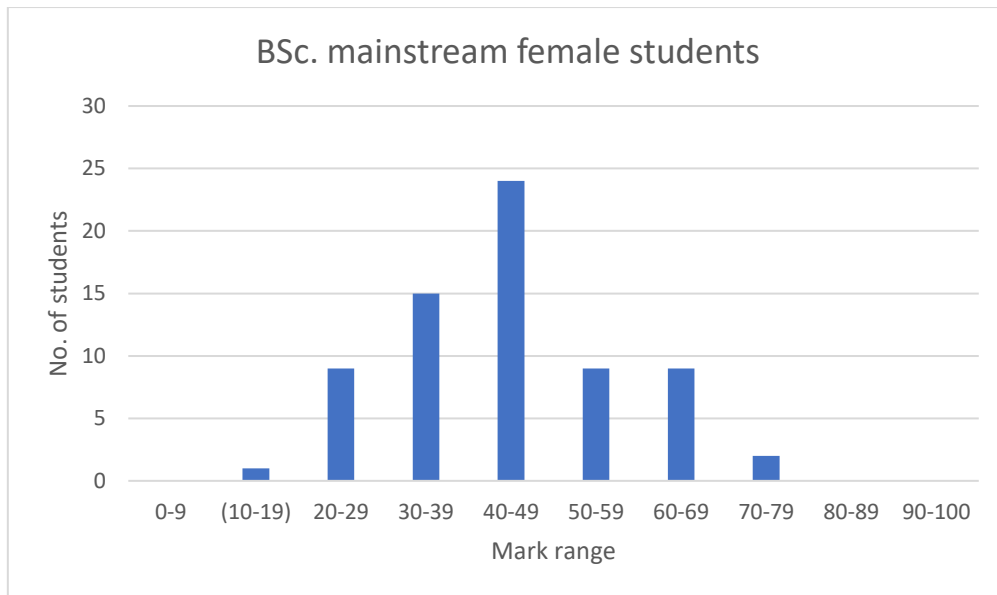


Figure 4.3. BSc. mainstream female results bar graph.

For the mainstream males, out of the 69 who wrote the questionnaire only 16 students (23%) were able to obtain a pass percentage of 50% and above. The pass percentage for both groups is quite low, which indicates that the students had various content gaps when they wrote the questionnaire (see Figure 4.4).

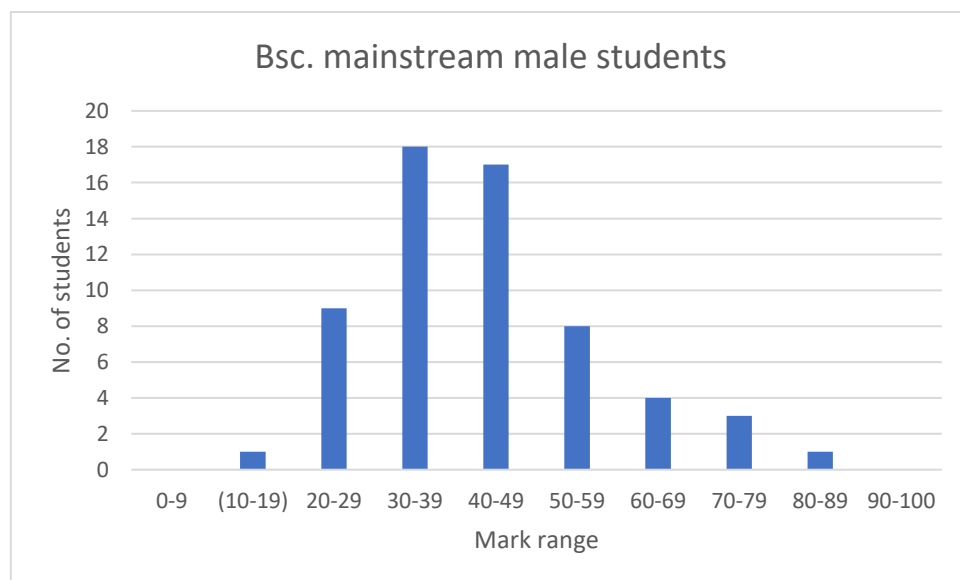


Figure 4.4. BSc. mainstream male results bar graph.

In the extended group, the results for the females and males are also represented in Figures 4.5 and 4.6:

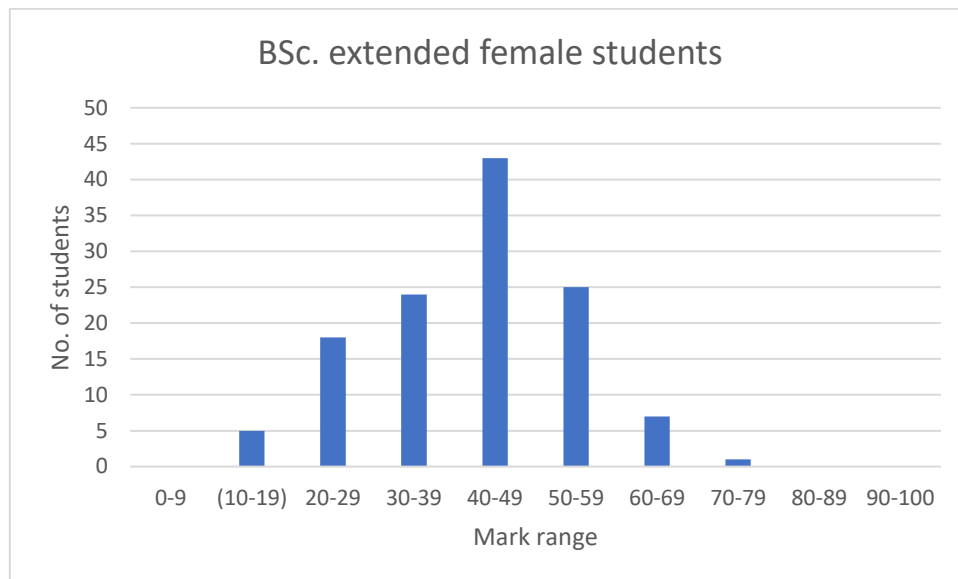


Figure 4.5. BSc. extended female results bar graph.

Figure 4.6 indicates that there were more students who obtained marks between 40-49, and out of the 123 students who wrote, only 33 of them (27%) obtained 50% and above in the questionnaire.

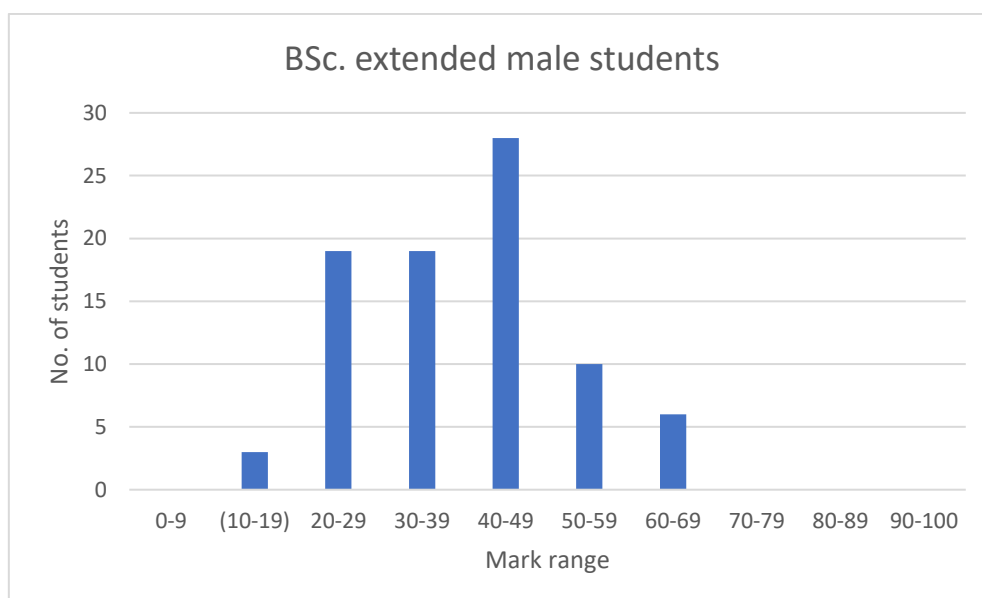


Figure 4.6. BSc. extended male results bar graph.

Out of the 85 male extended students, only 16 students (19%) obtained 50% and above in the questionnaire with the majority of students being in the 20-49 range as shown in Figure 4.6.

A further analysis of the extended and mainstream results using mean, mode and standard deviation is given in Table 4.4 and 4.5:

Table 4.4. Mark analysis of extended students.

<i>Gender</i>	<i>Mean</i>	<i>Mode</i>	<i>Standard deviation</i>
<i>females</i>	40.88	42	12.33
<i>males</i>	38.85	21	5.88

Table 4.5. Mark analysis of mainstream students.

<i>Gender</i>	<i>Mean</i>	<i>Mode</i>	<i>Standard deviation</i>
<i>females</i>	43.01	21	6,7
<i>males</i>	42.20	16	7.3

4.1.3. Stoichiometric problem-solving skills

In this section we discuss the type of questions, students' stoichiometry problem-solving skills, and the misconceptions and errors made when answering the questionnaire. The questions are divided into representation and conceptual questions. As explained in section 2.3.1 of the literature review, a conceptual problem requires understanding of concepts to obtain correct answers (Bilgin *et al.*, 2009). Representational questions required students to use representation, analytical and mathematical skills, while conceptual questions required students to use analytical, mathematical and reasoning skills.

4.1.3.1 Representational questions

The first part of the questionnaire to be analysed is the representational questions which tested the students' representational skills. The section comprised of questions that required learners to represent certain compounds using a chemical formula and a picture model from given keys for each atom. Understanding of number of atoms in a chemical formula and chemical reaction assists learners when balancing a chemical reaction, this skill is first introduced to the students in Natural Sciences Grade 9 (Question1). Furthermore, the questionnaire had questions where students had to balance a chemical equation (Question 6.1 and 7.1) and identify an unbalanced equation (Question 2), which also tested their mathematical and analytical skills thus

understanding of number of atoms. There was also a question where they had to represent a chemical equation from given formula and names of an acid and base (Question 1.2). The questions posed to the students were:

1.1 Shown below are three elements and a picture of an atom of each:

Oxygen 	Carbon 	Sulphur 
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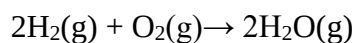
Complete the following table (Use the above atoms for illustrations):

Name of compound	Chemical Formula	Picture illustration of the compound
Carbon dioxide	1.1.1	1.1.2
Sulphur trioxide	1.1.3	1.1.4

1.2. Below are the representation of an oxygen and a hydrogen atom:

Oxygen 	Hydrogen 
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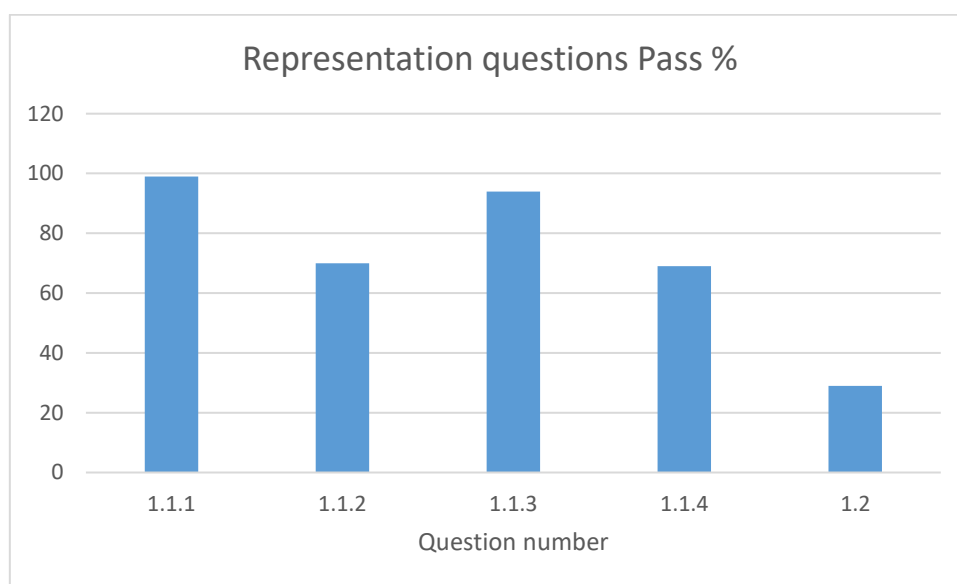
Use the above atoms to illustrate the following reaction:



The results of the questions above for all 338 students are summarised in Table 4.6 and Figure 4.7:

Table 4.6. Analysis of representation questions pass percentages

Question	1.1.1	1.1.2	1.1.3	1.1.4	1.2
No. correct	336	237	319	233	94
Pass %	99%	70%	94%	69%	29%

**Figure 4.7.** Representational question results graph

The results indicate that the students had a good understanding of how to represent single compounds (CO_2 and SO_3) but struggled in question 1.2 with representing the full chemical reaction and thus the overall performance of the students who managed to get the question correct was below 50% (29%).

Evidence of this struggle prevails when the learners had to represent a chemical reaction with given chemical names and formulae of the substances and to balance the chemical reaction. The questions where the learners needed to write formulae and balance equations were in the conceptual questions 6.1 and 7.1, they also had to identify a balanced equation in question 1. In Question 1 where the correct option is C, it was chosen by 305 (90%) students. This is a good result but 10% of the students who got the question incorrect have a misconception with only 2 students not answering the question. In question 6.1 the students had to balance the equation $\text{Zn(s)} + \text{HCl(aq)} \rightarrow \text{ZnCl}_2\text{(s)} + \text{H}_2\text{(g)}$. All formulae were given, and most students were able to balance the equation correctly (94%).

The question and information that was given to the students in 7.1 was:

“20.0 cm³ of a sulphuric acid (H₂SO₄) solution was titrated with a standardized solution of 0.05 mol.dm⁻³ (0.05 M) potassium hydroxide (KOH)”

The names and chemical formulae of both reactants were given to the learners, and they had to write a chemical equation and balance it. Only 26 (8%) of 338 students who participated in the study were able to correctly answer the question, which indeed does fortify that more emphasis should be done on teaching students how to understand chemical reactions and the cations and anions involved in the chemical reaction and how to balance atoms in a chemical reaction. One of the main misconceptions noted in the students' responses in question 7.1 was that they wrote the sulphate ion (SO₄²⁻) as SO₄⁻, this resulted in their incorrectly representing the chemical equation and ultimately also incorrect balancing of the equation.

In summary, the students showed a misconception with understanding of number of atoms in a chemical reaction, and it also affected their answers when they had to balance chemical reactions. Ability to write and balance chemical equations is an important skill in stoichiometry. Students must be able to balance and understand reaction ratios in the reaction to correctly answer stoichiometry questions.

4.1.3.2 Conceptual questions

The conceptual question section consisted of questions based on the following stoichiometric concepts:

- a) number of moles and molar mass;
- b) stoichiometric ratios;
- c) concentration;
- d) molar volume and STP (standard temperature and pressure), using stoichiometric ratios;
- e) titrations (which involve all the previous concepts);
- f) standard solution; and
- g) limiting reactant.

The problem-solving skills that students had to apply in these questions included mathematical, reasoning, representation, and analytical skills. The questions will be analysed according to the stoichiometry concepts listed above. The overall pass percentage for conceptual questions is summarised in Figure 4.8:

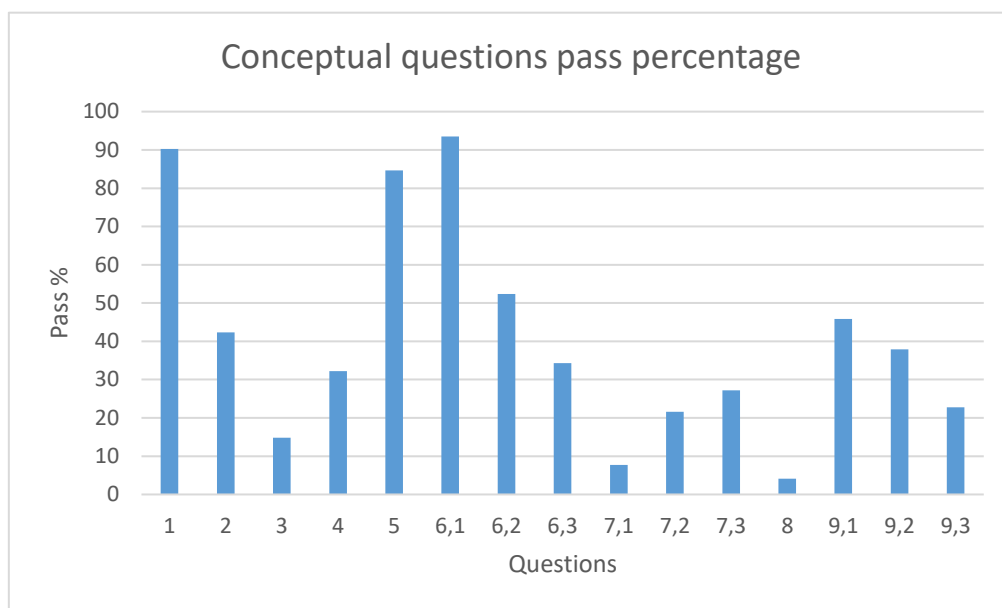


Figure 4.8. Pass percentage per conceptual question.

a) Number of moles and molar mass (Questions 3 and 5)

In the questionnaire, students had to use stoichiometry equations to solve questions that involved numbers of moles and molar mass. They first used the periodic table to calculate the molar mass of the substance in question, and then the number of moles using equation ($n=m/M$) to find the moles of the substance. In Question 3, the options given to students were:

- A. 2 mol – 283 students (83.73%)
- B. 1.5 mol – 3 students (0.89%)
- C. 1 mol – 50 students (14.79%)
- D. 0.11 mol – 1 student (0.3%)

The students struggled with remembering that hydrogen gas consists of diatomic molecules. The main misconception was that the students took the chemical formula for hydrogen gas as H and not H₂ as it is a diatomic molecule. Only 50 students (15%) from 338 were able to correctly answer the question with only 1 who did not answer the question.

In question 5, the question was:

The compound NaHCO_3 is commonly known as baking soda. A recipe requires 1600 g of baking soda¹, mixed with other ingredients, to bake a cake. What is the number of moles of baking soda?

The answers given were:

- A. 0.019 mol – 11 students (3.25%)
- B. 0.031 mol – 17 students (5%)
- C. 84 mol – 19 students (5.6%)
- D. 19 mol – 286 students (84.62%)

The number of students out of 338 who got it correct was 286 (85%), which is good but raises a question of concern given that all information that the students needed to solve the question was provided. The students had to calculate the molar mass of baking soda and then divide the given mass by the molar mass of the compound to get the number of moles. Out of the 52 students who answered incorrectly 5 students did not answer the question.

Mistakes included converting the mass into kg and using kg instead of grams (option A), incorrectly calculating molar mass of bicarbonate of soda as 52g/mol (option B): $M_{(\text{NaHCO}_3)} = 23+1+12+16 = 52\text{g/mol}$ and/or taking the molar mass of the compound (84g/mol) as the number of moles of the compound (option C). In this question students did not have to use reaction ratios to calculate unknown amount of substances, they only had to apply mathematical and analytical skills.

b) Stoichiometric ratios

Stoichiometric ratios were needed for most of the remaining questions, where calculations based on balanced reactions were required. These include questions on molar volumes (question 6), titrations (question 7), and limiting reagents (question 9). They will be discussed in the sections on those concepts. Common errors noted while marking and analysing the students' questionnaires were incorrect use of the ratios, not balancing equations correctly and not understanding how the ratios are used to determine the amount of unknown substances.

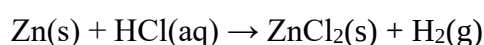
c) Concentration

¹ It was noticed after the administration of the questionnaire that the decimal point had been omitted by mistake, and the mass of baking soda was given as 1600 g instead of 1.600 g, which is absurdly large. This had no effect however, as the correct answer was thus D (instead of A).

Similarly, the concept of concentration (c) will be discussed with titrations (section (e)). The common misconception noted in concentration calculation was the students' errors when converting volume from cm³ to dm³. The students would also use incorrect formulae when solving questions and incorrect units of concentration and other variables such as molar mass, mass and/or number of moles. In summary, students struggle with analytical and mathematical skills when solving questions that involve concentration. Further insight will be provided in analysis of question 7.

d) Molar volume and STP (standard temperature and pressure) (Question 6)

8g of Zinc reacts completely with excess hydrochloric acid at STP to form hydrogen gas.



In question 6.1 the learners had to first balance the given equation and answer the questions that followed, out of 338 learners 316 learners (94%) were able to correctly balance the equation, as indicated in the previous section. A summary of question 6.1 is given in Table 4.7 below:

Table 4.7. Analysis of question 6.1.

	No. of students	Percentage (from 338)
Correct answer	316	93.50%
Incorrect answer	19	5.62%
No answer	3	0.89%

However, the learners struggled to use mole ratios to answer the questions that followed. In question 6.2, the learners had to use the given mass of the limiting reactant to determine the amount of HCl that reacted. The question was:

6.2 What is the amount of HCl that reacted?

- A. 0.22 mol – 55 of 338 students (16%)
- B. 0.25 mol – 177 of 338 students (52%)
- C. 0.06 mol – 42 of 338 students (12%)
- D. 0.12 mol – 57 of 338 students (17%)

For question 6.2, out of the 316 learners who correctly balanced the equation, 177 students (52%) correctly chose the correct option, which was B, by calculating the number of moles of

Zn and using the reaction ratios to then determine the amount of HCl that reacted. In option A, 55 (16%) of the 338 students used the given mass of zinc (8g) as the mass of HCl, the calculations are thus:

$$M_{\text{HCl}} = 1 + 35.5$$

$$= 36.5 \text{ g/mol}$$

$$n = m/M (\text{HCl})$$

$$= 8\text{g}/36.5\text{g}\cdot\text{mol}^{-1}$$

$$= 0.22 \text{ mol of HCl that reacted.}$$

42 students (12%) chose option C, while 57 (17%) chose option D, using incorrect reaction ratios of Zn to HCl (either 2:1 or 1:1 instead of 1:2) and 7 students did not answer the question.

In question 6.3, the question given to the learners and answer summary was:

6.3 How much volume of hydrogen was produced at **STP**?

- A. 8 dm^3 – 35 students (10%)
- B. 5.4 dm^3 – 55 students (16%)
- C. 2.76 dm^3 - 116 students (34%)
- D. 22.4 dm^3 – 102 student (30%)

The students had to determine the volume of hydrogen (H_2) produced at STP using $n=V/V_m$, with the given molar volume as $22.4 \text{ dm}^3/\text{mol}$. Option C was the correct answer, and 116 students (34%) managed to get it correct. 35 students (10%) chose Option A, using the mass of Zn given above as the volume of hydrogen gas produced. In the second option, learners used the ratio of HCl to H_2 as 1:1, instead of 2:1.

In option D, chosen by 102 students (30%), the students did not calculate the number of moles of H_2 produced from the reaction but took the reaction ratio of hydrogen and multiplied it by the molar volume given. The ratio of hydrogen in the reaction was 1 and the calculation was thus:

$$V = n \cdot V_m$$

$$= 1\text{mol} \cdot 22.4\text{dm}^3/\text{mol}$$

$$= 22.4 \text{ dm}^3 \text{ of } \text{H}_2$$

Students need to properly understand stoichiometry concepts and analyse questions correctly to be able to use given data correctly in calculations. The common mistake is that the students randomly plug in given values without considering the stoichiometric ratios of reactants and products. Furthermore, 30 students did not answer the question.

e) Acid-base titration (Questions 2; 4 and 7)

Titration reactions are one of the problematic topics that were noted in the DBE subject diagnostic reports of 2018-2022 and students have shown difficulties in writing ionisation or dissociation reactions and calculating concentrations of acids or bases from given data (mathematical skill). In this study the students struggled to represent a chemical reaction from given chemical names of sulphuric acid (H_2SO_4) and potassium hydroxide (KOH). The summary of the representation of the chemical equation is given in Table 4.8.

Table 4.8. Analysis of question 7.1.

	No. of students	Percentage (from 338)
Correct answer	26	7.69%
Incorrect answer	235	69.53%
No answer	77	22.78%

Starting with question 2, the question was:

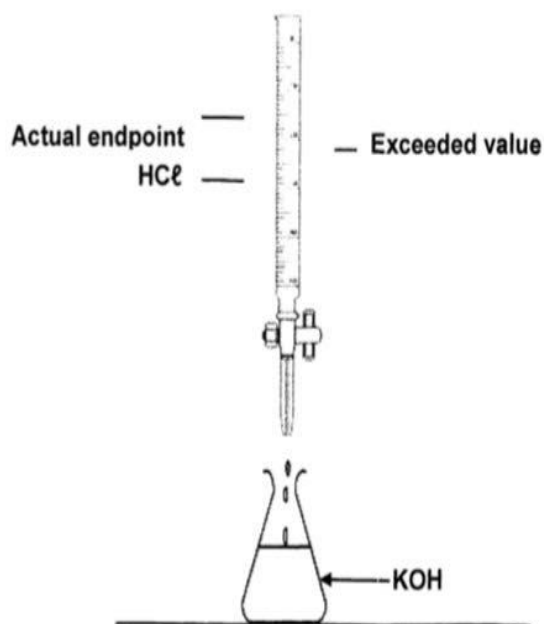
“Which one of the following represents the ionisation reaction of an acid?”

- A. $\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$ - 102 students (30%)
- B. $\text{H}_2\text{SO}_4 \rightarrow \text{H}^{2+} + \text{SO}_4^{2-}$ - 67 students (20%)
- C. $\text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$ - 143 students (42%)
- D. $\text{ZnO} \rightarrow \text{Zn}^{2+} + \text{O}^{2-}$ - 13 students (4%)

From the options provided, option C was the correct answer, and was selected by 143 students (42%). Option A was incorrect because it included a base, option B had an incorrect hydrogen charge of 2+ instead of 1+, and finally option D involved a metal oxide and not an acid. In addition to the statistics above, 13 students did not answer the question. This shows that some students are not able to write ionisation reactions, which are necessary for calculating the resulting pH of a solution after a titration.

In Question 4, which also involved the concept of acids and bases, the students also had to provide a reason for the answer they chose (reasoning skill). The question was:

In a titration involving HCl and KOH, as shown below, a learner accidentally exceeds the endpoint. The diagram provided was:



“Which one of the following is correct for the solution now in the conical flask?”

The answers that were given were as follows with summary:

- A. $[H^+] > [OH^-]$ and $pH > 7$ - chosen by 50 students (15%).
- B. $[H^+] < [OH^-]$ and $pH > 7$ - chosen by 67 students (20%).
- C. $[H^+] < [OH^-]$ and $pH < 7$ - chosen by 60 students (18%).
- D. $[H^+] > [OH^-]$ and $pH < 7$ - chosen by 109 students (32%).

The reasoning and analytical skills of the students were tested in this question. It was stated that the endpoint was exceeded during the titration which means that the solution in the conical flask would be more acidic than basic or neutral. Since the acid and base were both strong, at the end point the solution would be neutral and if it is exceeded, then the solution would be acidic. Option D, which was the correct option, states that the pH is less than 7 and the hydrogen ions are more than the hydroxide ions in solution as they are in excess.

In the reason for their answers, only 93 students were able to give a correct reason for their answer and 146 gave incorrect reasons with 99 of them not providing a reason for their answer or not attempting the question. Some of the incorrect answers that were given by the students are: “titration is between weak acid and strong base; a weak acid is combined with a strong base, making the solution basic; KOH dissociate/ionises completely thus the solution will be basic and have more hydroxide ions; KOH is in excess and is a strong base; and there is more acid than the base, therefore more H^+ ions than OH^- ions therefore $pH > 7$ ”. A summary of the reasoning question is given in Table 4.9 below:

Table 4.9. Analysis of question 4 reasoning question.

	No. of students	Percentage (from 338)
Correct answer	93	27.51%
Incorrect answer	146	43.20%
No answer	99	29.30%

Question 7 was a titration question where the students first had to write an acid-base reaction using chemical formulae and balance the equation. Only 26 (8%) of the students did this correctly, which led to the other sections of the question being answered incorrectly as they needed the correctly balanced equation to use stoichiometric ratios. The question was:

20.0 cm³ of a sulphuric acid (H₂SO₄) solution was titrated with a standardized solution of 0.05 mol.dm⁻³ (0.05M) potassium hydroxide (KOH). Using phenolphthalein indicator for the titration, the acid required 36.0 cm³ of the alkali for neutralization.

7.2 What is the number of moles of the base?

- A. 1.8×10^{-3} mol – 73 (21.60%)
- B. 0.05 mol - 82 (24.26%)
- C. 1.8 mol – 87 (25.74%)
- D. 1.0×10^{-3} mol – 49 (14.50%)

Option A was the correct answer where the students correctly used the given concentration, volume and stoichiometry ratios to find the correct answer, according to the results the students have gaps in the concept. In option B, the students considered the concentration of NaOH as the number of moles of the base, and in option C the students did not convert the volume from

cm³ to dm³. Lastly, in option D the students used the volume of the acid, and 49 (14.50%) did not answer the question. The next question was given as:

7.3 What is the concentration of the acid?

- A. 0.18 M – 57 (16.86%)
- B. 0.09 M- 94 (27.81%)
- C. 0.045 M – 92 (27.22%)
- D. 9×10^{-4} M – 26 (7.69%)

Option C was the correct option in the question, with less than 50% of the students getting the answer correct and 69 (20.41%) of the students not answering the question. In option A, the learners used the molar mass of the acid and divided it by the given volume to obtain concentration of the acid since the number of moles of the acid were not given in the question. In option B, the students used the number of moles calculated above of the base as the number of moles of the acid in a ratio of 1:1, which indicated that the incorrect balanced equation had an impact on how the students answered the question. Then in option D, the students were able to calculate the number of moles of the acid using the correct ratio (1:2), but then considered the moles to be the concentration of the acid and did not further use the concentration equation ($c=n/V$) to then calculate the concentration of the acid.

Thus, it can be said that the students presented gaps in their analytical, mathematical and representational problem-solving skills.

f) Standard solution (question 8)

In the question on the preparation of a standard solution, the overall percentage performance is 4% with only 14 students having correctly managed to calculate the mass needed to prepare the solution. This is one of the lowest performing questions in the questionnaire. The students needed to apply their analytical and mathematical problem-solving skills.

The question that was given to the students was “Show using calculations, how you would prepare a standard solution of 0.2 mol.dm⁻³ MgCl₂ in a volumetric flask that has a volume of 250cm³.”,

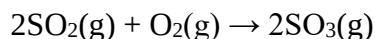
The common errors that were noted in the questions were that the students either did not convert or incorrectly converted the volume from cm³ to dm³, which makes the answer incorrect as the unit of concentration is mol.dm⁻³. The second error that the students made was that they

calculated the number of moles of the substance but did not calculate the mass that should be weighed to prepare the standard solution in the given volumetric flask. Another misconception was that the students used the volume of the volumetric flask in the molar volume equation and proceeded to calculate the number of moles of MgCl_2 using $n=V/V_m$. They did not understand that this equation applies to gases and at standard temperature and pressure. The students did not pay attention to the given information and went further to calculate using wrong equations that were provided in the formula sheet.

g) Limiting reactant (Question 9)

A limiting reactant is the substance that is used up first in a chemical reaction. The limiting reactant determines how much of the other reactants are able to react and thus helps us determine how much will be in excess. It also determines how much product will be produced when the reaction is complete. To answer such a question, students must know how to correctly use reaction ratios and how to relate reactants to products by using their analytical, mathematical and reasoning problem-solving skills. Question 9 was:

2 mol of oxygen is mixed with 3 mol of sulphur dioxide to form sulphur trioxide during the following reaction:



The question had three parts (9.1-9.3) and 9.1 required the students to choose an option and also explain their choice. An analysis of the average performance and misconceptions in each question is given below.

The first question was:

9.1 Which substance is the excess reactant? Give a reason for your answer.

- A. SO_2 - 95 students (28%)
- B. SO_3 – 34 students (10%)
- C. O_2 – 155 students (46%)
- D. None is in excess. – 34 students (10%)

For question 9.1 the correct answer is option C, and it was chosen by 155 students, however, only 48 students (31%) were able to correctly substantiate their answer, and 20 students did not attempt the question (6%). The students who chose option A compared the given moles of SO_2 and O_2 and concluded that since sulphur dioxide had more moles than oxygen and

therefore it is the substance in excess. One of the reasons given by the students who chose option A was:

$$n(\text{excess}) = n\text{SO}_2 - n\text{O}_2$$

$$= 3-2$$

$$= 1 \text{ mol of SO}_2 \text{ in excess.}$$

In option B, the students chose the product to be in excess, and did not provide a reason for their option. It could be that they did not understand the question. Option C was the correct answer and was chosen by 46% of the students. Option D was chosen by 34 students (10%), which means that the majority understood that both substances cannot be in excess. The summary of the reasons given is given in Table 4.10 below:

Table 4.10. Analysis of the pass percentage of the reasoning question in 9.1.

	No. of students	Percentage (from 338)
Correct answer	48	14.20%
Incorrect answer	182	53.85%
No answer	108	31.95%

The second question was:

9.2 What is the maximum mass of sulphur trioxide that can be formed?

- A. 192 g – 47 students (14%)
- B. 320 g – 59 students (17%)
- C. 80 g – 68 students (20%)
- D. 240g - 128 students (38%)

Option D was the correct answer where the students used the number of moles of the limiting reactant and the reaction ratio to determine the number of moles of sulphur trioxide, then proceeded to calculate the mass of the substance.

The misconception in option A is that the students calculated the total mass of SO₂ that was available at the start using 3 moles. In option B, the calculation performed by the students was:

$$\text{Maximum moles} = 3+2 = 5 \text{ moles of SO}_2$$

$$m = n.M$$

$$= 5\text{moles} \times 64\text{g/mol}$$

$$= 320\text{g of SO}_2$$

In options A and B the students calculated the mass of the limiting reactant and not that of the product, the students did not fully understand the question or read it well and hence they proceeded with calculations incorrectly. In option C, the students considered the molar mass of the substance instead of the mass. Additionally, 36 students (11%) did not answer the question.

The third part of the question was:

9.3 What is the amount of excess reactant that did not react?

- A. 1.5 mol – 52 students (15%)
- B. 2 mol – 81 students (24%)
- C. 1 mol - 88 students (26%)
- D. 0.5 mol – 77 students (23%),

Option D was the correct option, where the students followed all necessary steps to then determine the amount of the excess reactant that did not react, with 40 students having not answered the question (12%). The misconceptions were that in option A, the students took the amount of oxygen that reacted (1.5 mol) as the amount in excess, without differentiating between moles that reacted and moles in excess. In option B the students considered the total amount of oxygen to be in excess, and in option C the students tried to calculate the moles in excess as:

$$n(\text{excess}) = 3 - 2$$

$$= 1 \text{ mol of O}_2 \text{ in excess.}$$

They did not use the limiting reactant to determine the amount of the excess reactant that reacted so that they can determine how much of O₂ did not react. Thus it can be said that the students had content gaps that lead to them presenting gaps in their mathematical, analytical and reasoning problem-solving skills.

h) Summary

In summary, the gaps and misconceptions noted from the questionnaire are:

- a. Representing models of compounds and reactions.
- b. Recalling elements which consist of diatomic molecules.
- c. Understanding units of measurement and which concept they are related to. They consider molecular mass (g/mol) to be mass or number of moles (mol).
- d. Students confuse pH of an acidic solution with the pH of a basic solution.
- e. Identifying strong/weak acids or bases.
- f. Representing and balancing chemical equations when given chemical formulae of reactants.
- g. Using mole ratios to determine amount, mass, or volume of unknown substances.
- h. Calculating mass needed to prepare a standard solution.
- i. Converting volume from cm^3 to dm^3 .
- j. Choosing the correct equation to use in a question based on given data.
- k. Identifying the substance in excess and calculating the amount in excess.

From the findings and results of the questionnaire, it is evident that the students struggled with mathematical, analytical, and reasoning skills.

4.2. Interview analysis

In the interviews with staff members, 3 out of 4 scheduled interviews were conducted successfully and the data was recorded using a recording device. The fourth staff member was unavailable for an interview due to illness. The insights that were noted will be summarised below but will not be assigned to any specific member of staff, in order to maintain anonymity. The assessed topics in this study were also covered in theory classes in semester 1 with the students, and they also performed titration, percentage purity, and standard solution practicals. The common gaps and shortcomings identified by the staff members in theory assessments and during practical experiments were:

Gaps identified in theory:

- a. Students enter the university with knowledge gaps, and some do not have any background of chemistry. These students are generally enrolled in Agricultural courses.
- b. The students tend not to have confidence in the chemistry class hence they struggle to catch up with the content. In particular those Agriculture students who have not done Physical Sciences at school, or who began with a diploma course and then upgrade to a degree course struggle with the difference in workload.

- c. Students struggle with conversions, that is converting volume or mass units correctly.
- d. Students misunderstand how to use reaction ratios and incorrectly use them when solving stoichiometry concepts.
- e. The students struggle in understanding the limiting reactant concept, they do not have the conceptual understanding of why and how to calculate the limiting reactant.
- f. Students struggle with chemistry vocabulary and understanding of concepts like amount of substance, concentration, amount in excess and limiting reagent.
- g. The students had a challenge with the standard solution as well in theory and in the laboratory.
- h. The students tend not to balance chemical equations given to them before doing calculations. If an equation is not balanced, they assume the ratio is 1:1.
- i. The students do not include SI units in their answers and during calculations as well.
- j. The students use incorrect equations in their calculations without considering the data given and the reaction ratios. They also do not follow instructions in questions.

Gaps in the laboratory:

- a) The students did not know the difference between a pipette and a burette and how or when each is used.
- b) The students tend not to make enough effort when writing their practical reports. They sometimes copy which affects them when they write practical tests as they have not done the work themselves and still have misconceptions. They also rush when writing their reports and make many mistakes in their reports.
- c) Students struggle with correctly reading the burette. They also use the volume in mL and do not convert to dm^3 in calculations of concentration.
- d) Students did not know how to work out the total volume added from a burette, particularly if all the solution in the burette is used up. They would tend to have negative volume answers and negative concentration answers during calculations.
- e) Students use incorrect stoichiometric ratios when calculating amounts of substance.

f) Students had many breakages of apparatus in the laboratory when performing practicals.

g) Some of the students are not computer literate, and struggle to type their reports.

The gaps identified by the staff members were also evident in the answers to the questionnaire. To rectify the problems, staff members used various strategies. They used more quiz tests, they performed more practicals with the students, they had practical videos sent to the students prior to their entering the lab that assisted them in understanding what is expected from them. The staff members then noted at the end of the semester that there was an improvement in the number of students who passed their stoichiometry and also performed better in limiting reactant questions. Student assistants were also utilised to offer extra classes for students who needed more time to grasp concepts. These are possible if the necessary resources are available at learning institutions, hence the current study recommends that science schools should be equipped with more resources so that students can start to understand better and perform better at school level.

4.3. Research questions

4.3.1. Research question 1

“Which problem-solving skills do students exhibit a gap in (for example, analytical skills, reasoning skills, mathematical skills, or representation skills) during balancing chemical equations, limiting reactants, excess reactants, acid-base titrations, standard solutions, and mole ratio calculations?”

Stoichiometry questions require students to be able to write chemical equations, balance chemical reactions, calculate moles, and identify the limiting reagent (Gulacar *et al.*, 2020). Students should be able to analyse a question correctly, identify the given data, then choose the correct equation(s) to use and represent their answer. To do this correctly students apply different problem-solving skills in the process of solving the question. Additionally, students should be able to use proportional reasoning abilities to correctly perform stoichiometric calculations. Proportional reasoning ability (PR) is a person’s ability to recognize the relationships and ratios between quantitative variables (Gulacar *et al.*, 2013), this skill is important for stoichiometry calculations where balanced equations and mole ratios are involved. In addition to PR, a student applies analytical, representational, and mathematical problem-solving skills in those concepts. Furthermore, students should try to follow a problem-

solving strategy, such as the strategy proposed by Selvaratnam (1982, 1990). The problem-solving steps are:

- Step 1: Identify and give explicit symbols for the data and the goal and organize them.
- Step 2: Select the starting equation.
- Step 3: Proceed step by step to derive the answer.
- Step 4: Calculate using the starting equation.
- Step 5: Check, review and learn from the solution

Looking at the problem-solving strategy, students mostly struggled with step 1 and step 2, since it was common that they used incorrect equations to solve questions in the questionnaire. They also did not correctly apply step 5, where they could identify errors such as incorrect conversions of volume and incorrectly using given data. From the 338 students who participated, 85 were able to obtain 50% and above, which indicates a pass percentage of 25% overall. The topics that the students struggle with the most include standard solution, limiting and excess reactant, and acid-base titrations. The problem-solving skills that the students needed to apply and struggled with are highlighted per concept below.

Balancing chemical equations and mole ratio calculations

In the questionnaire, the students first struggled with representing balanced equations using keys as atoms. Some students would draw the equation and not balance it, and some would randomly connect atoms without looking at the given equation, thus question 1.2 was one of the lowest performing questions. In terms of balancing equations, the skill that the students needed to apply was mathematical and analytical skills and the students did not struggle to correctly balance the equation that was given in Question 6.1 (93%), however, the question where students had to write and balance a chemical equation when given chemical formulae of reactants was not well answered by the students (8%) which indicates a gap in the skill of representing chemical equations from chemical names of substances. Additionally, questions 6.2-6.3 needed the students to use stoichiometry ratios together with mathematical and analytical problem-solving skills to calculate the amount of unknown substances using the correct ratios. The performance dropped to 35% and 34% respectively in the questions that needed these skills. In summary, the students really struggled with analytical and mathematical skills when performing mole ratio calculations.

Limiting reactant

In this stoichiometry concept the students needed to apply mathematical, reasoning, and analytical problem-solving skills. They also needed to have sound knowledge of what is a limiting or excess reactant and how either one is determined. Question 9 recorded the lowest mark percentage, which means that the students presented a gap in understanding of the concept. One of the issues was that students did not correctly use their mathematical and analytical skills when using the stoichiometry reaction ratio in calculations, and the students also struggled with different amounts of reactants (i.e., initial amount, amount reacted, amount unreacted). Reasoning skills were also a problem as the students could not explain why they chose a certain substance as the substance is excess.

In question 6 where the excess substance was given, they performed better (52%). In conclusion, the students presented gaps in their mathematical, reasoning, and analytical problem-solving skills in the limiting reactant concept in terms of identifying the substance in excess and calculating unreacted amount of the excess reactant.

Acid-base titrations

This concept required students to be able to analyse the question (analytical skill) that was given to them, use the given information to write a balanced chemical reaction (representational skill) and use their mathematical skills to solve the questions that followed. The first titration question (7.2) was poorly answered (22%), as the students struggled with identifying correct units to use in different equations, could not convert volume correctly, had no understanding of the difference between mol and mol/dm^3 , and did not use stoichiometry ratios correctly. This means that the students did not use their analytical skills well in order to correctly analyse given data and choose correct equations to solve questions. Additionally, when using stoichiometry ratios, the students struggled to use mathematical and analytical skills, hence they recorded a low performance.

In summary, the students presented gaps in content understanding and the problem-solving skills needed in this concept.

Standard solution

In the standard solution question, the students needed to be able to use their analytical and mathematical problem-solving skills. The concept also needs understanding of how a standard solution is prepared, so that the students need to know the mass of the substance that needs to be weighed to prepare the solution of known concentration. Most of the students did manage

to calculate number of moles but did not know how to proceed from there, and some of the students used incorrect equations like the molar volume equation which did not apply at all to the concept as no gas was produced. The overall performance analysed above for this concept indicates that the students have a gap with this stoichiometric concept and a gap in the needed problem-solving skills.

4.3.2. Research question 2

“What stoichiometry practicals are expected to be done at school, and what concepts did students receive practical learning on at the high school level and has it helped them better understand those concepts?”

In Table 2.2 (chapter 2), the Annual Teaching Plan (ATP) for Grades 10-12 focusing on the stoichiometry syllabus was highlighted and the concepts were further divided into practical and/or theoretical. The number of prescribed practicals was also evaluated using the annual program of assessment (PoA) and it was found that each year, 1 or 2 chemistry practicals on which learners are formally assessed are done per grade. Some schools do not have resources, the students then do not get an opportunity to do any formal or informal practical work before entering university and from the student responses, 157 (46.45%) of them according to section A (b.14) had never performed any practical activity prior to university entry. The only formal stoichiometry practical that is prescribed to be done by the students in high school is a titration practical in Grade 12 and according to the student responses, out of the 338 who participated in the study only 118 students (34.9%) performed the practical. The pass rate in the titration question (Question 7) was relatively low with a 19% pass average for all three questions (7.1-7.3). The conceptual question (question 4) concerning the endpoint and how that affects the pH of the solution was also not well understood with a 32% performance. Even those who performed the titration practical did not all understand the concept.

According to the student responses, 69 students (20.41%) performed a practical on limiting reactant, and only 66 (19.53%) prepared a standard solution in the laboratory. The overall performance on the standard solution question (question 8 at 4%) shows that the students had many gaps in understanding the concept and applying mathematical and analytical skills, and that those who performed the practical still did not fully understand the concept. The limiting reactant concept was better answered by the students when they knew the substance in excess (question 6.2 at 52%) and showed a drop to 46% when they had to identify the substance in

excess (38% in question 9.2). The results on the concept however are higher than the percentage of students who performed the practical on limiting reactant, thus a positive relationship is identified in this concept only.

The observations highlighted from the interviews with staff members who worked with the students further indicated that indeed some students enter university with no practical background, which affects how they perform and their confidence in chemistry. In lower grades, no stoichiometry concept is allocated a formal task, which could possibly be the reason why students struggle with the topic. As noted in the student perceptions, all the students who participated in the study believed that the number of practicals done in high school should be increased and that they are not satisfied with the number of practical activities they performed at high school.

Hypothesis 1 which is related to the research question above will also be answered in this section.

4.3.2.1 Null Hypothesis a

There is no correlation between practical activities and students' problem-solving abilities in stoichiometry concepts.

The Pearson correlation coefficient, r , is a dimensionless index that ranges from -1.0 to 1.0 inclusive and reflects the extent of a linear relationship between two data sets. The formula for the Pearson product moment correlation coefficient, r , is where $\bar{x}$ and $\bar{y}$ are the sample means:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}$$

The correlation between practical activities and problem-solving abilities was tested using the number of practical activities that the students said they had done overall (section B.2 of the questionnaire), and the three stoichiometry practical concepts tested, being titration, limiting and excess reactant, and standard solution (Section A, part b: Questions 11-13 of the questionnaire) vs the overall student test scores. The Pearson correlation coefficient at p -value = 0.05 with degrees of freedom $N-2$ in the mainstream females was found to be $r(67) = 0.16$ with a critical value of 0.232 indicating a weak positive correlation between the two variables and for mainstream males $r(59) = 0.095$ with a critical value of 0.25 which indicates a very weak positive correlation between the variables. For extended student group, the females had a

critical value of 0,159 and the correlation coefficient was calculated as $r(121) = 0,059$ and for extended males it was $r(83) = -0,18$ with a critical value of 0.217. This indicates that there is a weak but positive relationship between practical activities and extended female students' problem-solving abilities but a weak negative correlation between the two variables for the male extended students.

Additionally, when analyzing the two samples together, the correlation coefficient was calculated as $r(336) = 0.018$ with a critical value of 0.104 with a p-value of 0.05 and N-2 degrees of freedom. Therefore, the null hypothesis can be rejected, as a weak positive correlation was found between the two variables when comparing the whole sample of students.

4.3.3. Research question 3

“What perception do the students have regarding practical learning and its importance?”

Section A (part b) obtained an indication of the resources at the schools the students attended, and their previous experience with practical work and other resources. The information is summed up in Table 4.11. Note that some students did not answer the questions, or answered only some of them, thus percentages are not 100).

Table 4.11. Analysis of section A(b).

Questions in Section A. (b) 1-10	Yes		No	
	Number	%	Number	%
1. Did your teacher do demonstrations for practicals due to COVID-19?	74	21.89	236	69.82
2. Did you watch online videos for prescribed practical assessments at your school?	159	47.04	168	49.70
3. Did you get a chance to read through your experiment manuals at your high school?	139	41.12	189	55.92
4. Has your teacher ever used PhET simulations at school?	29	8.58	250	73.96
5. Does your school have a laboratory?	208	61.54	124	36.69
6. Does your school have a computer lab?	171	50.59	158	46.75

7. Did your school have all the apparatus/material needed during practicals?	122	36.1	207	61.24
8. Did you have access to Wi-Fi at school?	107	31.66	223	65.98
9. Did your school have a library?	160	47.33	168	49.70
10. Can you operate a computer and type a practical report?	214	63.31	111	32.84

According to section A(b), during the covid-19 pandemic, most of the students were not exposed to any different demonstrations due to the restrictions that were observed, but they did watch online videos for the prescribed practicals that they had to perform. When asked if they had a chance to go through their practical manuals, 41% said yes while 55% of the students said no, which is a problem as students need to read through manuals prior to performing their experiments such that they understand what is expected from them. In terms of using PhET as an alternative hands-on activity to enhance student understanding according to many authors (Inayah & Masruroh, 2021; Mohafa *et al.*, 2022; Wu *et al.*, 2021), only 8% (29 students) had been previously exposed to such simulation and 250 students (73.96%) reported to have never been exposed to simulations. Many students (58) did not answer this question, a probable reason is that they did not know what PhET simulations are.

In terms of resource availability and whether students had access to a laboratory, computer lab and library the students reported that the majority (208 students, 61.54%) of the schools had a laboratory, however, only 122 (36.1%) students indicated that the laboratories had all the apparatus available for practicals. Additionally, 50% of the students indicated that they had a computer lab with 47% who said they did not, 31.66% said they had access to Wi-Fi with 50% saying they did not, and 47% said they had a library at school and 50% said they did not. Furthermore, even though a higher percentage of students indicated that they could operate a computer and type a practical report (214 at 63%), it is important to note that 111 (34.84%) students said they could not type and/or operate a computer coming into university, this is in line with the gaps identified during the interviews held with the staff members from the North-West University (NWU).

Section B was intended to ascertain students' attitudes towards practical work. In section B the study evaluated three aspects which are students' attitude concerning the importance, satisfaction, and frequency of practical work. This gives an indication of their perceptions towards practical work and practical assessments. The results obtained are analysed below by stream, starting with the mainstream and then extended students.

Section B.1

This section analysed students' perceptions towards the importance of practical work, and the average importance score is summarised in Table 4.12 below. The Likert scale used was:

1	2	3	4	5
Strongly disagree	Disagree	Neither agree/disagree	Agree	Strongly agree

Table 4.12. Analysis of section B.1.

Question:	Perception	Average			
		Mainstream		Extended	
		F	M	F	M
1	Practical work is not important for you to understand practical chemistry concepts.	1.5	1.6	1.3	1.6
2	Practical work increases the amount of schoolwork you do and causes fatigue.	2.3	2.5	2.2	2.3
3	Practical work does not help improve your problem-solving skills.	1.5	1.9	1.3	1.4
4	The practical work received at high school helped you to better understand chemistry concepts.	3.2	3.0	3.1	3.2
5	The alternative methods to hands on practicals (e.g. video sessions for practicals, online classes) assisted you in understanding practical content at high school during covid-19.	2.3	2.1	3.1	3.4
6	Practical work at high schools should be increased.	4.5	4.1	4.6	4.6
7	Practicals are easy for you to understand.	3.8	3.7	3.8	3.7
8	Practicals are boring and unnecessary.	1.5	1.6	1.4	1.5

9	The teacher allowed you to independently solve problems in each science practical.	2.8	2.7	2.7	2.8
10	I am able to write a full science report after a practical lesson.	3.3	3.2	3	3.1

From the table, it can be seen that on average, the students believe that practical work and assessment is important for them to better understand chemistry concepts and the students strongly agree that the amount of practical work should be increased at high school. This is an important insight, because according to the CAPS and PoA documents, the students only perform one or two formal chemistry practicals per grade in school and in some cases where labs are not present, the students do not perform the practical but use alternative methods to complete the task. However, when it comes to alternative methods and those that were used during the covid-19 pandemic, the students were neutral on how effective the methods are in helping them to understand practical content.

Section B.2

This section looked at students' satisfaction with the practical work and teaching they received at school and is analysed in Table 4.13. The average satisfaction (scale 1-5) is shown in the table and the Likert scale used was:

1	2	3	4	5
Very unsatisfied	Unsatisfied	Neutral	Satisfied	Very satisfied

Table 4.13. Analysis of section B.2.

Question	Perception	Average			
		Mainstream		Extended	
		F	M	F	M
1	How satisfied are you with the number of practical activities done at your high school?	1,5	1.9	1.8	2
2	How satisfied are you with how practical concepts were taught to you at your high school?	2,5	2.3	2.0	2.3

3	How satisfied are you with the teaching methodologies that were used in class at your high school during chemistry lessons?	3,3	3.1	2.8	3.0
4	How satisfied are you with the number of hands-on activities done in chemistry classes at high school?	2,8	2.8	2.5	2.7
5	How satisfied are you with the alternative teaching methods that were used due to covid-19 regulations during practicals?	1,5	1.5	2.0	2.3

From the table it can be seen that on average, students were not at all satisfied with the number of practical activities they did at high school or with the alternative teaching methods that were used due to Covid-19 regulations (average about 1,8 on Likert scale). They were more satisfied with the teaching methodologies that were used in general in Chemistry, however, with an average score of 3,1.

The responses to the last question in Section B (2) (how many practical tasks did you perform in grade 12 at your high school?) are summarised in Table 4.14.

Table 4.14. Analysis of number of practicals students said they performed.

Number of practicals done	Mainstream		Extended		Total	%
	F	M	F	M		
0	19	17	37	22	95	28.11%
1	8	11	28	10	57	16.86%
2	12	9	23	9	53	15.68%
3 or more	20	15	25	36	96	28.40%

According to the student responses, less than 30% did 3 or more practicals while 28.11% (95 students) did no practical at all before coming to university.

Section B.3

This section covered how frequently the students thought they should have practicals, visit the laboratory and library, and how often they actually did practicals. This is shown in Table 4.15 and the Likert scale used was:

1	2	3	4	5
Never	Once a month	Once per term	Every second week	Every practical topic

Table 4.15. Analysis of section B.3.

Question	Perception	Average			
		Mainstream		Extended	
		F	M	F	M
1	How often should students perform practical tasks?	4.6	4.4	4.3	4.2
2	How often did you visit the science laboratory at high school?	2.1	2.1	2.0	2.3
3	How often did you have practical lessons at high school?	2.7	2.2	2.5	2.6
4	How often were you allowed to perform experiments on your own at high school?	1.4	1.5	1.6	1.5
5	How often did you visit the school library?	1.8	1.7	2.0	1.8
6	How often should students have practical assessment?	4.0	4.0	4.1	4.4

The results indicate that students want to perform more practicals, in line with the results in section B.2, and that they also want more practical assessment. Additionally, the students are not satisfied with the number of practicals that were done at high school and have indicated

that more practicals and assessment should be introduced at high school. It can therefore be concluded that the students have a positive attitude towards practicals and practical assessment.

The perceptions of the students towards practicals and practical assessment were important for this study because they give an indication of whether students understand the significance of practical tasks. If the students have a positive attitude towards practical tasks, then they are more prone to understand the concepts being taught. The results from the interviews indicated that the students attended practicals in high numbers and had a positive attitude towards practicals in the laboratory as observed by their chemistry lecturers and laboratory technicians. Additionally, the students also responded that they enjoy practicals a lot in the student surveys done at the NWU by their lecturers. Their positive attitude saw an improvement in their overall performance in stoichiometry concepts as recorded by their respective lecturers. Furthermore, the students' pass percentage in the same concepts from the questionnaire were much better at the end of first semester after performing a number of practical activities based on the concepts.

In the questionnaire, a number of questions were asked to determine the students' perception towards the practicals done at high school, and if they are satisfied with the number of practicals that they performed at high school. The responses indicate that the students are not satisfied with how practical concepts were taught at school and are not satisfied with the number of practical activities done at high school. In terms of how often the students would want to have practical activities, the responses indicate that the students want to have practical activities and assessment every second week.

4.3.3.1 Hypothesis b

Students' have a positive perception about practicals and practical assessment.

The results from research question 3 indicate Hypothesis b can be accepted, due to the indication that the students have a positive perception about importance of practical activities in their understanding of stoichiometry or chemistry concepts as a whole. The results also showed that the students prefer to have more practical assessment and activities as it helps them better understand concepts.

4.3.4. Research question 4

"Is there a difference in the performance of students from well-resourced (generally urban) schools and students from under-resourced (typically rural) schools?"

This question can be answered by testing Hypothesis c.

Well-resourced schools are schools in quintiles 4-5 and private schools which are considered to be quintile 0 or do not fall in any of the school quintiles as they are not government schools (White & Van Dyk, 2019). To compare how learners from quintiles 0, 4 and 5 performed compared to those from quintiles 1-3, the average mark of all the students from different quintiles was evaluated. In the extended sample, the average mark for female students from well-resourced schools is 44,53 and the average from less resourced (poor schools) is 38,85 . In the same sample, the average mark of male students from resourced schools was 39.82 and from less resourced schools it was 37.83.

In the mainstream sample, the female students from well-resourced schools had an average mark of 45.91, and the female students from less resourced schools had an average of 41.81, which indicated there was no significant difference in how the two groups performed overall. The male students had averages of 49,5 for students from quintiles 4-5 and 40,94 for students from quintiles 1-3, which indicates a slight gap in how the two groups performed and this indicates that students from well-resourced schools do perform slightly higher than students from less resourced schools. is given in Table 4.16:

Table 4.16. Summary of average scores from different school quintiles.

Mainstream	Males		Females	
Type of school	Quintile 1-3	Quintile 0 & 4-5	Quintile 1-3	Quintile 0 & 4-5
Average mark	40.94	49.5	41.81	45.91
Extended	Males		Females	
Type of school	Quintile 1-3	Quintile 0 & 4-5	Quintile 1-3	Quintile 0 & 4-5
Average mark	37.83	39.82	44.53	38.85

4.3.4.1 Null hypothesis c

There is no correlation between the type of school attended (i.e., rural, farm, or urban) with students' problem-solving abilities in stoichiometry concepts.

A Pearson correlation was done to test the relationship between school quintiles and scores on the Chemistry test for the BSc. mainstream and extended samples. The Pearson correlation coefficient at p-value = 0.05 with degrees of freedom N-2 in the mainstream females was found

to be $r(67) = 0,0887$ with a critical value of 0.232 and for mainstream males $r(59) = 0,1615$ with a critical value of 0.25, this indicating a very weak positive correlation between school quintile and the chemistry scores for the two groups. For extended group, the females had a critical value of 0.159 and the correlation coefficient was calculated as $r(121) = 0,210464$ and for extended males it was $r(83) = 0,171637$ with a critical value of 0.217. Thus, there is only a very weak positive correlation for the extended males but a slightly stronger correlation between the quintile school that the female students attended and their chemistry scores.

Additionally, looking at the correlation of the whole female sample (194 female students) between type of school and overall performance the coefficient was found to be $r(192) = 0.163$ with a critical value of 0.138. Looking at the male sample for both groups (146 male students) it was found that the Pearson correlation coefficient is $r(144) = 0.155$ with a critical value of 0.159.

Furthermore, according to the results from research question 4, there was a statistical difference in the average scores of students from well-resourced schools to students from under-resourced schools. Thus, null hypothesis c can be rejected, and it can be concluded that there is a difference in how students from well-resourced schools perform as compared to students from under-resourced schools.

4.3.5. Research question 5

“Is there a difference in achievement between female and male students in the chosen stoichiometry concepts?”

A t-test was performed to determine if there was a difference in how males and females performed from each group, and it was found that the t-value for mainstream students was $t = 0,7406$ at a degree of freedom (df) of 128 (using $df = N-2$ because of two parameters) and a critical value of 1,645. Therefore, no significant difference was found between the scores of the male and female mainstream students ($P < 0,1$). For extended students the t-test had a value of $t = 0,235439$ for a df of 206 and a critical value of 1.645. Therefore, this indicates that there is no significant difference between the scores for extended males and females.

4.3.5.1 Null hypothesis d

There is no difference between male and female students.

According to the results above, no statistical difference between the gender groups of the extended and mainstream samples was recorded using a t-test. In addition, a comparison of the

whole group was done using a t-test. The recorded t-value using df of 336 (N-2) and a critical value of 1.645 was $t = 0.324$ for the whole population of 338 students from extended and mainstream males and females. This again indicates no statistical difference between the two genders, and thus we accept our null hypothesis. All the t-tests were calculated at 90% confidence level, thus it can also be concluded that there is no difference in performance between males and females.

Chapter 5: Conclusion

5.1. Summary of study

This study investigated the correlation between practical activities and the problem-solving abilities of first-year university chemistry students in stoichiometry, and the link between practical activities involving stoichiometry done at high school and students' problem-solving ability using a self-administered questionnaire based on limiting reactant, acid-base titrations, standard solution, and mole ratio calculations as they form the base of stoichiometric calculations. Results showed that students struggled with the mathematical, analytical and reasoning skills needed in problem solving and presented gaps in the above concepts. There was not much correlation between the number of practical experiments done at school and students' performance in the stoichiometry questionnaire, but lecturers reported that their performance improved after a semester of practical work at university. The overall perception towards practical work was positive, and the students also showed that they were not satisfied with how the practical chemistry concepts were taught and the amount of practical work they did at high school.

5.2 Limitations of the current study

One limitation of this study is that it could not determine the progress of the Department of Education since the implementation of CAPS in terms of resource distribution and training provided to ensure that teachers are well-equipped to deliver the prescribed content. This would have entailed going to the schools, which was outside the scope of the study. However, this would have helped the study to further determine the shortage of resources per school and progress made in provisioning the different areas and schools.

Another limitation is that the research did not use a pre- and post-test design where the progress of the learners could be evaluated as they progress through university. This is because the current study focused on how the lack of practicals done in high school affects students' understanding of stoichiometry concepts. Additionally, the researcher did not have any direct contact with the learners to implement any different teaching strategies that could be evaluated in improving the students' problem-solving skills in solving stoichiometry questions. The researcher also was not able to evaluate how the lecturer teaching methodology, resources used, and the practical approaches used by lecturers and laboratory technicians helped to improve

the students' understanding on the stoichiometry concepts as they showed an improvement in their overall achievement.

Furthermore, another limitation of the study was that the views of teachers and parents were not obtained. This may have added to the information obtained but would potentially have delayed progress of the study as ethical clearance from the department of Education would have been required. It would have been useful to evaluate teacher perceptions towards the importance of practical assessment and activities, their perceptions on the impact on lack of available resources at their respective schools and how it affects their content delivery. It may also have been useful to interview the parents of students who are living in surrounding areas near lower quintile schools. In-depth understanding of teacher and parent views towards lack of resources would increase suggestions towards the Department of Education to ensure that all schools have sufficient resources.

5.3 Main results

The main results of this study will be summarised according to the research questions that the study evaluated, and then general additional findings will follow.

a) In which problem-solving abilities do students exhibit a gap (for example, analytical skills, reasoning skills, mathematical skills, or representation skills) in balancing chemical equations, identifying limiting and excess reactants, working with acid-base titrations, standard solutions, and mole ratio calculations?

- In terms of problem-solving skills, the students mainly struggled with their analytical, mathematical and reasoning skills when performing stoichiometry calculations that needed the students to use reaction ratios.
- When it came to balancing equations, the students were able to balance an equation when it was given but struggled to write a chemical equation from given keys and also from chemical names of substances. They thus struggled with analytical and representational skills in this concept.
- In titration reactions, the students struggled with converting volume correctly and also used given data in incorrect equations thus they struggled with mathematical and analytical skills in this concept.
- In the limiting reactant and standard solution, the students struggled with analytical, reasoning and mathematical problem-solving skills. They had to correctly analyse

questions and use reaction ratios correctly when calculating the amount of unknown substances.

b) What stoichiometry practicals are expected to be done at school, and in what concepts did students receive practical training at the high school level and has it helped them better understand those concepts?

- The only formal practical related to stoichiometry that the students had to perform was a titration reaction in Grade 12, as there are no other recorded formal practical activities. According to the results from the questionnaire, it did not assist in increasing their understanding of the concept as the performance was relatively low.
- Some students reported that they performed a practical on limiting reactant and standard solution, however that also did not improve their overall performance in the questionnaire.
- Even though the students' performance in the questionnaire was low, it is important to note that after performing more practicals on the set topics, the lecturers reported an increase in the overall achievement of the students in the same topics. 'This is an indication that with more practical activities, students can improve their understanding of stoichiometry concepts.

c) What perception do the students have regarding practical learning and its importance?

- According to the answers provided by the students in the questionnaire, the results showed on average that the students have a positive attitude towards practical activities and how frequently they should perform practicals. They also had a positive perception to the impact of practicals on their understanding of stoichiometry concepts, which is also in line with the findings during the interviews as the staff members indicated that the students had a positive attitude towards practical learning as reported in their student survey.

d) Is there a difference in the performance of students from well-resourced (generally urban) schools and students from under-resourced (typically rural) schools?

- A Pearson correlation coefficient was used to evaluate this research question, and a weak positive correlation was found. In addition to the positive correlation, the students who came from higher quintile schools (more resources available) had a higher mark

average as compared to students who came from lower quintile schools (less resourced schools).

e) Is there a difference in achievement between female and male students in the chosen stoichiometry concepts?

- No statistical difference was found between how males performed compared to females from both sample groups.

5.4 Recommendations

According to the findings of the study, it can be recommended that the Department of Education increases the availability of resources at schools, to increase teacher training which will ensure that all teachers have a better understanding of the content being taught and how best to teach it. It is also recommended that more formal practicals be given to students on a yearly basis, and the department then follows up to ensure that each school has the necessary resources needed to perform the practical with the students. Additionally, it is recommended that students should be exposed to enough laboratory exercises before they enter university, they should also be taught how to operate a computer and how to type reports, to avoid students struggling when they reach university and increase their content knowledge and attitude towards chemistry.

It is also recommended that students be given more training about laboratory apparatus and how to correctly use the apparatus, they should be given an opportunity to interact with the apparatus and perform experiments on their own. Furthermore, when teaching practical stoichiometry concepts at high school, the content understanding should be enhanced more by performing practical activities in the lab or using virtual laboratories, where the students can perform hands-on activities that will assist in increasing their understating of stoichiometry concepts. When resources in schools are limited, a further way of introducing more practical work could be by the use of microscale kits. These could be provided to schools at a much lower cost than traditional apparatus, only a fraction of the amount of chemicals are needed, safety is greatly enhanced as only very small amounts of chemicals are used, and learners can even use the kits to perform experiments at home or in their own time.

When teaching calculations, conversions should be emphasized and more exercises on how to correctly convert can be given to students together with more emphasis on understanding of

correct units for each variable being calculated in chemistry, as well as how to correctly use equations and reaction ratios. Problem-solving strategies can be incorporated into teaching, to assist students when performing calculations so that they can reduce the mistakes they make.

5.5 Suggestions for further research

More research is needed on ways that can be implemented to improve students' problem-solving skills, and how it can be incorporated into how chemistry is taught at high school. More research is also needed on various methods that can be used together with alternative resources at under-resourced schools, which will reduce the effect of the lack of resources at these respective schools. Additionally, more research is needed on the progress made in South Africa since the implementation of the CAPS curriculum in terms of resource distribution across low-income areas, and the readiness of students as they transition from high school to university.

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ANNEXURES

Annexure A – Page 6 of CAPS

PHYSICAL SCIENCES GRADES 10-12

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Annexure B – Program of assessment (POA) grades 10-12 (2022)



education

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FET SCHOOLS

2022 PHYSICAL SCIENCES PROGRAMME OF ASSESSMENT GRADES 10 - 12

GRADE 10									
TERM 1	WEIGHTING	DATE	TERM 2	WEIGHTING	DATE	TERM 3	WEIGHTING	DATE	TERM 4
Experiment & Practical Test	12,5%	14-18 / 02 / 2022	Experiment & Practical Test	12,5%	03-06 / 05 / 2022	Experiment and practical test done in Term 2 to be recorded in Term 3.			2021 Final (Control Test)
Term 1: Flame Test (PROVINCIAL)			Measurement of velocity (PROVINCIAL) NB: Both experiment and practical test are to be recorded in Term 3.						75%
Control test	25%	16 / 03 / 2022	MID YEAR	25%	20 / 06 / 2022	Control test	25%	27 / 09 / 2022	2 x 100 marks papers
(1 Paper of 100 marks)			CONTROL TEST			(1 Paper of 100 marks)			
DISTRICT/			(1 Paper of 100 marks)			DISTRICT/			
SUB-DISTRICT						SUB-DISTRICT			
TOTAL	37,5%			25%			37,5%		
FINAL			25%						75%
			(Subject to change)						(Subject to change)

GRADE 11									
TERM 1	WEIGHTING	DATE	TERM 2	WEIGHTING	DATE	TERM 3	WEIGHTING	DATE	TERM 4
Experiment & Practical Test Term 1: Resultant of three non-linear force vectors (PROVINCIAL)	12,5%	21-25/ 02/ 2022				Experiment & Practical Test Electromagnetic Induction (PROVINCIAL)	12,5%	22-26/08/ 2022	2021 Final (Control Test) 2 x 100 marks papers 75% 14-18/11/2022
Control test Paper 1 & 2 DISTRICT/ SUB-DISTRICT	25%	11/03/ 2022	MID YEAR CONTROL TEST (1 Paper of 100 marks)	25%	13-15 /06/ 2022	Control test Paper 1 & 2 DISTRICT/ SUB-DISTRICT	25%	21/09/ 2022	
TOTAL	37,5%			25%			37,5%		
FINAL	25% (Subject to change)								75% (Subject to change)

GRADE 12									
TERM 1	WEIGHTING	DATE	TERM 2	WEIGHTING	DATE	TERM 3	WEIGHTING	DATE	TERM 4
Experiment & Practical Test Term 1: Principle of Conservation of linear momentum. (PROVINCIAL)	15%	28/02 - 04/ 03/ 2022				Experiment & Practical Test Electromagnetic Induction (PROVINCIAL)	15%	22-26/08/ 2022	2021 Final (DBE NSC Examination) 2 x 150 marks papers 75% 14-18/11/2022
Control test 100 marks: 1 paper – 2hrs Newton's laws; Momentum & Impulse; Vertical Projectiles; Organic molecules (Chemistry) DISTRICT/ SUB-DISTRICT	20%	14/03/ 2022	MID YEAR CONTROL TEST Paper 1 & 2 2 X 50 Marks 100 Marks	20%	13-15 /06/ 2022	Preparatory Examination Paper 1 & 2 2 x 150 marks papers (PROVINCIAL) (Chief Directorate Examination & Assessment)	30%	TO BE CONFIRMED (EXAMINATION & ASSESSMENT)	
TOTAL	37,5%			25%			37,5%		
FINAL	25% (Subject to change)								75% (Subject to change)

Annexure C – Program of assessment (POA) grades 10-12 (2023)



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CHIEF DIRECTORATE: CURRICULUM MANAGEMENT SERVICES FET SCHOOLS

2023 PHYSICAL SCIENCES PROGRAMME OF ASSESSMENT GRADES 10 - 12

GRADE 10											
TERM 1	WEIGHTING	DATE	TERM 2	WEIGHTING	DATE	TERM 3	WEIGHTING	DATE	TERM 4	WEIGHTING	DATE
			Experiment (15-19/05/2023) & Practical Test (22/05/2023) Flame Test (PROVINCIAL)	12,5%	15 - 22 / 05 / 2023	Experiment (04-08/09/2023) & Practical Test (11/09/2023) Measurement of Velocity (PROVINCIAL)	12,5%	04 -11/ 09 / 2023	2023 Final Examination Paper 1: 100 Marks Paper 2 : 100 Marks	60%	27 /11-13/12/2023
Control test (1 Paper – 100 marks) DISTRICT/ SUB- DISTRICT	25%	17 / 03 / 2023	MID YEAR EXAMINATION Paper 1: 75 Marks Paper 2 : 75 Marks = 150 MARKS	25%	15 & 20/ 06 /	Control test (1 Paper – 100 marks) DISTRICT/ SUB- DISTRICT	25%	22 / 09 / 2023			
TOTAL=100%	25%			37,5%			37,5%				
FINAL	FINAL MARK = 40%(ASSESSMENT TASKS) + 60% (FINAL EXAM) = 100%										

GRADE 11									
TERM 1	WEIGHTING	DATE	TERM 2	WEIGHTING	DATE	TERM 3	WEIGHTING	DATE	TERM 4
Experiment 14-17/ 02/2023 & Practical Test 20/ 02/ 2023 Newton's Second Law of Motion (PROVINCIAL)	12,5%	14-20/ 02/ 2023				Experiment 24-28/ 07/ 2023 & Practical Test 31/ 07/ 2023 Ohm's Law / Boyles Law (PROVINCIAL)	12,5%	24-31/ 07/ 2023	2023 Final Examination Paper 1: 150 Marks Paper 2 : 150 Marks TOTAL = 300 MARKS
Control test DISTRICT/ SUB-DISTRICT	25%	13/ 03/ 2023	MID YEAR EXAMINATION Paper 1: 100 Marks Paper 2 : 50 Marks = 150 MARKS	25%	13 & 16/ 06/ 2023	Control test DISTRICT/ SUB-DISTRICT	25%	19/ 09/ 2023	
TOTAL= 100%	37,5%			25%			37,5%		
FINAL FINAL MARK = 40%(ASSESSMENT TASKS) + 60% (FINAL EXAM) = 100%									

GRADE 12									
TERM 1	WEIGHTING	DATE	TERM 2	WEIGHTING	DATE	TERM 3	WEIGHTING	DATE	TERM 4
Experiment 27/02 - 02/ 03/ 2023 & Practical Test 03/ 03/ 2023 Preparation of Esters (PROVINCIAL)	15%	27/02 - 03/ 03/ 2023				Experiment 28-31/ 08/ 2023 & Practical Test 01/ 09/ 2023 Internal Resistance (PROVINCIAL)	15%	28/08/01/09/ 2023	2023 Final (DBE NSC Examination) 2 x 150 marks papers = 300 marks
Control test 100 marks: 1 paper – 2hrs Newton's laws; Momentum & Impulse; Vertical Projectiles; Organic molecules (Chemistry)	20%	16/03/ 2023	MID YEAR EXAMINATION Paper 1: 150 Marks Paper 2 : 150 Marks	20%	14 & 19 /06/ 2023	Preparatory Examination Paper 1 & 2 : 150 X 2 = 300 Marks (PROVINCIAL) (Chief Directorate Examination & Assessment)	30%	TO BE CONFIRMED (EXAMINATION & ASSESSMENT)	
TOTAL= 100%	35%			20%			45%		
FINAL FINAL MARK = 25%(ASSESSMENT TASKS) + 75% (FINAL EXAM) = 100%									

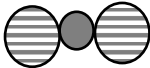
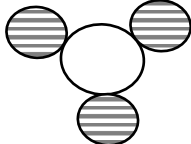
Annexure D – Marking guide for questionnaire Section C

Questionnaire marking guideline.

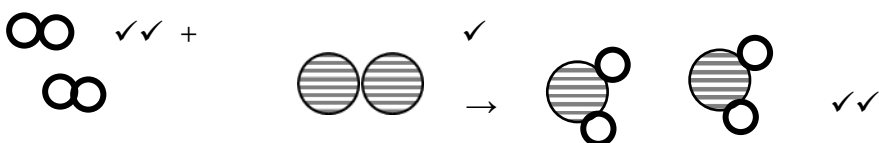
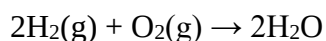
Grand total = 50 marks

1. Representational questions [11]

1. (6)

Name of compound	Chemical formula	Picture illustration of the compound
Carbon dioxide	1.1.1 CO ₂ ✓	1.1.2  ✓✓
Sulphur trioxide	1.1.3 SO ₃ ✓	1.1.4  ✓✓

1.2 (5)



2. Conceptual questions [39 marks]

1. C ✓✓ (2)

2. C ✓✓ (2)

3. C ✓✓ (2)

4. D ✓✓, because the acid is in excess, which causes a resulting acidic solution ✓.

(3)

5. D ✓✓ (2)

6.

6.1 Zn + 2HCl ✓ → ZnCl₂ + H₂ ✓ (2)

6.2 B ✓✓ (2)

6.3 C ✓✓ (2)

7.

7.1 H₂SO₄ + 2KOH ✓ → K₂SO₄ + 2H₂O ✓ (balanced) ✓ (3)

7.2 A ✓✓ (2)

7.3 C ✓✓ (2)

8. (5)

$$c = \frac{n}{V}$$

$$n = 0.2 \text{ mol} \cdot \text{dm}^{-3} (0.25 \text{ dm}^{-3}) \checkmark$$

$$n = 0.05 \text{ mol of MgCl}_2 \checkmark$$

$$m = n \times M_r$$

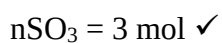
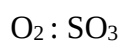
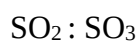
$$m = 0.05 \text{ mol} (95 \text{ g/mol}) \checkmark$$

$$m = 4.75 \text{ g of MgCl}_2 \checkmark$$

Weight the 4.75g of magnesium chloride, pour it into a 250cm³ volumetric flask and fill to the mark with distilled water. Shake well until all the magnesium chloride has dissolved. ✓

9.

9.1 C ✓✓ (6)



Therefore, SO₂ is the limiting reactant ✓ and O₂ is in excess. ✓

9.2 D ✓✓ (2)

9.3 D ✓✓ (2)

Total marks = 50

Annexure E – Participants consent form

Student Consent form

Let us first take this opportunity to thank you for participation, and to highlight again important points before we start.

I (student) agree that I am aware of the purpose of this study and hereby agree to participate. I am also aware that my participation is **voluntary** and that:

- The purpose of this study to determine gaps in stoichiometry and problem-solving skills for new students in the university, and to improve chemistry education.
- Any personal information that is accumulated about me during this study will be handled in the strictest confidentiality.
- I participate out of my own will in this study.

If you have any questions about this project, feel free to contact Prof. H. Drummond on 018 389 2051 between (8:00am – 16:30pm).

I (student) acknowledge that by signing underneath, I have read and understood the above points.

.....

Signature & Date:

Annexure F – Ethics clearance certificate



Private Bag X1290, Potchefstroom
South Africa 2520

Tel: 018 299-1111/2222
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Web: <http://www.nwu.ac.za>

Senate Committee for Research Ethics
Tel: 016 910 3446
Email: Feziwe.Mseleni@nwu.ac.za

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Faculty of Natural and Agricultural Sciences Ethics Committee (FNAS-REC)**, the Faculty of Natural and Agricultural Sciences Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-SCRE) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Assessing the relationship between practical activities and students problem-solving skills in stoichiometry				
Study Leader/Supervisor: Prof HP Drummond				
Student: K Abranches				
Ethics number:	N	W	U	-
	0	1	2	8
	7	-	2	1
	-	A	9	
	Institution		Study Number	Year Status
Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation				
Application type:	Single		Risk Category:	Minimal
Commencement date: 01/02/2021				
Expiry date: 31/08/2024				
Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.				

Special in process conditions of the research for approval (if applicable):

- The following documentation are archived by FNASREC and should be complete and kept up to date:
 - Research proposal
 - Signed approval from the scientific committee indicating the proposed risk category
- All researchers involved in the study should submit signed NWU code of conduct statements annually.
- All researchers of low risk studies should submit proof of relevant ethics training every two years.
- All researchers that take part in activities that pose a safety and security threat to the researchers or the environment should submit a risk assessment form annually.
- All research involving human interaction should follow best ethical practise and keep documents as proof. This includes informed consent, questionnaires, incorporation of risk-benefit, and responsible data management.
- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the FNASREC. Ethics approval is required BEFORE approval can be obtained from these authorities.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- *The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the FNASREC:*
 - *annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and*
 - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the FNASREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *Annually a number of studies may be randomly selected for an external audit.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility, the NWU-SCRF and FNASREC reserves the right to:*
 - *request access to any information or data at any time during the course or after completion of the study;*
 - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
 - *withdraw or postpone approval if:*
 - *any unethical principles or practices of the study are revealed or suspected;*
 - *it becomes apparent that any relevant information was withheld from the FNASREC or that information has been false or misrepresented;*
 - *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
 - *new institutional rules, national legislation or international conventions deem it.*
- *FNAS REC can be contacted for further information or any report templates via Roelof.Burger@nwu.ac.za 018 299 4269*

The FNASREC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the FNASREC or the NWU-SCRF for any further enquiries or requests for assistance.

Yours sincerely,



Prof. Roelof Burger
Chairperson Faculty of Natural and Agricultural Sciences Ethics Committee (FNASREC)