EXPLORING LEARNERS' PROFICIENCY IN STOICHIOMETRY AND ATTITUDES TOWARDS SCIENCE THROUGH PROCESS ORIENTED GUIDED INQUIRY LEARNING (POGIL) INTERVENTION

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By

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Declaration

I declare that this thesis that explored learners' proficiency in stoichiometry and attitudes towards science in relation to their participation in process oriented guided inquiry learning intervention is my original work. It has not been submitted in entirety or part for examination or degree at any other higher education institution. All the sources or materials used or cited are acknowledged and indicated in the list of references.

Signature **Date**: December 2020

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Dedication

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Abstract

Stoichiometry is one of the difficult topics in the senior secondary school chemistry curriculum. It is usually taught through the traditional lecture method of presentation that is non-engaging for learners. Consequently, there is poor understanding, achievement, and negative perceptions of stoichiometry and chemistry in general. The goal of this study was to explore learners' evolving proficiency in stoichiometry and attitudes towards science as a result of their participation in Process Oriented Guided Inquiry Learning (POGIL) activities. That is, POGIL which incorporates guided-inquiry and collaborative learning was introduced as an intervention strategy in learning stoichiometry. This was assessed by examining learners' experiences with learning stoichiometry before and after the POGIL intervention. The study further investigated possible contributing factors to learners' evolving proficiency in stoichiometry and attitudes towards science.

This study employed the socio-cultural learning theory as proposed by Vygotsky (1978). The role of socio-cultural features such as 'social interaction', 'cultural tools', 'self-regulation' and 'zone of proximal development' (ZPD) were explored with regards to learners' stoichiometry proficiency and attitudes towards science progression as they participated in POGIL activities. The work of Kilpatrick, Swafford and Findell (2001) on proficiency and Fraser (1981) on attitudes towards science were used as analytical lenses to understand learners' proficiency in stoichiometry and attitudes towards science, respectively.

This study was underpinned by the pragmatic research paradigm. Thus, a Quant + Qual concurrent mixed-methods approach which involves generating, analysing, and integrating both qualitative and quantitative data to provide answers to research questions was adopted. It was an intervention study carried out in two senior secondary schools in the Ilorin metropolis of Kwara State, Nigeria. A sample of 53 senior secondary school year two learners participated. Questionnaires and journal entries were completed by the 53 learners, while seven learners were interviewed.

Data were collected using both qualitative and quantitative data generating tools including pre- and post-tests. The stoichiometry learning questionnaire (SLQ), test of science related attitude (TOSRA) questionnaire, and stoichiometry achievement tool (SAT) were used to generate quantitative data while the SLQ, semi-structured interviews, and journal entries were the qualitative data tools. Data were generated in three phases. Phase one was baseline data through SLQ, TOSRA and SAT pre-tests. The second phase was the intervention phase where the POGIL approach was implemented in the classrooms and learners were engaged in journal entries. Post-intervention was the last phase where TOSRA and SAT post-tests were administered and semi-structured interviews were conducted with participants. Thus, data were analysed quantitatively and qualitatively.

Before the POGIL intervention, the findings of this study revealed that most of the learners perceived stoichiometry as difficult because of the instructional characteristics, the nature of stoichiometry concepts, and learners' attributes. After the POGIL intervention, however, learners showed increased proficiency in stoichiometry and attitudes towards science. Findings also indicate that learners' proficiency in stoichiometry and attitude towards science were associated with the facilitators or learning environment features, the nature of instructional characteristics, learners' perceptions of stoichiometry or science, and the extent to which learners could comprehend or master science concepts. Notably, these features are intertwined and cohere with the socio-cultural theory and POGIL principles. This study offered insights into how proficiency in stoichiometry and attitudes towards science may develop among senior secondary school learners in Nigeria. The findings point to POGIL as an example of an instructional approach that provides enabling characteristics and useful information for planning instructional activities for the development and nurturing of proficiency and attitudes towards science. The results suggest that the POGIL strategy could alleviate some of the factors perceived as contributors to difficulty in learning stoichiometry. As such, the study makes contributions to the field of science education in Nigeria particularly regarding how both the tenets of the socio-cultural framework (social interaction, cultural tools, self-regulation, and ZPD) and POGIL (guided-inquiry and collaborative learning) could be aligned to facilitate the development of proficiency and attitudes towards science. The study, therefore, recommends that POGIL should be used as an inquiry-based approach in science classrooms to promote the development of learners' proficiency and attitudes towards science. The study could also be utilised as a resource to guide or set a base for further investigation into the implementation of POGIL in other areas of chemistry or science as well as creating professional development spaces that promote community of practice among science teachers as observed in this study.

Keywords: Chemistry, stoichiometry, proficiency, attitudes towards science, inquiry based, POGIL, socio-cultural theory

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List of Abbreviations and/or Acronyms

CoP	Community of Practice
CU	Conceptual Understanding
FRN	Federal Republic of Nigeria
NECO	National Examination Council
PF	Procedural Fluency
POGIL	Process Oriented Guided Inquiry Learning
SAT	Stoichiometry Achievement Tool
SC	Strategic Competence
SLQ	Stoichiometry Learning Questionnaire
SPSS	Statistical Package for social science
SSS 2	Senior Secondary School year two
SSS	Senior Secondary School
STEM	Science Technology Engineering and Mathematics
TOSRA	Test of Science Related Attitude
WAEC	West Africa Examination Council
ZPD	Zone of Proximal Development

CHAPTER ONE: SITUATING THE STUDY

> *Science education needs to be concerned equally with both the structure of knowledge, which is the content component, and with the development of the skills for acquiring, applying, and generating knowledge, which is the process component.* (Hanson, 2006, p. 1)

1.1 Introduction

The purpose of this study was to explore learners' evolving proficiency in stoichiometry and attitudes towards science as a result of their participation in the Process Oriented Guided Inquiry Learning (POGIL) activities. This chapter introduces the study by presenting the background, rationale, and significance of the study. It also highlights the focus of the study by outlining the research goal and the research questions. Lastly, I present a brief definition of the key concepts used in this thesis and overview of each of the thesis chapters.

1.2 Background to the Study

One of the key challenges in the field of science education over the years, globally and in Nigeria, is the decline in learners' engagement in and attitudes towards science (Akuche & Adeniyi, 2017; Bennett, Lubben, & Hampden-Thompson, 2013; Juan, Hannan, & Namone, 2018). Yet, it is widely acknowledged that science education is important to every country as it contributes to the scientific development and economy of the nation (Akuche & Adeniyi, 2017; Juan et al., 2018). Sakiyo and Badau (2015, p. 32) assert that "strides in science and technology were catalysts in the development of many countries in the world". The on-going advancement in science and technology creates an increasing need for more entrances into science-oriented careers (Juan et al., 2018). The primary focus of this study was to explore the mediating effect of process-oriented guided inquiry learning (POGIL[1]) on proficiency in

[1] POGIL is a learner-centred instructional strategy whereby learners work in small groups on specially designed activities that follow a learning cycle paradigm.

stoichiometry and attitudes towards learning science of senior secondary school learners in Ilorin metropolis, Kwara State, Nigeria.

Science education literature reports that learners' enrolment and performance in sciences globally over years is worrisome (Agunbiade, Ngcoza, Jahawar, & Sewry, 2017; Barthlow & Watson, 2014). Globally, many learners at senior school, when science becomes optional, are inclined toward pursuing subjects in humanities or business studies rather than the sciences (Mujtaba, Sheldrake, Reiss, & Simon, 2018) or later at tertiary institutions (Bennett et al., 2013; Wong, 2016).

The corresponding trend with the decline in uptake of science subjects or courses is also reported among Nigerian senior secondary school learners (Agbaje & Alake, 2014; Jack, 2013; Olorundare, 2014). For instance, Agbaje and Alake (2014) report that the Nigerian science education system produces fewer science graduates than is required by its economy. This direction in a developing country like Nigeria is worrisome because of its consequences on the learners' chosen careers and subsequently on the growth of the country (Agbaje & Alake, 2014; Akuche & Adeniyi, 2017). Tytler and Osborne (2012) confirm that school science has failed to engage learners sufficiently in pursuing future careers in science and consequently has driven learners' attention away from science as a topic of interest. This has been a matter of concern in the field of science education for over 40 years globally and is no exception in Nigeria (Akuche & Adeniyi, 2017; Bichi, Hafiz, & Abdullahi, 2017).

For instance, Nigeria is facing not only a shortage of learners' enrolment in science and science-related fields but also a deficit of learners who are achieving in science (Omwirhiren, 2015). As a result, science and mathematics education reform from primary to senior secondary education has been at the centre of national debate with efforts focusing on improving learners' enrolment and achievement in them (Akuche & Adeniyi, 2017). In consequence, the National Policy on Education (Federal Republic of Nigeria (FRN), 2013) encourages advancement in science, technology, and mathematics, in order to lay the foundation for the technologically oriented workforce needed to compete globally. It is vital to increase the number of science-literate people in a country, not only to ensure global competitiveness, but also because it is part of our everyday life (Barthlow & Watson, 2014; Wong, 2016). In the context of this research, a brief outline of science provisions/main features of the education system in Nigeria is presented.

1.3 The Nigerian Education System

The Nigerian Education system comprises nine years of compulsory basic education; six years of elementary education and three years of junior secondary education (FRN, 2013). Learners are awarded primary school leaving certificates on completion of the six years of elementary schooling and then they progress to junior secondary school education. The curriculum in junior secondary education includes English, mathematics, integrated science and technology, Nigerian language, religious studies, civil and vocational studies, agricultural science, business studies, and creative arts (ibid.).

The junior secondary school education lasts for three years, completing the basic stage of education. Learners are awarded the junior school certificate to progress to the senior secondary school based on their performance in the final examination administered by the State Ministry of Education. Senior secondary education lasts three years before students proceed to tertiary institutions where the programmes are for three or four years, depending on the area of study chosen (FRN, 2013). In addition to the two compulsory subjects (mathematics and English language), the national policy requires all learners at senior secondary school to study at least one science subject – the choices being biology, chemistry, and/or physics (Bichi et al., 2017; FRN, 2013).

Essentially, science education is a prerequisite for the technological advancement of Nigeria, and it occupies a unique position in the Nigerian senior secondary school curriculum (FRN, 2013). It is compulsory for all learners at junior secondary schools to study integrated science throughout this three-year period of schooling. Integrated science is a prerequisite subject for all senior secondary school science subjects. The junior secondary science curriculum includes introductory themes from each of the following science fields: physics, chemistry, biology, agriculture, and earth sciences. These fields are integrated without emphasis on specificity to inform young learners and to open up a world of possibilities in science with equal attention to each field.

However, at the senior secondary school level, a learner must either take up science, social science, or art courses for the senior secondary years one to three, leading to the final senior certificate examination. Learners who choose science courses must take chemistry, biology, and physics in addition to the compulsory English and mathematics while those who choose social science or art courses must take biology as the compulsory science course as required for senior secondary school learners.

1.4 The Nigerian Learners' Performance in Science

Biology, chemistry, and physics are the core science subjects offered in the senior secondary school years. Learners are required to have at least a credit equivalent of 50% pass in these three science subjects as a prerequisite for admission into a tertiary institution to study pure or applied sciences, medical sciences, environmental or agricultural sciences, and engineering courses. Conversely, reports from the two public examination bodies in Nigeria, West Africa Examination Council (WAEC) and National Examination Council (NECO), reveal that learners' performance in the three core science subjects is on a downward trend with increasing failure rates specifically in chemistry and physics (Bichi et al., 2017; Sakiyo & Badau, 2015).

Numerous studies have revealed that Nigerian learners are inclined toward pursuing subjects in arts or social sciences rather than sciences at senior school (Agbaje & Alake, 2014; Babalola, 2017; Jack, 2013; Omwirhiren, 2015) and subsequently at tertiary institutions (Olorundare, 2014). For example, the Senior School Certificate Examination conducted by the WAEC (2016) showed that arts and social sciences subjects recorded a higher percentage enrolment (between 45% and 70% of the total candidates) compared with the enrolment for science subjects (less than 40%). The result of this would be a system producing fewer science graduates to meet the demands for the increasing number of science-related professionals required by the global economy (Hampden-Thompson & Bennet, 2013; Mujtaba et al., 2018).

Therefore, more learners studying in the field of science are required to meet the expected demand for the increasing number of science-related professionals (Mujtaba et al., 2018). Sakiyo and Badau (2015) in their study on the trend of Nigerian learners' performance in mathematics and sciences for five consecutive years, found that the pass rates in mathematics and biology increased by 17.9% and 20% respectively. In contrast, the pass rate in chemistry and physics decreased by 21.3% and 17% respectively. This is a worrisome situation as science study is not complete without chemistry, the 'central science'.

Chemistry is central to other science subjects and its importance cannot be overemphasised (Jack, 2013). As presented in the Nigerian curriculum, chemistry is a branch of science which involves the study of matter, its composition, properties, explanation, and predictions of how it behaves (Gallaher & Ingram, 2011; Jack, 2013). Chemistry is fundamental in the world of industrialisation and is an important branch of science that is central to many professional fields such as medicine, biomedical sciences, engineering, and technology and these fields are very central to the development of any nation (Jack, 2013; Uce, 2009).

Despite the key role of chemistry as being central in science, the performance in and attitudes of learners to the subject over the years is of serious concern (Oloyede, 2010; Omiko, 2017; Uce, 2009). Uce (2009) avows that chemistry is one of the most challenging courses in the senior secondary school science sequence. Other research in the field of science education has also identified chemistry as one of the difficult science subjects at senior secondary school level (Furio, Azcona, & Guisasola, 2002; Olorundare, 2014; Schmidt-Rohr, 2020).

Fewer learners take chemistry in their senior secondary education and these few often perform poorly in the subject (Ajayi & Ogbeba, 2017). Stoichiometry forms the basis of chemistry and if learners are not proficient in stoichiometry, they cannot be proficient in chemistry (Paideya, 2010). As highlighted in the WAEC (2015) chief examiners' reports, learners are weak in solving problems on stoichiometry and stoichiometry-related concepts in chemistry. Likewise, in 2016, the chief examiners' report highlights that learners' inability to write balanced reaction equations is a weakness associated with the general poor performance in chemistry for the year. The chief examiners' report (2016) shows that learners could not establish the mass-volume relationships from the stoichiometry of the reaction equations. This trend was continuously observed in 2017 and 2018 reports where learners' poor performances were associated with answering many stoichiometry questions such as inability to differentiate between molar mass and relative atomic mass, calculate mass concentration of solution, and calculate volume of gas evolved amongst other weaknesses identified (WAEC, 2017; 2018).

1.5 Statement of the Problem

The failure rate of Nigerian senior secondary school learners in chemistry remains high (Jack, 2013; Olorundare 2014; Omiko, 2017). According to Omiko (2017), learners' performance in chemistry at the senior secondary school final year examination is always at the lowest rung of the ladder, after physics, with only 21% performing at or below proficiency and only 1% at a proficient level. This situation is of great concern as chemistry is one of the core subjects required for admission into science programmes at tertiary institutions (Jack, 2013).

Learners tend to be frustrated and exhibit a poor attitude when they do not understand important science concepts or perform poorly in them (Agunbiade et al., 2017; Babalola, 2017; Dahsah & Kruatong, 2010). According to Agunbiade et al. (2017), learners' attitudes and continuing engagement in science are connected to the difficulty they experience in science studies. For instance, many learners develop negative attitudes towards science and in particular, towards chemistry once the concept of stoichiometry is introduced (Agbaje & Alake, 2014; Dahsah & Kruatong, 2010). Agbaje and Alake (2014) suggest that learners' attitude towards chemistry or science, in general, has the potential to predict their performance in it and hence their future career preferences.

Many factors have been attributed to influencing learners' attitudes and performance in chemistry. These factors include: the traditional methods of teaching; abstract nature of the subject contents; teachers' pedagogical knowledge of the subject; instructional characteristics and classroom experience among others (Agunbiade et al., 2017; Barthlow & Watson, 2014; Onabanjo, 2000; Sedlacek & Sedova, 2017). Onabanjo (2000) offers a context-specific perspective of why the problem persists. For instance, he outlines the features of the traditional science classrooms where learning is constrained in many ways and active participation and learning by the learners are not encouraged. Several studies have also identified some topics in the senior secondary chemistry curriculum which are perceived as difficult to teach and learn by teachers and learners respectively (Dahsah & Kruatong, 2010; Denuga, 2019; Furio et al., 2002; Gongden, Gongden, & Lohdip, 2011; Schmidt-Rohr, 2020). There seems to be a consensus among these studies identifying stoichiometry as a difficult concept for both teachers and learners.

With this heightened awareness of the need for science and technology, researchers in science education are continuously trying to develop new teaching approaches which they hope might improve the learning of some chemistry topics, such as stoichiometry (Barthlow & Watson, 2014; Denuga, 2019; Granger, Bevis, Saka, Southerland, Sampson, & Tate, 2012; Juan et al., 2018; Omwirhiren, 2015). Learners' active engagement and interactions in learning are now recognised as being essential to gaining understanding, long-term retention and increased positive attitudes towards learning science (Agunbiade et al., 2017; Moog & Spencer, 2008; Sedlacek & Sedova, 2017). There is increasing attention on learners' affective domain with regard to science making a difference to this trend of declining achievement and engagement (Aydeniz & Kotowski, 2014; Tytler & Osborne, 2012). It is against this backdrop that this study sought to explore the influence of Process Oriented Guided Inquiry Learning (POGIL) on learners' proficiency in stoichiometry and their attitudes towards learning science.

1.6 Rationale and Significance of the Study

The literature abounds with evidence of poor achievements and enrolment in chemistry because of the difficulties encountered by learners and the suggestion of potential remedies (Furio et al., 2002; Olorundare, 2014). Consequently, learners encountering difficulty in science is associated with learners' attitudes to science (Agunbiade et al., 2017; Babalola, 2017). Stoichiometry is a fundamental mathematical chemistry topic that should be mastered by all science learners because of its link with other areas of chemistry (Furio et al., 2002; Gongden, et al., 2011). Despite these ideals, however, studies in the field of science education highlight stoichiometry as a difficult concept in the chemistry curriculum (Furio et al., 2002; Gongden, et al., 2011; Olorundare, 2014; Omiko, 2017; Schmidt-Rohr, 2020).

Jack (2013) argues that one of the problems in implementing science concepts in the classroom is the lack of appropriate instructional material and approach to teaching. To enhance a deeper understanding of scientific concepts and learners' attitudes towards learning science, appropriate learning strategies have to be introduced (Agunbiade et al., 2017; Jack, 2013). Concurring, Agunbiade et al. (2017) confirm that learners' perceived difficulty in science fades away when they are engaged in a variety of interactive science activities in learning a concept.

Countless previous studies have investigated difficult topics in chemistry and very few explicitly focused on the causes of the difficulties, with many not agreeing on the reasons for the difficulties encountered. A common factor that was identified, by which the challenges could be alleviated, is the active science classroom that would provide a favourable learning environment (Arthur & Kreager, 2017; Schwartz, 2009; Sen, Yilmaz, & Geban, 2016). According to Schwartz (2009), it is important to explore the "processes by which knowledge is built" (p. 199). Concurrently, Arthur and Kreager (2017) affirm that instructional strategies that engage learners in active learning are connected to positive learning outcomes.

Science education research indicates that an active learning approach such as POGIL could engage, accomplish, and empower learners in learning and comprehending difficult concepts (such as stoichiometry in the context of this study) (Campbell, 2014; Hanson, 2006; Moog & Spencer, 2008; Sen et al., 2016). The effectiveness of POGIL in improving learners' achievement in many science classrooms has been proven to be successful (Arthur & Kreager, 2017; Campbell, 2014; Sen et al., 2016). For instance, POGIL has been proven to have increased achievement for college learners in some countries such as Australia, Turkey, and the United States of America (Barthlow & Watson 2014; Hanson, 2006; Moog & Spencer, 2008; Sen et al., 2016).

However, its effectiveness in secondary school chemistry classrooms, and particularly in stoichiometry, has not been thoroughly researched (Barthlow & Watson, 2014; Sen et al., 2016). A review of literature also revealed that the effect of POGIL on senior secondary school learners' attitudes towards science is scarce. Moreover, there is paucity of research in Nigeria that explicitly investigates learners' proficiency in stoichiometry nor are there studies that investigate the effect of active inquiry-based learning strategies such as POGIL.

After working on learners' attitudes towards science in an informal science learning environment, I became increasingly interested in being able to work in my area of interest and contribute to bring about the positive changes in science education that I feel strongly about. A further investigation into how learners' attitudes progress in the formal school setting through a doctoral study seemed an obvious way. The POGIL method appeared to provide the avenue for encompassing the features identified for quality science outcomes in my previous master's study (Agunbiade, 2015).

Specifically, this current study aimed to address these gaps in the literature and sought to provide a new perspective on learners' proficiency in stoichiometry and their attitude towards science through their participation in POGIL. It was hoped that POGIL could be one possible way to explore learners' evolving proficiency in stoichiometry and attitudes towards chemistry or science in general. The gaps outlined above provide a rationale for this study, which sought to explore the effectiveness of POGIL on learners' proficiency in stoichiometry and their attitudes towards science.

Furthermore, the POGIL intervention might help teachers to develop instructional materials that actively engage their learners. This might not only enhance the knowledge and competence of teachers in teaching difficult concepts, but it was also anticipated that it might help learners develop critical thinking and scientific skills necessary to succeed in the field of science. In addition, understanding how proficiency develops in senior secondary school science learners is an important contribution to the field of science education in Nigeria and potentially to the growing field of active learning pedagogy. Finally, this study aimed to contribute theoretically and methodologically to science education research, particularly regarding the socio-cultural theory as part of an active and collaborative learning approach.

1.7 Research Goal

The goal of this research was to explore the influence of learners' participation in the Process Oriented Guided Inquiry Learning (POGIL) instructional strategy on their proficiency in stoichiometry and their attitudes towards learning science. The focus was on how learners' proficiency in stoichiometry and attitudes towards science shift as they participate in the POGIL intervention.

1.8 Research Questions

To achieve the above goal in alignment with the research problem and purpose, the following main research question guided this study:

How does the Process Oriented Guided Inquiry Learning (POGIL) instructional strategy influence learners' proficiency in stoichiometry and their attitudes towards science?

In order to answer the main question above, it was explored from four perspectives:

1. What enabled and/or constrained learning of stoichiometry concepts by learners in the senior secondary school prior to the POGIL intervention?
2. How do learners' proficiency in stoichiometry change (if at all) over the period of participation in the POGIL intervention?
3. How do learners' attitudes towards science change (if at all) over the period of participation in the POGIL intervention?
4. What experience do learners value (if any) during their POGIL lessons?

The socio-cultural learning theory (Vygotsky, 1978) that recognises the social and personal aspect of learning provided the framework for the rationale of this study, by which these questions were explored. The socio-cultural learning theory is briefly described below.

1.9 Socio-cultural Theory

The socio-cultural learning theory as offered by Vygotsky (1978) views learning as a socially mediated process in which knowledge is acquired through collaboration with more knowledgeable others in the environment. Socio-cultural learning theory stresses that knowledge is constructed and developed, and cultural tools or artefacts are shared as individuals interact within a group (Wertsch, 2007). Thereby, the role of social interaction and mediating tools in the learning process are emphasised. In other words, learning is seen as a socially engaged process of collaboration and engagement. Within the socio-cultural framework, the concepts of social interaction, cultural tools, self-regulation, and zone of proximal development (ZPD) are explored in this study (Vygotsky, 1978).

The notion that learners' engagement and social interaction are central to meaningful learning indicate the suitability of the socio-cultural theory for this study. In the context of this study, the features of socio-cultural theory were explored in the intervention phase. Hence, this framework was adopted by means of which learners' evolving proficiency in stoichiometry and attitudes towards science in relation to participation in POGIL was explored.

1.10 Brief Definitions of Key Concepts

Attitudes towards science:	Attitude towards science is a favourable or unfavourable feeling which centres on one's evaluation of science.
Conceptual understanding:	A clear understanding of ideas or the principles and the ability to connect new ideas to existing ones as well as the retaining of new knowledge.
Inquiry-based learning:	A systematic learner-centred instructional strategy with emphasis on problem-solving, collaborative work, and critical thinking.
POGIL:	A teaching and learning philosophy or methodology which involves the key learning views of exploration, knowledge construction and application, integrated into the learning process to promote both content and skills acquisition.
Procedural fluency:	The knowledge and the ability to carry out procedures skilfully with a high degree of flexibility, in an accurate and efficient manner.

Proficiency:	Successful learning that connotes the ability to correctly navigate through a procedure and meet set goals of reasoning, connecting, and communicating ideas/concepts.
Socio-cultural theory:	The theory describes the fundamental role of social interaction in the learning process.
Stoichiometry:	Stoichiometry is an aspect of chemistry that involves the study of the amount of substance (reactants and products) involved in a reaction.
Strategic competence:	The ability to formulate, represent, and solve problems by representing it numerically, graphically, verbally, or symbolically.

1.11 Outline of the Study

This thesis consists of nine chapters.

Chapter one outlined the background/context of the study, the rationale, and significance of the study, the research goal, and questions, as well as a summary of the thesis chapters.

Chapter Two presents a review of the literature on stoichiometry, proficiency, and attitudes construct. Studies on POGIL and its various effects are also detailed.

In Chapter Three, Vygotsky's socio-cultural theory that informed this study is described. The relevance of this theory to this study is detailed.

Chapter Four discusses the research methodology of this study. It also outlines research issues relating to the ethics, validity, and reliability of the study.

In Chapter Five, the data generated and the results of analysis of the stoichiometry learning questionnaire (SLQ) in response to research question one are presented.

This is followed by the results and discussion of stoichiometry achievement test (SAT) and test of science related attitude questionnaires (TOSRA) in chapters six and seven, respectively. This is in response to research questions two and three correspondingly.

Chapter Eight presents the results and discussion to research question four which were generated from the semi-structured interviews and learners' journaling activity.

Chapter Nine contains the summary of the findings of this study, the conclusions drawn, new knowledge generated from this study, and limitations as well as recommendations arising from the findings that need to be addressed by future research.

1.12 Chapter Summary

In this chapter, I introduced the study, presenting the background, context, significance of the study, research goal, questions, and the outline of the whole thesis. The key concepts in this study were also briefly described. In the next chapter, literature related to this study is reviewed.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

> *Inquiry-based learning allows learners to develop key scientific ideas through learning how to investigate and build their knowledge and understanding of the world by using skills employed by scientists such as raising questions, collecting data, reasoning and reviewing evidences in the light of what is already known, drawing conclusions and discussing results.* (Ramnarain, 2021, p. 1)

2.1 Introduction

In this chapter, the review of the literature that informs this study is detailed. Firstly, I explore the concept of stoichiometry as a fundamental chemistry topic and as it relates to senior secondary school learners. Following this, I present literature on learners' proficiency, detailing the proficiency strands explored in this study. Next, I discuss the studies pertaining to learners' attitudes towards learning science, and the key constructs of attitudes relevant to this study. Lastly, the POGIL instructional strategy and various studies on it are discussed.

2.2 Stoichiometry

Stoichiometry is an important component of chemistry that involves the study of the amount of substance (reactants and products) involved in a reaction (Furio et al., 2002). It is a mathematical concept that is used to determine how much product will be produced or formed from a given quantity of reactants (Gallaher & Ingram, 2011). Reactants are substances that entered and are altered in the course of chemical reactions to produce another substance called the product. For example, sodium hydroxide and hydrochloric acid react to produce sodium chloride and water (the products from the two reactants):

$$NaOH\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$$

Stoichiometry involves problem-solving using a balanced chemical equation, ratio, or proportion (Furio et al., 2002; Gallaher & Ingram, 2011). For example, the above equation is balanced since there is the same number of atoms on the reactant and product sides. It is a central chemistry concept that is widely used in calculations in general and physical chemistry

(Schmidt-Rohr, 2020). As a result, if learners do not understand stoichiometry, the value and intellectual competence in chemistry cannot be achieved (Furio et al., 2002; Paideya, 2010; Schmidt-Rohr, 2020). For instance, Schmidt-Rohr (2020) points out that stoichiometric concepts are required throughout chemistry – in equilibrium calculations, general chemistry, and many quantities in physical chemistry.

Sub-topics covered under the stoichiometry concept include mass-mole, balancing of chemical equations, relative atomic mass, chemical formulae, reacting masses, reactions involving gases among others (Gallaher & Ingram, 2011; Sen et al., 2016). Unless these basic topics and their applications are well understood, related topics such as electrochemistry, acids and bases, chemical equilibrium and so forth, become arduous for the learner (Okanlawon, 2010; Schmidt-Rohr, 2020). In resonance with Sirhan (2007) who asserts that fragments of ideas either strengthen or act as barriers for further learning, learners' competency in stoichiometry can either reinforce or deter the understanding of related concepts and chemistry as a whole.

As alluded to in the previous chapter (Section 1.5), stoichiometry is considered one of the most difficult chemistry concepts to master. For instance, Uchegbu, Oguoma, Elenwoke, and Ogbuagu (2016) investigated the difficult chemistry topics among Senior Secondary School Two (SSS 2[2]) learners in Nigeria. Most of the learners identified stoichiometry units such as mass-volume relationships, chemical symbols, formulae and equation and chemical reaction amongst others as difficult chemistry topics (Uchegbu et al., 2016). Their findings corroborated that of Chandrasegaran, Treagust, Waldrip, and Chandrasegaran (2009) that stoichiometry concepts are among the top listed difficult chemistry concepts. Learners demonstrate difficulty in stoichiometry in several ways such as decreasing interest in class participation when stoichiometry topics are introduced, poor achievement in test/external examinations, reduced time on task or activities and poor attitudes towards the subject or science generally (Barthlow, 2011; Dahsah & Kruatong, 2010; Uchegbu et al., 2016).

Furio et al. (2002), in their study conducted in Spain, found that learners encounter great difficulty in calculating the amount of substance and moles in stoichiometry problems. A similar view is expressed in Boujaoude and Barakat's (2003) report on Lebanese learners that incorrect procedures are used by learners in solving mole, volume, mass and molar quantities

[2] SSS 2 learners are learners in the senior secondary school year two. SSS 2 learners have one year left for the completion of the three years of senior secondary school education before they can proceed to tertiary institution.

problems in stoichiometry. These authors confirm that learners do not have accurate understanding of the mole concept, limiting reagent, and balancing of chemical equations.

In addition, Fach, DeBoer, and Parchmann (2007) conducted a study in Germany to evaluate the effectiveness of specific teaching and learning materials to assist learners in solving stoichiometry problems. The findings from their study revealed that learners do not understand the definition and relationship between stoichiometry entities and, consequently, learners find it challenging to apply the appropriate strategies or procedures for solving stoichiometry problems (Fach et al., 2007). Likewise, in Nigeria, the WAEC (2018) chief examiner's report on chemistry affirms that learners perform poorly in stoichiometry questions or related concepts which consequently affects their performance in chemistry generally.

Similarly, Opara's (2014) study conducted in Nigeria on learners' performance in stoichiometry reports that a lack of problem-solving skills has persistently resulted in learners' poor performance in stoichiometry and chemistry as a whole. The author concludes that engaging learners in collaborative learning significantly enhances their performance in stoichiometry compared to their peers taught through the lecture method. She advocates for implementation of collaborative learning in Nigerian science classrooms as an instructional strategy that can promote proficiency and achievement in science. Correspondingly, the socio-cultural theory emphasises the importance of collaboration amongst learners or learners and teachers in the learning process as the means of constructing meaningful knowledge (Shabani, 2016; Wertsch, 2007). From the socio-cultural theory perspective, collaborative learning encourages give and take while meanings are negotiated, and knowledge built as a group – this process promotes meaningful learning (Shabani, 2016).

Various factors are recognised as having contributed to learners' difficulty in learning stoichiometry. For instance, Omwirhiren (2015) states that the cause of the persistent poor performance of learners in chemistry amongst other factors is the lecture method adopted by chemistry teachers. The instructional strategies in Nigerian secondary school science classrooms are mainly driven by the 'chalk and talk' method, whereby teachers serve as the main channel of knowledge that is transferred to the passive learners with no input or critical thinking from the learners (Omwirhiren, 2015; Opara, 2014). The emphasis on the coverage of content in the school syllabus and traditional approach to teaching chemistry has resulted in learners learning chemistry without meaningful understanding, gaining just enough information to pass examination (Omwirhiren, 2015). Concurrently, Uchegbu et al. (2016) in their study report that learners usually perceive chemistry topics such as stoichiometry as difficult because of the inappropriate teaching methods and lack of utilisation of instructional materials or hands-on practical activities. For instance, Asheela, Ngcoza, and Sewry (2020) in their study argue that hands-on practical activities play an important role in the science classroom in bridging the gap between school science and the community. These scholars encourage the use of easily accessible resources to reinforce conceptual learning and help learners find relevance between scientific concepts and their immediate environment (Asheela et al., 2020).

Furthermore, Omwirhiren (2015) maintains that some learners understand some specific individual concepts under stoichiometry, but cannot integrate the different concepts, synthesise information, and solve problems when the need arises. As a result, learners are not proficient because of their tendency to learn by rote instead of connecting concepts (Opara, 2014). Learners could memorise the process to solve a particular problem, but when the variables are changed, they become confused and cannot proceed further. Yet, meaningful learning of concepts occurs when learners comprehend concepts and have the ability to connect to previous knowledge as well as adjusting according to situations (Omwirhiren, 2015). Meaningful learning subsequently increases learners' proficiency which helps learners in solving problems and related tasks (Omwirhiren, 2015; Opara, 2014). Learners who are proficient in mathematics problem solving might find it easy to solve stoichiometry problems in chemistry (Opara, 2014).

The importance of mathematics in understanding science has long been recognised globally (Menis & Fraser, 1992; Ajao & Awogbemi, 2012; De Berg, 2012). Mathematics has been identified as a gatekeeper that prevents learners from enrolling in certain Science, Technology, Engineering and Mathematics (STEM) related courses such as chemistry. Some learners come into the chemistry class without the requisite mathematics skills (De Berg, 2012; Preininger, 2017). For example, Preininger (2017) asserts that some of the basic mathematics skills used in calculations such as proportions, logarithms, measurements, graphing, and others must be successfully transferred to solve chemistry problems in the chemistry classroom. Learners' knowledge of basic mathematical concepts is applied to the real-world situation in the chemistry class (Preininger, 2017).

Many studies report the positive and high correlation between learners' proficiency in chemistry and mathematics (Ajao & Awogbemi, 2012; De Berg, 2012; Kaundjwa, 2015; Preininger, 2017). Ajao and Awogbemi (2012) assert that learners who find mathematics easy, tend to develop a positive attitude towards learning chemistry and this correlates to increased proficiency in it. However, those who find mathematics difficult, choose not to do chemistry as they find chemistry concepts difficult to comprehend (Ajao & Awogbemi, 2012). Likewise, De Berg (2012) asserts that most learners detest science because of the mathematics involved.

In addition, fractions and algebra are among the most important yet most difficult topics that learners encounter in mathematics (Koopman, Thurlings, & Den Brok, 2019; Preininger, 2017). Koopman et al. (2019) state that many learners do not have the basic knowledge required to solve problems related to fractions and thus find it difficult to solve problems with improper fractions and mixed numbers. Coincidentally, solving stoichiometry problems requires these basic mathematics skills because it involves understanding and balancing equations using coefficients and relative ratio/proportions of chemicals in a reaction (Preininger, 2017).

Furthermore, Okanlawon (2010) suggests that learners' under-achievement in stoichiometry could be a result of the calculations involved, the balancing of chemical equations, and the interpretation of word problems into equations. He states that learners' proficiency in stoichiometry requires adequate problem-solving skills and retention of prior knowledge (Okanlawon, 2010). In agreement, Hanson (2016) avows that the persistent difficulty in solving stoichiometry problems is due to the inability to translate word problems to mathematical equations appropriately. She emphasises that basic mathematical computational skills should be taught and mastered by learners before the learning of stoichiometry (Hanson, 2016). Okanlawon (2010) and Hanson's (2016) views concur with the WAEC (2017) chief examiner's report that revealed that most learners find it difficult to extract and translate word problems to mathematical statements in solving stoichiometry questions.

In the USA, Preininger (2017) examined the effect of enriching chemistry with mathematics on learners' attitudes towards mathematics and science. She reports that learners' mathematical competency fosters their achievement in chemistry and future career selection, suggesting that learners' mathematical skills have a wide-ranging implication for increasing the number of science professionals in society. This author in her exploratory study advocates for embedding mathematics in the teaching of chemistry to influence learners' attitudes towards chemistry as well as proficiency in chemistry learning objectives (Preininger, 2017). In the next section, the concept of proficiency as it relates to this study is discussed.

2.3 Proficiency

The American Mathematics Assessment of Two-Year Colleges (AMATYC, 2018) defines proficiency as the ability of learners to:

- Know and execute procedures fluently;
- Demonstrate evidence of understanding of a concept;
- Make sense of and solve problems; and
- Defend their work and critique the work of others.

In other words, proficiency entails the ability to correctly navigate through a procedure and meet set goals by giving relevant details that demonstrate the understanding of concepts at focus (stoichiometry, in the case of this study) (AMATYC, 2018).

Kilpatrick, Swafford, and Findell (2001) in the National Research Council report simply define proficiency as a term that captures what it means for anyone to learn successfully. Proficiency could connote successful learning that involves reasoning, connecting, and communicating ideas/concepts to other related concepts (Kilpatrick et al., 2001). These authors describe proficiency in relation to mathematics as consisting of five interwoven strands which are:

i. "Conceptual understanding (CU); comprehension of mathematical concepts, operations, and relations;
ii. Procedural fluency (PF); skills in carrying out procedures accurately, flexibly, accurately and efficiently;
iii. Strategic competence (SC); ability to formulate, represent and solve mathematical problems;
iv. Adaptive reasoning (AR); capacity for logical thought, reflection, explanation, and justification; and
v. Productive disposition (PD); habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy" (Kilpatrick et al., 2001, p. 116).

Kilpatrick et al. (2001) further argue that these strands are interdependent, separate yet interwoven and, when developed over time, result in learners' progressive proficiency. These strands provide a framework for discussing the knowledge and skills that define proficiency; therefore, it is important to examine these five strands of proficiency as discussed below.

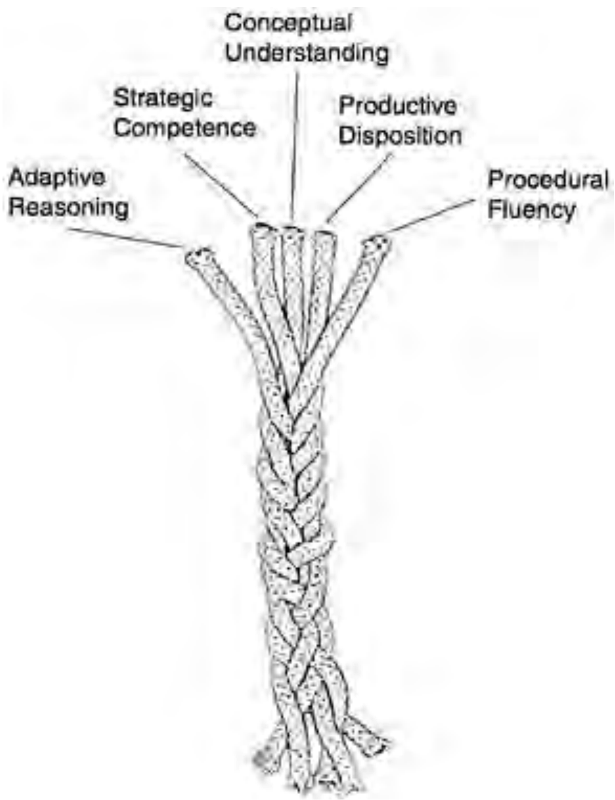


Figure 2.1: Intertwined strands of proficiency (Kilpatrick et al., 2001, p. 117)

2.3.1 Conceptual understanding

Konicek-Moran and Keeley (2015) define conceptual understanding (CU) as the ability to think and use a concept other than in areas in which it is learnt; represent or make comparisons to it; state it in one's own words and be able to build a mental or physical model of the concept. Similarly, Kilpatrick et al. (2001) refer to CU as learners having a functional grasp or understanding of ideas and recognising the context in which an idea would be useful. In the same vein, Schneider and Stern (2010) allude that conceptual knowledge represents a clear understanding of ideas or the principles that govern the domain under investigation and the ability to connect new ideas to existing ones as well as retaining the new knowledge. For Widiyatmoko and Shimizu (2018), CU is one of the basic competencies needed by learners for learning science successfully.

Konicek-Moran and Keeley (2015) describe CU using the illustration of baking a cake from scratch without any recipe and baking a cake from a packaged mix. Regarding baking of a cake from scratch, one must know all the ingredients required, the quantity of each ingredient that is required, how these ingredients react, and how these ingredients are mixed to get the perfect result. With this knowledge, one will be able to manipulate or adjust ingredients to make a variety of cakes. In contrast, baking using the packaged mix involves following the directions on the package without understanding what goes into making the cake and in what quantity. Thus, baking from scratch involves CU rather than just following a procedure without understanding (Konicek-Moran & Keeley, 2015).

A learner with CU in a domain of learning will be able to identify and justify the connections among concepts and procedures, as well as integrate, modify, and successfully apply the skill in related contexts to solve problems efficiently (Kilpatrick et al., 2001; Schneider & Stern, 2010). To illustrate, in the context of this study a learner with the CU of stoichiometry understands stoichiometry principles, can connect new stoichiometry entities to the existing concepts already acquired, and can identify which representations are best suited for a specific purpose in solving stoichiometry problems. Accordingly, Widiyatmoko and Shimizu (2018) explain that CU can be investigated by asking learners to distinguish between two similar concepts, explain a concept, label a diagram, or give an example. For example, learners with CU in stoichiometry should be able to distinguish between moles and mass and describe how they are related.

Dukerich (2015) posits that CU cannot be transferred from the teacher to the learners by mere explanation or watching the teacher solving problems on the board but must be learnt collaboratively to understand a phenomenon. Knowledge is thereby built through observation, analysis, and inferences among others, while the teacher provides direction for investigation of the phenomenon (Dukerich, 2015). Concurring, and extending on Vygotsky's (1978) seminal work, Widiyatmoko and Shimizu (2018) explain that meaningful learning occurs when learners construct knowledge, create new ideas from existing knowledge, or apply the new knowledge. This process, according to these scholars, requires CU rather than rote learning. From this viewpoint, CU is understood as a skill that occurs through social interactions among learners and the teacher (Widiyatmoko & Shimizu, 2018). This resonates with Vygotsky's (1978) socio-cultural learning theory underpinning this study that views learning as a social process.

Furthermore, Boujaoude and Barakat (2003) assert that conceptual understanding is the major determinant of positive problem-solving skills. Knowledge gained with adequate understanding provides the basis for generating new knowledge and solving new and unfamiliar problems (Kilpatrick et al., 2001). This suggests that an inadequate understanding of concepts impedes the problem-solving ability of the learner. Correspondingly, Kilpatrick et al. (2001, p. 381) point out that "conceptual thinkers were the more successful problem solvers".

2.3.2 Procedural fluency

Procedural fluency (PF) is described as the knowledge of procedures, and the ability to carry out procedures skilfully with a high degree of flexibility in an accurate and efficient manner (Kilpatrick et al., 2001; Suh, 2007). PF enables learners to deepen their understanding of concepts and identify relationships between concepts. A learner who demonstrates PF in stoichiometry would have knowledge of the appropriate procedure to draw from in solving stoichiometry problems. Additionally, such a learner would be able to draw from a wide variety of strategies should a particular approach not solve a given problem. It is recognised, however, that CU is necessary before PF (Azeem, Gondal, & Faisal, 2014; Suh, 2007).

Graven and Stott (2012), like the authors above, affirm that PF is an actual calculation technique that enables learners to solve problems by executing stepwise procedures, quickly and precisely. In essence, PF will grant the learner the ability to execute a series of action or calculation procedures in a certain sequence and in a skilful way to solve the problem. For example, a procedural fluent learner in stoichiometry will be able to execute the simple procedure of:

i. Writing a chemical equation and balancing it;
ii. Converting the known quantities to moles;
iii. Using the molar ratio from the balanced chemical equation to find the unknown number of moles; and lastly
iv. Converting the number of moles to the unknown quantity that is desired to solve the given problem.

Findings from research indicates that problem-solving in chemistry ranges from inadequate CU to PF (Boujaoude & Barakat, 2003; Denuga, 2019). Denuga (2019) points out that the challenge is most learners do not know when to apply a particular procedure which results in the incorrect application of rules in solving stoichiometry problems (Denuga, 2019).

However, problem solving is a function of adequate CU and PF (Boujaoude & Barakat, 2003; Graven & Stott, 2012). For instance, Boujaoude and Barakat (2003) reveal that learners who possess adequate understanding of the concept and application of PF are efficient problem solvers as they execute tasks in fewer steps/procedures and less time. Similarly, Graven and Stott (2012) assert that PF involves computing concepts practically, mentally, and procedurally which is manifested in using the most efficient method in solving a problem. These scholars aver that PF is not about answering questions correctly regardless of the method used to answer it. This contradicts the notion of efficiency and fluency. Rather, PF involves using the most efficient method in an accurate and fluent manner to achieve the result (Graven & Stott, 2012). In addition, Kilpatrick et al. (2001) argue that learners with insufficient procedural fluency will struggle in deepening their understanding of concepts and solving problems.

Toth and Sebestyen (2009) in their study conducted in Hungary examined the relationship between learners' knowledge and problem-solving procedures using a text containing stoichiometry problems. They confirm that learners' level of understanding corresponds to their problem-solving strategies (Toth & Sebestyen, 2009), although some other authors dispute this fact and report that learners can successfully solve problems algorithmically without understanding the underlying concept of the problem (Boujaoude & Barakat, 2003; Hanson, 2016; Okanlawon, 2010; Toth & Sebestyen, 2009).

Drawing from the views of the authors above, my view is that PF will enable the learner to quickly recall and correctly execute procedures. This suggests that learners will be experienced in integrating concepts and procedures as well as building on familiar procedures as they create their own informal strategies and procedures. In addition, learners will be able to justify their choice of appropriate procedures in solving problems or completing the task and thereupon strengthen their understanding and skills.

2.3.3 Strategic competence

Another key strand of proficiency identified by Kilpatrick et al. (2001) is strategic competence (SC). These scholars define SC as the ability to formulate, represent, and solve mathematical problems, often referred to as problem-solving skills. In other words, SC is the ability to know and employ strategies required to solve problems by representing them numerically, graphically, verbally, or symbolically (Suh & Seshaiyer, 2014). It seems this resonates more with stoichiometry problems which are predominantly word problems that require mathematical representations or writing and balancing chemical equations to solve the problems. Strategic competency in stoichiometry would mean that learners could identify, extract, and represent relevant data from the text given in order to analyse and solve stoichiometry problems correctly.

The example given below illustrates learners' strategic competency in solving a simple stoichiometry problem.

Problem: How many moles are in 92.2g of Fe?

Learners' first step would be to identify the key elements to the problem and represent the word problem given mathematically. This could be executed by creating symbolic representations to solve the problem.

Step 1: Given:	grams (**m**) of Fe
	92.2g of Fe
Known:	molar mass (**M**) of Fe
	Molar mass of Fe = 55.85g
Unknown:	moles (**n**)

Step 2: $n = \frac{m}{M}$ representing the problem with symbols and equation

Step 3: $\frac{92.2\cancel{g}}{55.85\cancel{g}/mol} = 1.65 \text{ mol}$

Answer = 1.65 moles are in 92.2g of Fe

As we can see from the example given above, a strategically competent learner would effectively recognise the given and unknown entities, formulate the connections between the entities using mathematical representation, and lastly, use the appropriate strategy to solve the problem. Strategically competent learners would know the different strategies as well as the most appropriate strategy to use to solve a particular problem (Suh & Seshaiyer, 2014).

To represent a problem accurately, learners should first understand the problem, identify its key features or elements, ignore irrelevant items given and then be able to generate mathematical representations that capture the key elements. An important characteristic of a proficient problem-solving learner is the ability to formulate mental representations of problems, identify relationships and devise a unique solution strategy accordingly – this is referred to as *flexibility* (Kilpatrick et al., 2001; Suh, 2007). Essentially, strategic competent individuals are flexible in their problem-solving processes and strategies (Suh & Seshaiyer, 2014). Groves (2012) asserts that learners must be fluent in procedural knowledge and have some degree of conceptual understanding to develop SC.

Kilpatrick et al. (2001) postulate that CU and PF form one's knowledge while SC and Adaptive Reasoning (AR) (see Section 2.3.4) are skills. They indicate that SC and both CU and PF have a shared relationship (Kilpatrick et al., 2001). The development of strategies for solving given problems depends on the understanding of the concepts/elements involved in the problem and their relationships; this also pivots on the fluency in solving the problem strategically (Kilpatrick et al., 2001; Sabilah, Siswono, & Masriyah, 2018). Sabilah et al. (2018) avow that strategically competent learners can select the most appropriate procedures from different strategies to solve a problem and forthwith develop their procedural fluency in the process. This is to say that as learners' CU deepens, their PF also increases, and SC comes into play at every step of their PF. In essence, conceptual understanding is a significant determinant of strategic competency. More so, learners' SC is observed when they start to replace cumbersome procedures (first adopted when understanding the procedure) with more concise and appropriate procedures (Suh & Seshaiyer, 2014). SC does not only point to learners' diverse strategies but also requires providing adequate time and space for learners to develop the skill (Suh & Seshaiyer, 2014). This affords the learners the opportunity to reason, argue, and justify their strategic thinking, which then develops into adaptive reasoning (Suh & Seshaiyer, 2014), the next strand to be discussed.

2.3.4 Adaptive reasoning

Adaptive reasoning (AR) is described as the "capacity to think logically about the relationships among concepts and situations" (Kilpatrick et al., 2001, p. 129). AR helps learners to work through concepts, procedures, and their proposed solution and to detect if they all fit together and make sense – it holds all elements of problem-solving skills together (Dhlamini & Luneta, 2016). According to Alexander, White, and Daugherty (1997), learners can demonstrate AR if the following conditions are present: learners have adequate knowledge, task is both clear and motivating, and the context is familiar. Learners' adaptive reasoning is evident in their ability to justify their completed tasks (Alexander et al., 1997). AR is developed through regular opportunities given to learners to discuss the concept and procedures used in solving problems or completing their tasks (Alexander et al., 1997; Kilpatrick et al., 2001). This process sharpens learners' reasoning skills and improves their conceptual understanding (Alexander et al., 1997; Kilpatrick et al., 2001).

Adaptive reasoning relates to the other strands of proficiency mentioned above: conceptual understanding, procedural fluency, and strategic competency. Learners' adaptive reasoning ability comes into play when they are determining the appropriateness of a procedure to solve a particular problem. In the process, they draw on their strategic competence to keep track of their progress in solving the problem and to plan an alternative if the current procedure is not efficient (Kilpatrick et al., 2001). To determine whether a solution to a problem can be justified, students need to have reasonable adaptive reasoning skills. In the same vein, if learners have adequate conceptual understanding of an area, they could explain the connection among concepts and procedures and thus justify their solution accordingly.

2.3.5 Productive disposition

Kilpatrick et al. (2001, p. 131) define productive disposition (PD) as: "The tendency to see sense in mathematics to perceive it as both useful and worthwhile, to believe that steady effort in learning mathematics pays off and to see oneself as an effective learner and doer of mathematics".

PD represents a habitual inclination to see learning (stoichiometry in this case) as useful and worthwhile coupled with one's efficacy and ability in solving related problems (Kilpatrick et al., 2001). As it relates to this study, PD thus describes the process of learners identifying and seeing the usefulness of stoichiometry, their passion, enthusiasm, and resilience for stoichiometry concepts as well as belief in their abilities in solving stoichiometry problems.

Kilpatrick et al. (2001) portray PD as a habit that can be learned, and thus it can be taught. They maintain that learners' PD develops when the other four strands (CU, PF, SC, and AR) develop – in turn, PD also helps each of the four strands to develop (Kilpatrick et al., 2001). If learners possess PD, it will mean that they believe that stoichiometry is not difficult, and that with diligent effort and resilience, stoichiometry concepts can be learned and used appropriately; thus, the other four strands of proficiency will be developed. Equally, as the four strands develop, PD also evolves, implying that, as learners' CU deepens and they build SC in solving stoichiometry problems, stoichiometry/science will make more sense to them. Thus, their attitudes towards science will become more positive as they see and believe in themselves as science learners.

In the same vein, when learners see themselves as capable science learners (PD), they are able to further develop their PF and AR because they are more confident in their abilities (Kilpatrick et al., 2001). A learners' disposition (also described as attitude) to science is a significant factor in determining their success in science (see Section 2.5). Additionally, Kilpatrick et al. (2001) and Sabilah et al. (2018) both agree that learners who view their problem-solving skills as changeable rather than fixed, are likely to embrace learning opportunities to develop their skills. This suggests that attitudes play a vital role in learners' developing proficiency.

All things considered, even though the five strands are interrelated, the focus of this study is on the first three strands of proficiency which are: CU, PF, and SC. This is because when these three strands are developed, they help the development of the other two: AR and PD (Kilpatrick et al., 2001). Moreover, Sabilah et al. (2018) assert that the emphasis should be on SC, as learners with strategic competence will indirectly master the other strands – CU and PF.

As discussed in the sections above, SC is supportive with CU and PF, therefore, in my view it would suffice to focus on the first three strands in defining proficiency. Notwithstanding, learners' productive disposition (attitudes) is assessed in the study using the Test of Science Related Attitude (TOSRA) questionnaire (see Section 4.5.2). Thus, for this study, learners' proficiency in stoichiometry is defined by:

- Learners' clear understanding of stoichiometry concepts and the relationship between concepts – conceptual understanding;
- Learners' fluency with procedures which includes building, modifying, and recognising appropriate procedures in solving stoichiometry problems – procedural fluency; and
- Leaners' ability to formulate and represent stoichiometry constructs numerically or graphically, to utilise various problem-solving strategies and to identify a unique strategy to solve stoichiometry problems – strategic competence.

A proficient learner in stoichiometry should be able to extract relevant information from a given text, identify connections between quantities, utilise symbols for representation, and identify and implement a potential strategy to solve the problem.

Researchers have identified that proficiency develops over time and increases as a product of coherent curriculum and instructional strategies (Azeem et al., 2014; Graven & Stott, 2012). Learners should be afforded a reasonable amount of time to engage in activities around specific concepts, developing understanding, solving different problems, and building connections for them to develop proficiency in it. Overall, proficiency, is an essential precursor of academic success (Mata, Monteiro, & Peixoto, 2012). Learners' development of proficiency in science content and practices is facilitated by affective dimensions such as attitude (Koballa & Glynn, 2007; Mata et al., 2012). Equally, Guido (2018) points out that one of the significant factors that affects learners' academic proficiency is their attitudes towards learning. Given the significance of the affective dimension for science learning, the next section will explore the concept of attitude towards science as an affective domain of science and its relationship to learners' academic success.

2.4 Attitudes Towards Science

Koballa and Glynn (2007, p. 78) define attitude as "a general and enduring positive or negative feeling about some person, object or issue". For Mata et al. (2012), it is a disposition towards a person/object that has been acquired by an individual through their beliefs and experiences which could be changed. A positive attitude reflects a positive emotional disposition in relation to the subject and in the same manner, a negative attitude relates to a negative emotional disposition (Mata et al., 2012). In a similar view, Romine, Sadler, and Wulff (2017) inform that attitude is in response to a person or object and can be seen as negative or positive. Romine et al. (2017) further delineate attitudes as values, beliefs, mental state, feelings, and predisposition to actions. Attitude towards science is considered as one of the most important affective concepts in science education (Romine et al., 2017).

In the literature, the attitude construct has been conceptualised in numerous ways. For instance, some studies define attitude as a cognitive domain while others classify it as an affective domain, some researchers even use it interchangeably (Aydeniz & Kotowski, 2014; Bae & Debusk-Lane, 2019; Osborne, Simon, & Tytler, 2009). Therefore, there is a need to clarify what attitude means in these two domains and how it relates to this study.

Osborne et al. (2009) provide a distinction between the cognitive domain of attitude and the affective domain. The authors argue that the cognitive domain involves the processing of information, construction of knowledge, and meaning while the affective domain involves emotion, feelings, and perceptions of a learning task. Osborne, Simon, and Collins (2003) following the description of Gardner, succinctly clarifies that 'attitude towards science' is an affective domain while scientific attitude defines the cognitive domain. Likewise, Aydeniz and

Kotowski (2014) assert that attitude towards science involves the evaluation of the domains of science learning such as motivation to learn science, perception of science, interest in science-related activities among others, while the evaluation of scientific meta-theory is what is called scientific attitudes.

Nonetheless, Koballa and Glynn (2007) affirm that learning in science depends on the integration of both the cognitive and affective domains. This current study aimed at looking at learners' feelings and views about science which the affective domain encapsulates. Thus, for the purpose of this study, the concept of 'attitude towards science', as seen in the affective domain, is used.

Attitude towards science is a favourable or unfavourable feeling which centres on one's evaluation of science (Osborne et al., 2009). It deals with emotions, feelings, values, and perception of learning and consequently helps learners in their approach to learning activities (Tytler & Osborne, 2012). The concept of 'attitude towards science' is multifaceted. Therefore, in the literature, attitude towards science is often used interchangeably or encompasses multiple sub-constructs such as interest in science, enjoyment of science, the value of science, perception of science, motivation, and other affective variables (Aydeniz & Kotowski, 2014; Osborne et al., 2003; Tytler & Osborne, 2012). These sub-constructs have been used to develop dimensionality of scales to measure the attitude construct in many studies (Aydeniz & Kotowski, 2014; Belge Can & Boz, 2012; Fraser, 1981; Osborne et al., 2003).

Numerous studies have employed these varying sub-constructs to assess attitude towards science. For instance, Ainley and Ainley (2011) assessed attitudes using the sub-constructs of interest, enjoyment, and value of science while Potvin and Hasni (2014) used the sub-constructs of interest and motivation to assess attitudes towards science. It seems that the various descriptions and uses of the term 'attitude towards science' have a common characteristic: attitude towards science is a subjective feeling towards or against science, it can be measured and evolves.

Therefore, in this study, the sub-constructs employed in measuring attitudes towards science are enjoyment of science, interest in science or science-related careers, and perception (value) of science. These three sub-constructs are selected from the 11 different constructs outlined by Osborne et al. (2003) in their review and are also represented in the test of science-related attitude (TOSRA) questionnaire to describe attitudes towards science (Fraser, 1981) used in this study.

2.4.1 Enjoyment of science

Fraser (1981) offers that learners' engagement in leisure-time activities that relate to science can be termed enjoyment of science. Hartley (2006) defines enjoyment as an emotional concept that describes what a person feels, not what they think. Correspondingly, Kaya and Ebenezer (2007) refer to enjoyment of science as the pleasure, confidence, and fulfilment that activities in science give to learners. This implies that learners enjoying science will have confidence in their abilities and positive views about science activities.

Moreover, Manasia (2015), in her exploratory study on the enjoyment of learning, offers that enjoyment is an intrinsic emotion that is linked with learner's motivation for learning, the learning process, and academic achievement. She points out that enjoyment can be synonymous with satisfaction or having fun, which is related to a context or a learning situation.

2.4.2 Interest in science

The second sub-construct of attitude explored in this study is interest in science. Wong (2016) defines interest as the feeling of wanting to know or learn something or someone. Learners' interest in science or science-related careers indicates a response of liking or disliking science activities or science careers (Hofstein & Mamlok-Naaman, 2011; Osborne et al., 2003). To Hidi and Reninger (2006, p. 111), interest is a "relatively enduring predisposition to re-engage particular content over time". Some other studies describe interest in science as curiosity, appreciation, and engagement in science and science-related activities (Hidi & Reninger, 2006; Romine et al., 2017). Hofstein and Mamlok-Naaman (2011) conclude that learners who have an interest in science are stimulated to engage more in science activities and consider pursuing science careers.

Furthermore, Romine et al. (2017) in their study on conceptualising student affect for science and technology in the middle school, explain that interest is of two main types: personal and situational interest. Personal interest, also known as individual interest, is an intrinsic and enduring feeling towards an activity or object, while situational interest depends on external factors and is short-lived (Romine et al., 2017). However, situational interest can be sustained through reoccurrence and persistence of meaningful tasks or activities that triggered it (Romine et al., 2017). The authors further argue that personal and situational interest are interrelated, for instance, a sustained situational interest can progress into a personal interest which can be facilitated by the instructional activities or the dynamics of the learning environment (Romine, et al., 2017). For Hidi and Reninger (2006), interest in science is a factor associated with continuing science learning and science career decisions.

In addition, enjoyment and interest are separate but complementary emotional sub-constructs (Karakolidis, Pitsia, & Emvalotis, 2019). Interest is one of the main factors that lead to enjoyment and, in turn, enjoyment determines one's effort devoted to certain activities of interest (Karakolidis et al., 2019). These two constructs are essential conditions for effective learning to occur (Hidi & Reninger, 2006; Karakolidis et al., 2019).

2.4.3 Perception of science

The perception of science is the third sub-construct of attitude towards science explored in this study. Perception of science is described as the awareness and the understanding of value of science in everyday life (Kaya & Ebenezer, 2007; Osborne et al., 2009). It refers to learners' views and thoughts about the complexity of science (Agunbiade et al., 2017). Putting it differently, Kurniawan, Astalini, Darmaji, Putri, Jannaha, and Puspitasari (2019) describe perception of science as the process by which learners' experiences of events in the learning environment are communicated into the brain as information (either 'good' or 'bad'). This information then forms their thought process about science learning (Kurniawan et al., 2019). These scholars avow that learners who have a positive perception of science will be more enthusiastic about science learning and activities and subsequently this influences their proficiency in science (Kurniawan et al., 2019).

As alluded to above, the affective domain of science plays an important role in the process of learning science. For instance, Koballa (2007, p. 4) informs that the "affective domain is not just a simple catalyst, but a necessary condition for learning to occur". There exists a connection between learners' affective domain and academic performance and one can potentially predict the future career preferences of learners once the affective domain is positively influenced (Aydeniz & Kotowski, 2014; Belge Can & Boz, 2012). Belge Can and Boz (2012) maintain that the affective domain of learning science is important and if ignored could have a significant effect on the cognitive domain.

Given these points, one can deduce that if learners are not motivated or interested in a particular subject or subject area, it could significantly affect their engagement and achievement in it. Many studies have reported the correlation between learners' affective domain such as attitude towards science and achievement in science (Juan et al., 2018; Knezek et al., 2013; Karakolidis et al. 2019; Koopman et al., 2019). This and other factors related to attitudes towards science are discussed below.

2.5 Studies on Attitudes Towards Science

In this section, firstly, the review of studies on learners' attitude towards science is presented. This is followed by the discussion on learners' attitude towards science and achievement in science. Lastly, other factors relating to attitude towards science relevant to this study is discussed. These are segmented into sub-sections as follows.

2.5.1 Learners' Attitude Towards Science

Learners' attitudes towards science have been declining over the years (Fulmer, Ma, & Liang, 2019; Juan et al., 2018). Studies have shown that learners who have positive attitudes towards science in the early years of education are more likely to enrol in science courses in tertiary institutions which would result in taking up science or science-related careers (Fulmer et al., 2019; Juan et al., 2018; Roberts et al., 2018). However, many learners before or in middle school have a fixed notion that science is too challenging, boring, and uninteresting (Agunbiade, 2015; Bae & DeBusk-Lane, 2019). This perception of science has influenced their attitudes towards it and their participation in science activities (Agunbiade, 2015; Fulmer et al., 2019; Roberts et al., 2018).

Some studies have identified that the critical period in which learners begin to develop their attitudes towards science occurs between the ages of 11 and 14 (Bae & DeBusk-Lane, 2019; Juan et al., 2018; Wong, 2016). According to Juan et al. (2018), attitudes towards science are formed early in life and may have an impact on an individual's relationship with science later in life. This shows the importance of understanding the way in which learners' attitudes towards science are shaped in the elementary or middle school years, so as to enhance science education in Nigeria.

2.5.2 Attitudes Towards Science and Achievement in Science

The literature variously reports that learners' positive attitudes towards science have a significant effect on learners' achievement in science and vice versa (Hofstein & Mamlok-Naaman; Knezek et al., 2013; Koopman et al., 2019; Wong, 2016). Other studies suggest that learners' achievement scores provide an understanding of their proficiency in the subject (Fulmer et al., 2019; Juan et al., 2018; Koopman et al., 2019). Although the aim of this study is not to outline a causal web consisting of these factors, some potential connections between science achievements, attitudes towards science, and proficiency are outlined based on previous studies and explored.

Weinburg (1995) conducted a meta-analysis study on the correlation between the cognitive and affective domain of science learning. He found that learners who have higher scores in attitudes also have increased achievement in science. For Weinburg, the affective domain correlates with the cognitive domain of science and that one must not be considered to the exclusion of the other (Weinburg, 1995). His findings suggest that a positive attitude towards science is a precursor to learners' achievement in science.

Pierre and Oughton (2007) share a similar view and they argue that the cognitive and affective domain of learning science complement and are dependent on each other. Developing a positive attitude towards learning science is important for achievement and consequently, interest in enrolment in science-related careers (Karakolidis et al., 2019; Knezek et al., 2013; Noam & Shah, 2013; Pierre & Oughton, 2007). It seems Pierre and Oughton's (2007) findings resonate with the findings of other research (Karakolidis et al., 2019; Knezek et al., 2013; Noam & Shah, 2013; Park et al., 2009). An example is, Park, Khan, and Petrina's (2009) quasi-experimental study of achievement, attitude towards science, and career aspiration of middle school learners in Korea. Park et al.'s (2009) results indicate that an improvement in learners' achievement significantly influences their attitudes towards science, future course selection, and career aspirations in science. Learners' attitudes towards science appears to be positively influenced when learners do better in science or vice versa (Park et al., 2009).

Similarly, a study on the relationship between Turkish learners' attitudes towards science and their science achievement proved to be correlated (Akpinar, Yildiz, Tatar, & Ergin, 2009). In another study, Welch (2010) asserts that a promising way to promote learners' long-term achievement in science is to emphasise the development of a positive attitude towards learning it. Some other studies (Agunbiade, 2015; Bybee & McCrae, 2011; Gongden et al., 2011; Omwirhiren, 2015; Uce, 2009) indicate that lack of proper understanding of fundamental science concepts (such as stoichiometry in chemistry), could deter learners in the early stage of the learning process and consequently they could develop poor attitudes and achievement in it.

If learners' achievement in science is very poor, the likelihood of taking up a science or science related career in the future decreases as learners see themselves as incompetent science learners (Grabau & Ma, 2017; Ito & McPherson, 2018; Tripney, Newman, Bangpan, Niza, Macintosh, & Sinclair, 2010). In contrast, Tripney et al. (2010) accentuate that learners with higher levels of attainment in science, measured by the examination grades, are more likely to choose science courses. A similar viewpoint from Ito and McPherson (2018) is that higher grades in Science Technology, Engineering and Mathematics (STEM) courses is associated with the sense of fit into STEM fields. However, learners' perception of sciences as requiring exceptional intelligence and perseverance, result in eliminating science career choices or lowers the interest in science for learners who assume their intelligence is inadequate (Ito & McPherson, 2018).

Furthermore, Karakolidis et al. (2019) allude that enjoyment of, and interest in science lessons are positively related to learners' achievement in science and these have been important markers of learners' trajectories in science. Many learners are not interested in studying science or science-related courses in post-compulsory education mainly because their performance in science is very poor and there are alternative studies or career choices they could pursue (Karakolidis et al., 2019; Wong, 2016). Nonetheless, DeWitt et al. (2019) enlighten that, while poor performance in science can inhibit learners from further enrolment in science, their achievement per se may not hinder the development of a positive attitude towards science.

Grabau and Ma (2017) explored the role of enjoyment of science and interest in science in predicting learners' science achievement in the USA. It was found that learners with these two attributes have high achievement in science (Grabau & Ma, 2017). Some other studies also suggest that enjoyment of and interest in science are strongly associated with science achievement and even broader academic achievement (Bae & DeBusk-Lane, 2019; Hofstein & Mamlok, 2011; Ozel, Caglak, & Erdogan, 2013). These studies, which examined the sub-constructs of enjoyment and interest in science, resonate with the focus of this study in which learners' enjoyment, interest, and perception of science are explored as they participate in a POGIL science classroom.

A similar claim by Gardner (2006), is that the combination of both internal (attitudes) and external forces such as learning environment and family influence drives an individual in the learning process. Numerous research findings confirm that the intrinsic factor (attitude towards science) is the driving force behind engagement and better learning outcomes in science (Ainley & Ainley, 2011; Bybee & McCrae, 2011; Karakolidis et al., 2019; Roberts et al., 2018; Wong, 2016). Learners who have positive attitudes towards science are likely to learn faster and achieve better in science (Gardner, 2006).

Conversely, some other studies inform that there is no causal relationship between attitude towards science and achievement in science (Bae & Debusk-Lane, 2019; Geesa, Izci, Song, & Chen 2019; Osborne et al., 2003; Wong, 2016). Osborne et al. (2003) argue against attributing learners' achievement in science to their attitude towards science. They claim that learners could be successful in science without having a positive attitude in science. For Osborne et al. (2003), learners' self-efficacy is a better predictor of their achievement in science than attitude alone, although Brown et al. (2016) offer a contrasting opinion, that even more than self-efficacy learners' attitude towards science is a more significant component in improving learners' achievement in science as well as inspiring them to continue in science learning.

To corroborate this view, Wong (2016) gives detailed characteristics of science learners as follows: *Science adverse* learners are learners with no positive attitudes or aspirations towards science and usually do poorly in science. *Science intermediate* learners have some positive attitudes towards science with average achievement in it. The *science intrinsic* learners have very high positive attitudes towards science but their achievement in science is poor while the *science prominent* learners are high science achievers as well as having a high level of attitude and aspiration towards science (Wong, 2016).

Wong's (2016) explanation suggests that the relationship between science achievement and attitude towards science remains ambiguous, as learners with less positive attitudes towards science could achieve good results. Learners who experience high levels of externally imposed goals or other extrinsic factors (for example, future employment or value of having a career in science or related fields, learners' socio-economic class, family among others) could have high achievement in science but poor attitudes towards science (Ainley & Ainley, 2011; Bae & DeBusk-Lane, 2019; Juan et al., 2018; Wong, 2016). The influence of the affective domain, specifically learners' attitudes towards science, appears significant even though there could be some other factors that affect their achievement in science.

2.5.3 Other Factors Influencing Learners ‘Attitude Towards Science

In the literature, some other factors have been identified as having an influence on learners' attitudes towards science. Learners' perceived difficulty with science affects their attitudes towards it (Agunbiade, 2015; Papanastasiou & Zembylas, 2004; Tripney et al., 2010). Agunbiade (2015) explains that learners with a negative perception of science – who indicate science as a difficult subject to comprehend – would likely not consider further study or career options related to science. Learners' attitudes toward science can distort their perception of science information and the degree of its retention (Agunbiade et al., 2017; Papanastasiou & Zembylas, 2004). Once learners have the notion that science is difficult and they cannot be successful in it, they put less effort into learning science and eventually perform poorly which then confirms their belief. This confirmation further increases their poor attitude towards science (Agunbiade, 2015).

In addition, it has been reported that many learners are not putting in the effort to be successful in chemistry as some of them believe that chemistry is too difficult to understand (Denuga, 2019; Kaundjwa, 2015). Some teachers observe a decline in learners' engagement and underachievement in chemistry especially after stoichiometry is introduced (Denuga, 2019; Kaundjwa, 2015). At this point, when learners lose focus, their understanding of concepts is diminished and their grades in chemistry begin to drop (Kaundjwa, 2015; Papanastasiou & Zembylas, 2004). This could subsequently discourage learners from considering science or related fields at their next level of education. Sharing similar sentiment, Juan et al. (2018) enlighten that learners' continuing engagement with and enrolment in science is influenced by whether they enjoy science, their perception of science, and their proficiency in it. Concisely, Koballa and Glynn (2007) remark that attitude is viewed as both the facilitators for and the product of science learning.

Mujtaba et al. (2018) inform us that family encouragement and science teaching approaches have an influence on learners' attitudes to science. Learners who receive support from their parents or siblings with regards to science learning, tend to develop a positive attitude towards science (Mujtaba et al., 2018). They affirm that the use of interactive activities has an influence on learners' enjoyment and interest in science. Agunbiade et al. (2017) concur, emphasising that learners find creative and interactive science lessons fun, and hence they develop a positive attitude towards science. Correspondingly, Brown et al. (2016) in their study explored the relationship between the STEM curricula and attitudes towards science, and they report that learners develop self-interest in science when they are continuously exposed to a positive science experience and hence develop a positive attitude towards science.

More so, other factors such as, gender, family influence, teacher effectiveness, commitment to teaching, and interaction with learners could be a contributor to learners' attitudes towards science (Bybee & McCrae, 2011; Kobiatko, Torkar, & Rovnanova, 2017; Raved & Assaraf, 2011). Kobiatko et al.'s (2017) study in Slovakia report that a teacher's personality is a significant factor that influences learners' attitudes towards biology as a school subject. Likewise, Raved and Assaraf (2011) explicate that learners' attitudes towards science are influenced by many factors, including teacher-learner interaction, diversity of teaching strategies, and relevance of the topics taught to learners' immediate environment. Having parents that are in science fields could also influence a learner's attitude towards science (Preininger, 2017).

Bybee and McCrae (2011) add that a learner's attitude towards science is influenced by their perception of how science is related to their lives and immediate environment. Lending support, Roberts et al. (2018) enlighten that the academic and social experiences of learners are also important factors that influence their attitudes towards science. More specifically, learners' attitudes toward science could be influenced by their peers, as the desire to fit in is paramount to learners at this early stage (Roberts et al., 2018). This resonates with Vygotsky's (1978) socio-cultural theory that emphasises working in collaboration with others in order to gain competency.

2.5.4 Learners' Attitude Towards Science and Proficiency

Among other variables outlined in the literature, learners' attitude is regarded as a key factor in explaining variability in learners' proficiency (Koopman et al., 2019; Lee & Lo, 2017). Learners' attitude towards a particular subject is considered as one of the key factors in motivating learners to learn and attain proficiency in the subject (Koopman et al., 2019). It seems that learners with a positive attitude towards science might be more involved in science activities and might try to engage more in strategies that will help them to deal with their difficulties and in the process to attain proficiency.

Sadi and Cakiroglu's (2015) study on science achievement informs that proficiency in science contributes to learners' achievement in it. In another study, Lee and Lo (2017) investigated the relationship between learners' attitude and proficiency. The authors aver that learners' proficiency level is a factor in the variation of learners' attitudes. Hence, hypothetically, learners with a lower level of proficiency may have a less positive attitude towards science and vice-versa. Likewise, Molla and Muche (2018) explored learners' proficiency in biology by examining the difference in learners' achievement in biology before and after the study. They indicate that learners' proficiency in science is a predictor of their achievement in it and learners' proficiency could be assessed by their achievement. Many recent studies also share similar views and report that learners' attitudes in science enhance learners' proficiency in science and learners' proficiency in science is a better predictor of their achievement in it as well as an important factor in their career choice (Ganeb & Montebo, 2018; Mujtaba et al., 2018; Vincent-Ruz & Schunn, 2017).

Furthermore, Koopman et al. (2019) investigated the factors influencing learners' proficiency development and revealed that teaching quality, as well as the degree of learners' participation in their lesson, influences learners' proficiency development. This corresponds with Cocca and Cocca's (2019) view that creating and enriching the learning experience for learners, specifically learner-centred teaching strategies, could have a more significant impact on their proficiency than any other variable. More so, learners' classroom experience and the teaching approaches of science teachers have been found to influence learners' attitudes and achievement in science (Agunbiade et al., 2017; Mujtaba et al., 2018). This suggests that teaching strategies and interventions that may positively influence learners' attitudes towards science and development of proficiency are an imperative.

Koopman et al. (2019) and Cocca and Cocca's (2019) argument on how learners' proficiency and attitudes are developed as they participate in an interactive and creative educational setting harmonises with the Vygotsky socio-cultural learning theory informing this study. The socio-cultural theory views an individual's knowledge and 'way of being' to be changeable as they interact with other members in the environment. This suggests that the social influence of others in a learning environment also affects one's attitude and proficiency.

The traditional teaching methods in science classrooms do not meet learners' needs (Agunbiade et al., 2017; Opara, 2014). Hence, science education studies have shown the need for an active learner-centred pedagogy that engages learners, encourages collaboration with peers, and enhances performance (Agunbiade et al., 2017; Eberlein et al., 2008). Learners' active participation in the learning process, as well as the use of instructional strategies that emphasise the teaching of process skills and learner-centred inquiry-based instruction, has been highly recommended (Brown et al., 2016; Hanson, 2006; Nhase, 2019; Otor, 2013). Strategies such as interactive classes, problem-solving, collaborative groups among others that strengthen teaching and learning processes, need to be adopted to enable comprehension and resolve the perceived abstractness of science (Agunbiade et al., 2017; Mujtaba et al., 2018; Hanson, 2014; Sen et al., 2016).

More recently, strategies that would facilitate a shift from passive to active learners, such as inquiry-based, learner-centred instructional strategies have been investigated (Brown et al., 2016; Gongden et al., 2011; Granger et al., 2012; Nhase, 2019; Otor, 2013). Otor (2013) states that science teachers should be knowledge builders and not knowledge providers. Sirhan (2007) suggests that opportunities to engage with instruction and to construct, analyse, and share knowledge should be given to learners as this allows the bringing together of conceptual understanding in a meaningful way. He asserts that this ensures active learning and a chance for a real understanding of concepts to be developed. This relates with the socio-cultural learning theory that highlights that learning is a process in which a learner constructs knowledge from pre-existing ideas but not from mere transmission of knowledge (Vygotsky, 1978). Likewise, Gongden et al. (2011) affirm that learners learn best when they are actively engaged in a task towards the learning outcome rather than just sitting and hearing about it. Thus, encouraging positive classroom interactions for all learners is critical for increasing learners' proficiency.

Furthermore, Nafees, Farooq, Tahirkheli, and Akhtar (2012) claim that learners that are taught science via the inquiry instructional method have increased recall abilities which translates to increased performance in science. Their study reports that inquiry-based learning increased understanding of concepts which translated to improved performance in science compared with the lecture-based classroom (Nafees et al., 2012). Also, Mujtaba et al. (2018) enlighten that inquiry-based teaching and learning approaches engage learners to apply scientific methods in their learning process more, rather than focusing on teachers to disseminate knowledge.

In agreement with these authors, Nhase (2019) highlights the active engagement of learners in an inquiry-based science classroom. The author found that learners developed basic scientific process skills while participating in an inquiry-based science lesson. Some other studies support this notion that inquiry-based learning is associated with higher achievement in science and with improving learners' intrinsic domain of learning (attitude) (Brown et al., 2016;

Kaundjwa, 2015; Mujtaba et al., 2018; Sen et al., 2016). Thus, it would be beneficial to explore how an inquiry-based teaching approach could influence learners' proficiency and attitudes towards science.

Hanson (2006) defines inquiry-based learning as a systematic instructional strategy where learners are given tasks that develop their thinking skills. Likewise, Ramnarain (2021, p. 2), states that inquiry-based learning, "allows learners to develop key scientific ideas through learning how to investigate and build their knowledge and understanding of the world". Inquiry-based learning enables learners to explore ideas or analyse information, develop understanding, and make an argument to support their interpretation of the concept presented using scientific skills (Pedretti, 2010; Ramnarain, 2021). As alluded to in the epigrapgh, it equips learners to investigate and generate concepts in the learning community (classroom) (Ramnarain, 2021). With inquiry-based learning, the prevailing teacher-centred classroom is redefined thereby shifting the communication pattern to being learner-centred (Nhase, 2019; Ramnarain, 2021).

Therefore, inquiry-based learning is described as learner-centred, with emphasis on problem-solving, collaborative work and critical thinking, which is fundamental to the development of scientific knowledge, its application, as well as higher-order thinking skills (Bada, 2015; Hanson, 2006; Nhase, 2019). The inquiry method of learning is proposed to bring the abstract nature of chemistry to an understandable level for learners (Bada, 2015; Barthlow & Watson, 2014). In support, Nhase (2019) remarks that the science curriculum should be based on engaging inquiry approach to learning as opposed to the lecture method which leads to rote learning. She argues that learners in an inquiry-based classroom take ownership and learning is more productive than the traditional classroom (Nhase, 2019). Science should not be taught as a subject with facts to be memorised but rather as a process way of thinking (NRC, 2000).

Pedretti (2010) describes four types of inquiry-based learning approaches. Confirmation inquiry is when learners engage in experimental activities and obtain predictable results in order to confirm a principle. The second type is the structured inquiry wherein learners are given questions and the procedures to investigate a concept. Guided inquiry is the third type where learners are presented with questions and guided towards procedures for investigation to reach a conclusion. The fourth type of inquiry involves learners themselves choosing and investigating different topics. This type of inquiry is considered unsuitable for classroom learning (Pedretti, 2010).

Martin-Hansen (2002) further enlightens that guided-inquiry learning is differentiated from other types of inquiry such as open and directed inquiry. He explains that in guided-inquiry learning, learners interact with each other, and are given the opportunity to pose questions and clarify questions with minimal interference from the teacher who is the facilitator of the learning process. All these aspects are encapsulated in Process Oriented Guided Inquiry Learning (POGIL) (Barthlow & Watson, 2014; Hanson, 2006). This underscores the aim of this study, the focus being on exploring learners' evolving proficiency in stoichiometry and their attitudes towards science as they participate in a guided-inquiry learning approach (POGIL). The overarching philosophy of POGIL is a learner-centred approach in alignment with the socio-cultural view of learning (Hanson, 2006).

2.6 Process Oriented Guided Inquiry Learning (POGIL)

Hanson (2006) defines Process Oriented Guided Inquiry Learning (POGIL) as a teaching and learning philosophy and methodology encompassing ideas and structures about the learning process. He expounds that the POGIL process leads to an expected learning outcome. It involves the key learning views of knowledge construction and application, exploration, experiences, discussion, interaction, and reflection, all integrated into the learning process to promote both content and skills acquisition (Hanson, 2006; Moog & Spencer, 2008). POGIL was designed on the following seven learning process skills to promote mastery of content and development of skills:

i. "Working collaboratively in a group (learning teams);
ii. Guide inquiry activities within the group;
iii. Critical and analytical thinking;
iv. Developing problem-solving skills;
v. Drawing conclusion from data analysis and reporting;
vi. Meta-cognitive activities; and
vii. Individual responsibilities: application and assessment of knowledge gained" (Hanson, 2006, p. 3).

POGIL entails learners taking an active role in learning subject content, interacting with peers in small groups (called the learning teams), and using scripted inquiry activities collaboratively to construct their own knowledge while the teacher assumes the role of a facilitator (Eberlein et al., 2008; Hanson, 2006; Moog & Spencer, 2008). In the teams, members take up roles such as manager, recorder, or spokesperson to facilitate productive participation and interaction in the teams, and the roles are rotated in every session (Farrell, Moog, & Spencer, 1999; Hanson, 2006). The learning team gives opportunity for discussion among members, responding to critical thinking questions, application of new knowledge, developing positive relationships with others, reflection, and assessment of performance (Eberlein et al., 2008; Hanson, 2006).

Correspondingly, Molla and Muche (2018) elucidate that small group learning is a pedagogical practice that helps learners to gain in both academic and social relationships as well as to accomplish shared goals. In the same vein, Kilpatrick et al. (2001) argue that learning in a small group provides learners with the opportunity to discuss ideas, make inferences, construct new understanding, identify effective and ineffective problem-solving strategies, as well as give explanations for their reasoning. This guided-inquiry group discussion builds learners' proficiency and consolidates their learning of key concepts (Kilpatrick et al., 2001; Molla & Muche, 2018).

POGIL provides the teacher with the tools to optimise learning as well as allowing learners to take greater responsibility for their learning (Sen et al., 2016). It is built on the notion that learners learn best when they are:

- "Actively engaged and thinking in the classroom;
- Drawing a conclusion by analysing data, models or examples and by discussing ideas;
- Working together in self-managed teams to understand concepts and solve problems;
- Reflecting on what has been learned and improving on performance; and
- Interacting with the instructor as a facilitator of learning" (Hanson, 2006, p. 3).

The POGIL strategy involves learning activities that were developed from the learning cycle model (Hanson, 2006). The learning cycle is a model of instruction based on the work of Piaget which encourages learners to develop their own understanding of a concept, explore, and deepen their understanding and be able to apply the concept to new situations. The learning cycle consists of three phases: exploration, concept invention or formation, and application. These phases are fundamental to constructivist theories and are actualised in POGIL (Eberlein et al., 2013; Hanson, 2006; Moog, Creagan, Hanson, Spencer, & Straumanis, 2006).

2.6.1 POGIL exploration stage

The first stage of the POGIL learning cycle is the exploration stage. In this stage, learners are afforded the opportunity to: analyse data; explore and generate information from graphs; make observations; explore diagrams and/or instructions from a worksheet; do laboratory experiments, among others. These activities will guide them to develop understanding of concepts to be learned and ultimately lead to achieving the learning objectives (Arthur & Kreager, 2017; Hanson, 2006). Learners can propose and test a hypothesis in an attempt to explain or understand the exploration presented to them. The aim of the exploration phase is to allow the learners to engage in critical thinking and questioning in an attempt to explain or understand the information that has been presented to them (Arthur & Kreager, 2017; Moog et al., 2006). This phase creates a foundation for the rest of the process (Arthur & Kreager, 2017). Critical thinking involves the identification of key issues, relationships, asking questions as well as developing answers to the questions (Hanson, 2006). A critical and analytical thinking teaching strategy encourages the development of process skills (Hanson, 2006).

Two key aspects must be present in the exploration phase. Firstly, the teacher must provide the appropriate information to learners so as to develop the desired concepts and avoid misconceptions Secondly, a carefully constructed sequence of guided questions must be provided to enable the learners to reach the appropriate conclusion to the phenomenon under investigation (Eberlein et al., 2008; Moog, et al., 2006). Often, teachers begin the exploration phase with a short quiz or an activity from previous lessons which could lead to deduction and prerequisite knowledge for the current lesson (Eberlein et al., 2008; Farrell et al., 1999). Similarly, Juan et al. (2018) avow that positive teacher-guided instruction often includes modelling a variety of examples and guiding principles, for learners to have a clear understanding of how a task should be completed. If this is not done, learners' efforts to complete a task might be ineffective for the learning process.

2.6.2 POGIL concept formation/invention stage

The exploration phase is followed by concept invention or formation. Learners can be guided to make discoveries and draw conclusions from a concept explored but not explicitly known or introduced. This is known as concept invention (Farrell et al., 1999; Hanson, 2006). Concept formation is when learners are provided with models, illustrations, or demonstrations of the concept and are given the opportunity to develop understanding of it, create connections, and identify applications (Bartlow, 2011; Sen et al., 2016).

Representative learners from each team report or discuss the team's findings to the entire class which further reinforces their understanding of the concepts. Additional information can be introduced at this stage and most times the teacher introduces the standard name of the concept or process under study after learners have discovered patterns, developed understanding, or relevance and significance of the model explored. Both the exploration and concept formation phases help learners to develop an understanding of concepts (Sen et al., 2016).

2.6.3 POGIL application stage

The third phase of the learning cycle is the application. This is the phase where new knowledge or discoveries from earlier phases are reinforced by synthesising, engaging in problem-solving activity, exploration, and transferability of knowledge to a new situation or unfamiliar context (Eberlein et al., 2008; Hanson, 2006; Moog & Spencer, 2008). The application stage is where learners are able to assess the knowledge they have gained by using it in problem-solving exercises which will give them confidence and the ability to transfer the new knowledge to an unfamiliar context (Barthlow, 2011).

Succinctly, POGIL activity starts with a brief orientation of the learners to the learning goals and outcomes expected; the teacher who is the facilitator does this and also monitors the group interactions (Eberlein et al., 2008; Moog & Spencer, 2008). Learners make use of diverse learning materials in the three stages which include carefully designed worksheets, amongst other materials, to help learners progress gradually through the exploration, concept formation and application phases (Eberlein et al., 2008; Hanson, 2006). The underlying system in POGIL is a gradual shift from the passive traditional 'chalk and talk' method to a more active problem solving and collaborative approach to learning. This system encompasses the use of guided inquiry activities, learning teams, and the skill developing process.

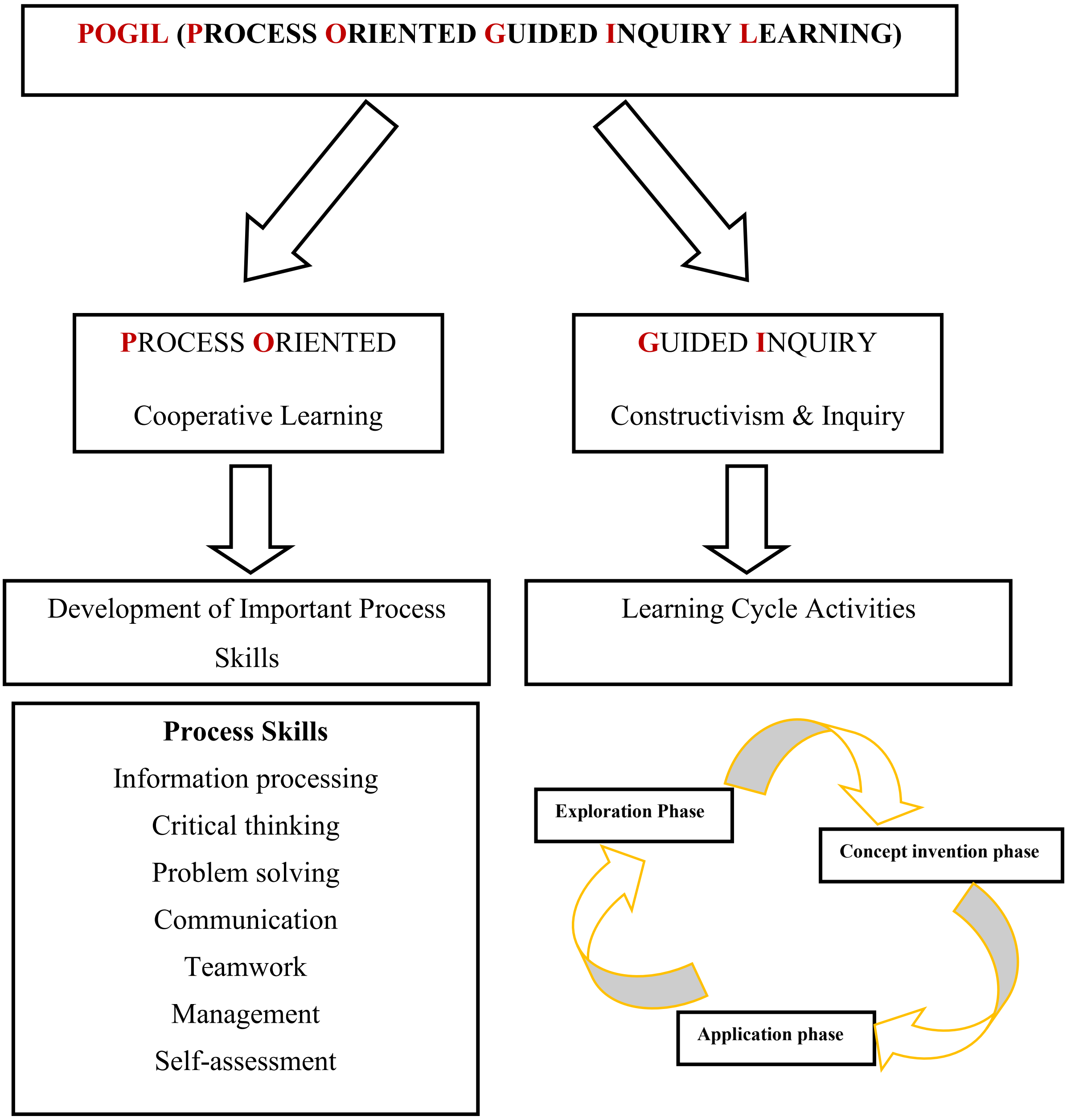


Figure 2.2: Diagrammatical representation of POGIL (Adapted from Sen et al., 2016, p. 31)

2.6.4 Review of studies on POGIL

A growing number of studies show that POGIL has proved to be effective in college chemistry teaching, in particular (Barthlow, 2011; Brown, 2010; Campbell, 2014; Farrell et al., 1999; Moog & Spencer, 2008) and in other science classrooms (Brown, 2010; Eberlein et al., 2008; Kaundjwa, 2015). For instance, in a comparative study conducted by Farrell et al. (1999), they reported that learners who were taught through the POGIL approach had higher test grades and developed positive attitudes towards learning chemistry compared to those who were taught using the traditional teaching method.

In addition, Pedretti (2010) reports the effect of inquiry-based activities on 11th-grade learners' attitudes and understanding of stoichiometry. The author indicates that learners' attitudes towards chemistry improved after participating in the inquiry-based activities for a full academic year. Although Pedretti (2010) mentions that there was no significant difference between achievement levels of learners in the inquiry-based and lecture groups, she believes that this finding could be that the methodology needs to be improved before noticeable differences can be seen (Pedretti, 2010).

Hein's (2012) study on organic chemistry in the USA also confirms the effectiveness of POGIL in improving achievement in chemistry. She reports that the POGIL experience positively impacted learners on all levels of proficiency. More so, learners who learned through POGIL activities had a greater grasp of the content knowledge compared with their counterparts in the non-POGIL classrooms. Both teachers (facilitators) and learners in the POGIL classroom described POGIL as more enjoyable compared to the traditional sessions (Hein, 2012).

Similarly, in Australia, Vanags, Pammer, and Brinker (2013) investigated the impact of POGIL on long term retention of information compared to a traditional teaching method. They found that students that participated in POGIL sessions showed improved long-term retention of material over the control group. In addition, while retention of information in the control and POGIL groups were assessed with pre-and post-test quizzes, the POGIL groups showed increased performance at the post-test while an increment was not observed for the control group, despite showing the best performance at the pre-test. This indicated that the POGIL group had retained the material they had studied (Vanags et al., 2013).

A study by Kaundjwa (2015) on the effect of POGIL on science foundation students' achievement in stoichiometry problems at the University of Namibia shows significant differences in achievement between the POGIL group and the lecture group of students. The study confirms that the POGIL group students demonstrated improved understanding of stoichiometry concepts and their interrelatedness, compared to the traditional group. More so, the POGIL group could give correct explanations for their answers on stoichiometry problems.

This suggests that these students attained a level of proficiency as alluded by Kilpatrick et al. (2001).

Sen et al. (2016) conducted a study to examine the effect of POGIL on senior secondary school Turkish learners' misconceptions relating to electrochemistry. They found that the POGIL approach helped the learners in the deeper acquisition of scientific concepts and in critical questioning of their thoughts (Sen et al., 2016). The authors concluded that learners' misconceptions in electrochemistry were rectified systematically using the POGIL approach (Sen et al., 2016). Sen et al.'s (2016) findings are parallel to that of Barthlow (2011) who indicates that POGIL is influential in shifting learners' alternate conceptions in chemistry. POGIL provides opportunities for learners to discuss their confusing ideas on complex concepts in chemistry and explore their abilities (Barthlow, 2011).

Other studies reported that POGIL activities increase learners' in-depth understanding and achievement in chemistry (Brown, 2010; Campbell, 2014; Farrell et al., 1999; Marais & Combrinck, 2009; Sen et, al., 2016). Brown (2010) states that POGIL influenced learners' deeper understanding of concepts as opposed to the previous rote learning style. The learners in the study confirmed that their self-confidence and attitudes towards learning chemistry also improved as against the previous notion of abstractness and difficulty of the subject (Brown, 2010). Learners that had experience with POGIL activities developed effective interpersonal and communication skills as well as higher-order thinking skills which helped with the integration of concepts (Barthlow & Watson, 2014; Sen et al., 2016).

In contrast with all the findings above, some studies (Chase, Pakhira, & Stein, 2013; Jack, 2013; Judd, 2014; Pedretti, 2010) report no significant effect of the POGIL approach on teaching and learning chemistry despite the many positive effects of POGIL reported in the literature. These studies claim that POGIL is not as effective in increasing learners' achievements as reported in the literature (Jack, 2013; Judd, 2014; Pedretti, 2010). Jack (2013), for instance, points out that the effect of POGIL instruction on teaching and learning is limited as she informs that the 'concept mapping' approach is more effective in science classrooms. Concurring, Judd (2014) affirms that learners' understanding and achievements in both the POGIL and traditional method of teaching are the same. Judd's findings are consistent with Chase et al. (2013) and Pedretti's (2010) studies that inform that there was no significant difference between achievement levels of learners in the inquiry-based POGIL and the lecture group.

Furthermore, instructors have been concerned that the POGIL method may not provide the opportunity to cover as much content in comparison to the traditional lecture method that allows for extensive content coverage whether there is comprehension or not (Barthlow, 2011; Moog, et al., 2006). However, this claim has been found baseless by various studies maintaining that POGIL pedagogy does not thwart the opportunity to learn as much content as in the lecture method (Barthlow, 2011; Hanson, 2006; Moog & Spencer, 2008; Sen et al., 2016). More so, many studies indicate that learners in POGIL classrooms demonstrate better retention of content and achieve as much or even more than learners in the traditional science classrooms (Farrell et al., 1999; Hanson, 2006; Hu & Shepherd, 2013; Sen et al., 2016).

According to Lamm (2017), generally, inquiry-based learning might pose a challenge to both the teacher and the student at the first instance. However given time, once the necessary skills are acquired, the teachers and learners no longer see it as such. For Quigley, Marshal, and Deaton, (2011), a teacher's anxiety is often about losing control in an inquiry-based classroom as learners are prone to argue while interacting to complete their given tasks. Hence, in an inquiry-based classroom, teachers have the responsibility of managing the classroom interactions and creating a respectful learning environment.

Nevertheless, it is recognised that an instructional approach that engages learners and encourages cooperative learning increases learners' conceptual understanding as well as critical thinking skills (Arthur & Kreager, 2017; Eberlein et al., 2008; Hanson, 2006; Sen et al., 2016). Based on evidence drawn from previous studies, it is obvious that most authors claim that a learner-centred instructional approach (such as POGIL) facilitates the development of positive attitudes towards science and optimises learning (Arthur & Kreager, 2017; Hanson, 2006; Hein, 2012; Kaundjwa, 2015; Sen et al., 2016; Vanags et al., 2013). There appears to be a pattern of important outcomes observed in these studies: (1) mastery of content is higher with POGIL than the traditional teaching methods, (2) learners have more positive attitudes towards science, (3) learners' learning skills develop over time, and (4) learners are not bored and worn out in the learning process.

Overall, POGIL emphasises collective active learning by members and affords teachers the opportunities to assist learners in generating knowledge rather than merely 'dishing out' information – new knowledge is built upon existing knowledge to construct meanings (Arthur & Kreager, 2017; Sen et al., 2016). Actual understanding and learning require active integration of new knowledge with existing knowledge, identifying and resolving contradictions, making inferences, and posing and solving problems on the part of the learner (Arthur & Kreager, 2017; Hanson, 2006). Thus, knowledge construction is personal and constructed in the mind of the learner and the teacher is a facilitator of knowledge. Vygotsky (1978) refers to this as constructivism which is one of the paradigms for enhancing learning. This learning perspective is discussed in the next chapter.

Even though the literature have presented several benefits of POGIL, teachers are central to the changes that may occur in educational practices (Huber, Endedijk, & Van Veen, 2020). Teachers' professional learning is seemingly essential for changing teachers' instructional practices. This emphasises the importance of professional development programmes in science education. The nature of POGIL suggests that, for effective implementation of this approach in the science classroom, teachers are required to have a broad understanding of what POGIL is and how it should be implemented in the science classroom. Thus, they should be exposed to appropriate professional development activities or programmes. Although this study focused on learners, teachers played a significant role in the implementation of the POGIL in the intervention phase of the study. I will briefly outline the importance of teachers' professional development as it related to this study.

2.6.5 Teachers' professional development programmes

Osborne and Dillion (2008) assert that teachers' professional development has been identified as one of the important driving factors for improved science education outcomes. Huber et al. (2020, p. 3) define teachers' professional development programmes as, "the systematic effort to bring about the change in the classroom practices of teacher, in their attitudes and belief and in the learning outcomes of students".

In other words, professional development is engaging teachers in activities that could enhance the quality of their teaching and lead to school improvement. Professional development programmes often take place in formal settings as well as informally through collaboration and mentoring between colleagues (Postholm, 2018).

Numerous teachers' professional development programmes have been organised (Huber et al., 2020; Postholm, 2018), however it is uncertain if the results were satisfactory (Huber et al., 2020). Huber et al. (2020) enlighten us that in order to achieve desired outcomes for a professional development programme, some characteristics must be present. These characteristics are focus, activities, collaboration, coherence of content, and duration and could be used to design and refine professional programmes to optimise their effectiveness (Huber et al., 2020; Postholm, 2018). Nonetheless, Postholm (2018) maintains that teachers' professional development is more effective when embedded in teachers' specific subject areas. In the context of this study, Huber et al. (2020) and Postholm's (2018) views aligned with the designed POGIL teachers' training workshop.

In addition, the literature emphasises the critical role of the school principal in teachers' professional development programmes (Huber et al., 2020; Postholm, 2018). Creating a learning community and establishing support for the teachers are few of many expectations required of the principal. Throughout the course of this study, the school principals of the participating schools provided this support, for instance, one of the principals gave permission for the use of the science laboratory premises during the POGIL workshop.

The teachers (facilitators) in this study participated in a POGIL training workshop where they had substantial time to plan and participate in collaborative lesson planning and received peer feedback while creating a strong support for each other. These workshops arguably could be regarded as a professional development programme aligning with the five characteristics outlined by Huber et al. (2020).

The workshops focused on developing teaching and learning practices with POGIL intervention. It introduced teachers to the POGIL framework, the team formation, and facilitation strategies. The teachers were active at deliberating extensively on aligning the stoichiometry curriculum to the POGIL framework as well as creating lesson plans through POGIL based activities. Teachers openly discussed and collaborated during this workshop while they acquired new ideas and reflected on their practices. They had a common goal, that of increased subject matter knowledge and understanding of the curriculum. This process created a connection bewteen a community of practice and improved classroom teaching. Ngcoza and Southwood (2019) in their work on developing professional networks through teacher collaboration assert that for teachers to develop, they need to learn. Thus, they refer to teachers' collaborative approaches to professional development as a "web of development" (Ngcoza & Southwood, 2019, p. 7). According to these scholars, when teachers collaborate to co-construct knowledge and engage in development activities in an enabling environment, they create a professional "web of development" (ibid.).

2.7 Chapter Summary

In this chapter, stoichiometry in chemistry and studies on stoichiometry as it relates to this study, were discussed. Discussions on proficiency, the strands of proficiency, and the definition of proficiency in this study were presented. Also, studies on learners' attitudes towards science and factors influencing attitudes towards science as identified in the literature were detailed. Lastly, the POGIL and potential benefits of POGIL in science classrooms were enumerated. This chapter together with the earlier chapter on the problem statement was guided by the theoretical framework which is discussed in the next chapter.

CHAPTER THREE: THEORETICAL AND ANALYTICAL FRAMEWORK

> *A theoretical framework 'is the blueprint for the entire dissertation inquiry ... it undergirds your thinking with regards to how you understand and plan to research your topic as well as concepts and definitions from that theory that are relevant to your topic.* (Grant & Osanloo, 2014, p. 13)

3.1 Introduction

The theoretical framework provides a guide for the researcher to situate and contextualise the study and to decide on the type of data needed for a particular study, thereby making findings more meaningful and generalisable (Grant & Osanloo, 2014). In this chapter, the theoretical framework that provides structure to the entire study is presented. It presents the knowledge that the study builds on and an explanation of concepts significant to this study.

Wortham (2004) describes learning as changes in what the learner knows and who the learner is. Likewise, Azeem et al. (2014) argue that a learner's proficiency is not fixed but a skill that can be developed based on the learner's exposure to activities and tasks. Johnstone (2000) offers three levels of representations with learning in chemistry, namely, macroscopic, microscopic, and the symbolic. Learners acquire knowledge at the microscopic level to explain observations at the macroscopic levels (Johnstone, 2000). The ability of learners to construct knowledge through the linking of relevant concepts on the macroscopic level with that on the microscopic level is regarded as constructivism (Jack, 2013).

The educational application of constructivism dates to the time of Socrates who suggested that teachers and learners should construct knowledge by talking with one another and by asking questions (Park et al., 2009). A social constructivist classroom is learner-centred where the teacher's role is to provide the opportunity where learners can hypothesise, pose questions, investigate, and create meanings (ibid.). Consistently, Process Oriented Guided Inquiry Leaning (POGIL) principles are linked to the socio-cultural theory where learners take progressive responsibility for their own learning, placing more value on learners learning rather than on teachers teaching (Hanson, 2006). The POGIL instructional strategy employed in this study is rooted in social constructivism which believes that an individual learns through interaction within a group rather than mere transmission of knowledge (Hanson, 2006).

Vygotsky's (1978) social constructivism, finding its roots in the socio-cultural framework, proposes that learners engage in construction of individual interpretations of their experiences to make meaning. An underlying perspective to this study is that knowledge is generated through collective meaning-making rather than individual minds. This is central to socio-cultural learning theory which positions learners as central in activities, context, and how they interact in the process. The work of Vygotsky on socio-cultural theory provides a starting point for this perspective, thus, this study draws from the socio-cultural theory of learning as posited by Vygotsky (1978).

3.2 Vygotsky's Socio-cultural Theory

Jean Piaget developed the cognitive development theory which focuses on individuals and how they construct knowledge (Piaget, 1997). Piaget proposed that a pattern of behaviour is developed through the process of intake of new knowledge (assimilation) and adapting it into the existing (accommodation) when going through the four stages of development. Lev Vygotsky criticised the linear stages of development of Jean Piaget and developed the socio-cultural learning theory. He proposes that social interaction is an integral part of learning through which knowledge is constructed on two levels; first on the social level through interaction with others (*the inter-psychological*) and then integrated inside on the individual level (*the intra-psychological*) (Harrison & Muthivhi, 2013; Vygotsky, 1978). For Vygotsky (1978), the social interaction plays a fundamental role in cognitive development and social interaction which are independent but interactive processes.

According to Vygotsky, "learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers" (Vygotsky, 1978, p. 38). He claims that development is actually the transformation of socially shared activities into internalised processes. In other words, interacting with people in the environment or collaborating with peers stimulates potential cognitive development processes which are then internalised and become one's independent achievement (Vygotsky, 1978). This suggests social interaction as a 'medium' of acquisition of skills and construction of knowledge. This viewpoint is important to this study and it is important to examine the fundamental principles of socio-cultural theory.

3.3 Features of Socio-cultural Theory

The key features of Vygotsky's socio-cultural theory are summarised below:

- **Social interactions** are critical; knowledge is co-constructed between two or more people;
- Human development occurs through the cultural transmission of **tools** (language, symbols). Language is the most critical tool. Language develops from social speech to private speech to covert (inner) speech;
- **Self-regulation** is developed through internalisation (developing an internal representation) of actions and mental operations that occur in social interactions; and
- **The zone of proximal development (ZPD)** is the difference between what children can do on their own and what they can do with assistance from others. Interactions with adults and peers in the ZPD promote cognitive development (Schunk, 2012).

I now briefly discuss these tenets as they relate to this study.

3.3.1 Social interactions

Vygotsky explains that knowledge is personally constructed but is influenced by and enhanced because of experiences and social interaction that occurs in a setting (McRobbie & Tobin, 1997; Schunk, 2012; Vygotsky, 1978). Knowledge from the socio-cultural perspective is socially negotiated and constrained by social processes. Vygotsky (1978) believes that the process of social interaction stimulates the linking of abstract representation in an individual. He claims that learning occurs during interaction with others and is supported by it. The socio-cultural theory describes learning as a process in which skills and knowledge are transformed from the social into the cognitive plane (Schunk, 2012; Shabani, 2016).

Consistently, POGIL emphasises interaction among members of the learning teams, discussion about learning materials, drawing conclusions (which help in developing conceptual understanding), and important skills (Barthlow & Watson, 2014; Sen et al., 2016). Barthlow and Watson (2014) argue that learners develop critical thinking skills through dialogue during social interactions when they work collectively on tasks and engage in problem solving.

Lending support, Sen et al. (2016) argue that an individual's development of skills such as critical thinking, problem solving, communication, teamwork, and self-assessment is facilitated when one actively engages with other individuals in a setting.

Vygotsky's socio-cultural perspective acknowledges that the development of individuals is dependent on participation with others in relevant activities, practices, and environment to constitute a mutual relationship (Robbins, 2005; Shabani, 2016). Learning is a process that does not occur independently or automatically but occurs during a process that requires the engagement of two or more individuals in a practical activity (Harrison & Muthivhi, 2013; Shabani, 2016). This suggests that for social interaction to lead to successful learning, it should be framed within activities that have a clear purpose, such as joint problem-solving activities.

Social interaction spaces in this study played a significant role. For example, in the POGIL classroom, learners in the learning teams were engaged in joint activities specific to completing a task. The POGIL learning cycle enabled learners to investigate and discuss a pattern with their peers. Through this process, learners came up with theory based on their investigation and were given the chance to explain their theories as well as query the theories developed by other learners. From the socio-cultural perspective, learners should be encouraged to test the viability of their understanding with peers, listen, and make sense of other learners' ideas. This process of discussion and checking of ideas with peers is an essential element of learning and enables meaningful understanding (McRobbie & Tobin, 1997).

Embedded in the learning process of POGIL are the cooperative learning teams and the responsibility of individuals in the application and assessment of concepts (Eberlein et al., 2008; Farrell et al., 1999). Cooperative learning is an approach in which learners work in small groups to help one another learn (Slavin, 2008). The learning teams in POGIL interact with each other to reach a shared conclusion and common goal about the concepts under investigation (Sen et al., 2016). Equally, the socio-cultural theory considers the collaborative aspect of developing shared understanding rather than focusing on individual constructions of knowledge (Shabani, 2016). In the teams, members take up roles, negotiate and discuss with peers, take measurements, or record data in an experiment or activity. Therefore, they are no longer mere listeners, but rather active participants in their learning process. Robbins (2005) argues that knowledge is more contextually specific and mediated by particular tools or artefacts in interaction with others in a social setting. Learning is mediated in the social context through cultural tools.

3.3.2 Cultural tools

Another important concept within the socio-cultural theory is the mediating role of cultural tools. Vygotsky (1978) argues that humans use symbolic tools or signs (artefacts) that were created by their culture over time to mediate and regulate their relationships with others in the world. He describes cultural tools as means of achieving ‘things’ in the world. These tools are acquired during development and passed on to subsequent generations. For Robbins (2005), cultural tools include ways of thinking or ways of doing.

Wertsch (2007) opines that learning is more successful if mediated through cultural tools which helps one in the mastery process. He highlights the use of cultural tools such as language, signs, symbols, art works, and artefacts (including video, models, diagrams, charts) in mediating learning. Concurring, Shabani (2016) accentuates that the construction of knowledge is a process mediated by physical and psychological tools and artefacts. These scholars point out that cultural tools mediate and connect development of skills and functions. The concept of mediation suggests that an individual’s connection with their environment is not direct but mediated by these symbolic tools. Vygotsky’s viewpoint is that learners jointly develop understanding of a concept through dialogue, thus language is the vehicle or the cultural tool of thought (Robbins, 2005).

As learners participate in joint activities, they work with and transform specific cultural tools or artefacts in which they engage (Robbins, 2005). Similarly, the learning teams in POGIL often consist of learners with different competency levels – novice, proficient, and expert. In my view, mediational tools in the POGIL classroom include individual learners’ or teams’ ways of doing things. Also, a mediating sign could be associated with use of appropriate language to make learning of stoichiometry concepts easier. For instance, each learning team uses appropriate language among themselves to understand and complete the task given. Learners can acquire strategies on solving specific problems, and pass this on to each other – each learning team adapting a cultural tool for its own needs or use. They also utilise artefacts in the form of charts, videos, models, and worksheets as mediational tools between the learners and concepts to be learned, thereby promoting effective understanding (Farrell et al., 1999; Vygotsky, 1978). During this study, the cultural tools that were used by each learning team and how they were used or integrated within the POGIL activities are of importance to this study.

3.3.3 Self-regulation

In the learning process, Vygotsky indicated that an individual internally reconstructs external operations and this is referred to as internalisation (Vygotsky, 1978). Extending on Vygotsky's seminal work, Pintrich (2000, p. 453) defines self-regulated learning as: "An active constructive process whereby learners set goals for their learning and then attempt to monitor, regulate and control their cognition, motivation and behaviour, guided and constrained by their goals and the contextual features in the environment".

Self-regulation is a process that is focused on trying to control or regulate one's cognition, motivation, and behaviour (Pintrich, 2000). These scholars explain that this process can be facilitated or constrained by other individuals in the environment such as peers, teachers, or task characteristics and assessment structures. Taking a different angle, Harrison and Muthivhi (2013) refer to self-regulation as the acquisition, internalisation, and mastery of new psychological tools during mediation (which consequently leads to development of new mental processes). The authors enlighten that the coordination of mental processes, such as planning and formation of concepts, does not occur independently of individuals' social environment but through the gradual internalisation of concepts (ibid.).

Diaz and Cadime (2017) enlighten that both individual and environmental factors such as family, peers, and the school influence the development of self-regulation. In agreement, Makila, Marecia, and Wasanga (2017) argue that learners can develop self-regulation when they are in an environment that enables them to engage collaboratively in problem-solving and goal-directed tasks (Makila et al., 2017). Self-regulation occurs through social interaction, when learners acquire conscious control of their own thinking in exploring inner potential (Diaz & Cadime, 2017; Harrison & Muthivhi, 2013; Vygotsky, 1978). This suggests that internalisation is crucial for the development of self-regulation.

In tandem, the principles of POGIL confirm that learning is effective when learners are given opportunities to generate information themselves rather than just supplying the information (Hanson, 2006; Powell & Kalina, 2009). In the same vein, Vygotsky states that the teacher assumes the role of a facilitator in a social constructivist classroom rather than being an instructor (Vygotsky, 1978). However, assuming the role of a facilitator does not imply you cannot give instructions to learners, but instead, the instructions given must allow learners to generate meaning themselves – Vygotsky refers to this as self-regulation (Harrison & Muthivhi, 2013).

The guided inquiry activities in POGIL are oftentimes challenging to accomplish independently, signifying the requirement of the more knowledgeable other (MKO) (Stott, 2016). The MKO is someone such as the teacher, peer, or even a computer that knows more than the learner regarding a particular concept or task (Powell & Kalina, 2009; Stott, 2016). Learners in a POGIL classroom can achieve self-regulation through conscious mediation by the teacher or peer (assuming the role of MKO as espoused by Vygotsky (1978)), who provides the appropriate mediating tools in terms of charts, models, symbols, problem-solving strategies or steps, and unpacking difficult concepts (Arthur & Kreager, 2017; Eberlein et al., 2008; Harrison & Muthivhi, 2013).

Learners get to the next level of problem-solving skills when they receive support from others who guide them to the point of internalisation (Schunk, 2012). Researchers draw attention to self-regulation as an important factor in academic achievement (Artuch-Garde, Gozales-Torres, De la Funete, Vera, Fernández-Cabezas, & López-García, 2017; Makila et al., 2017; Schunk, 2012; Vincent-Ruz & Schunn, 2017). Vincent-Ruz and Schunn (2017) affirm that learners' poor achievement in science is often a result of lack of self-regulated learning. They indicate that self-regulation stimulates scientific reasoning which consequently leads to better learning outcomes. The authors also note that learners' proficiency in a learning area gives them the confidence needed for self-regulation. It could thus be deduced that self-regulated learners are competent learners.

The centrality of social mediation is apparent in self-regulation (Harrison & Muthivhi, 2013; Makila et al., 2017). Social mediation is an important behavioural skill needed for learning and acts as a predictive factor of resilience which is an individual internal factor (Artuch-Garde et al., 2017). Accordingly, self-regulated learners seek feedback on their performance and make effort for adjustment for future learning (Makila et al., 2017; Wolter, 2010). This implies that learners' capacity for long-term persistence in problem-solving is associated with resilience (Artuch-Garde et al., 2017). Self-regulation entails setting goals and control of impulses thereby significant in developing resilience (Diaz & Cadime, 2017).

Resilience is an acquired skill rather than a fixed trait which is one of the positive outcomes of self-regulated learners (Artuch-Garde et al., 2017; Makila et al., 2017). Artuch-Garde et al.

(2017) affirm that the ability to self-regulate is associated with a high level of resilience in learners. Resilience is a developmental process that can be influenced by the mindset of learners and their environment (Artuch-Garde et al., 2017; Makila et al., 2017). For instance, where learners believe or are taught that they can develop their intellectual ability, they tend to persevere when faced with learning challenges and subsequently perform better.

The teacher's role in a POGIL classroom is reconceptualised from transferring skills and knowledge to the act of supporting learners in making meaning and sense of learning (Eberlein, et al., 2008; Vygotsky, 1978). This process enables learners to develop greater awareness and mastery of their own thinking processes involved in solving specific problems as well as the gradual deliberate use of their newly acquired skills, subsequently becoming resilient learners (Farrell et al., 1999; Harrison & Muthivhi, 2013). The teacher models the desired learning task and uses mediating tools to assist learners to move into and through their zone of proximal development (ZPD). This mediation process is central to learning (Vygotsky, 1978).

3.3.4 The Zone of Proximal Development

The Vygotskian viewpoint indicates that the origin of knowledge construction is not in the mind but in social interaction, co-constructed between more and less knowledgeable individuals (Shabani, 2016). The Zone of Proximal Development (ZPD) is described as two levels. The first is the present level in which the learner is capable of accomplishing tasks independently and the second level is the potential level of development, which the learner could accomplish with the help of others (Stott, 2016; Vygotsky, 1978).

Therefore, ZPD is the distance between an individual's independent level of competence in problem solving and the potential level that could be reached with the support and guidance of a more skilled adult, or through collaboration with peers (Schunk, 2012; Stott, 2016). Individuals could attain their potential level of competence through the support of a MKO and interaction with peers. Vygotsky affirms that the ZPD is the primary activity space in which learning occurs (Schunk, 2012; Shabani, 2016). Once an activity has been mediated and successfully completed, there is progression in the learner's competency level, and they can do more independently. This implies that effective internalisation occurs when there is social interaction (Vygotsky, 1978).

Vygotsky analysed the related concept of mediation and the ZPD and affirmed that learning can lead to developmental change, and mediation can influence the learners' capacity to develop (Harrison & Muthivhi, 2013; Schunk, 2012). This process of transformation does not occur independently and automatically but requires social interaction and collaborative engagement of learners in a practical activity that has a clear purpose (Shabani, 2016; Stott, 2016). Likewise, in a POGIL classroom, learners master completion of activities in their learning teams, internalisation occurs with each individual at a different pace, and then self-regulation is acquired (Eberlein et al., 2008; Schunk, 2012).

Lave and Wenger (1991), developing on the work of Vygotsky, argue that learning is a social activity. They argue that learning is achieved through participation and experiences in the social enterprise of a particular setting rather than something that happens within the minds of individual. Lave and Wenger's situated learning theory describes learning as evolving from being an 'apprentice' to an 'expert' (Lave & Wenger, 1991). They emphasise that the learning process does not only help in development of skills and knowledge but also a change of behaviour or attitude. In other words, learning through interaction with others transforms who we are and what we can do (Wortham, 2004). A 'novice' (less proficient) learner in a group activity can also become an 'expert' (more proficient) when they contribute their little knowledge to the group activity.

It does follow, that in science-rich environments learners' ways of being or proficiency are transformed in accordance with the practices experienced in the environment (Eberlein et al., 2008; Shabani, 2016). Learners in a science classroom not only learn science but in the process of engagement and interaction, they develop productive dispositions in science (Stott, 2016), a strand of proficiency (Kilpatrick et al., 2001). For instance, in the context of this study, learners participating in POGIL activities could develop appropriate problem-solving skills and their 'apprenticeship' could evolve to be 'expert' or proficient in stoichiometry concepts. Over time, engaging in joint problem-solving activities could change their everyday thinking process to a stage of proficiency. This process is based on their experiences since they can recall similar situations in the past and the course of actions taken that proved effective.

The learning cycle of POGIL incorporates Piaget's work on the significance of prior knowledge (Hanson, 2006), but the level of understanding and performance abilities of learners vary depending on how much support is provided to reach their potential achievement levels, resonating with Vygotsky's viewpoint. Learners reach their optimal level of ability in a highly engaging and supportive learning environment in agreement with the socio-cultural theory (Barthlow, 2011; Vygotsky, 1978). Therefore, as learners participate in POGIL activities, it could be expected that their evolving proficiency in stoichiometry and their attitudes towards science can be explored through the features of Vygotsky's socio-cultural theory of *social interaction*, *mediation*, *self-regulation,* and *ZPD*.

Taken as a whole, the POGIL instructional strategy aligns suitably with Vygotsky's socio-cultural framework that identifies the integral role of social interaction, mediation, self-regulation, and ZPD in developing skills and making meanings. As alluded to earlier, POGIL provides a supportive learning environment in which learners learn complex skills through the integration of existing knowledge to produce higher-level applications. The notion that learners' active engagement and social interaction are central to true comprehension, long-term retention of knowledge, and evolving ways of being (attitude), indicate the suitability of socio-cultural learning theory for this study. Hence, Vygotsky's socio-cultural theory offers a framework by means of which learners' evolving proficiency in stoichiometry and attitudes towards learning science in relation to participation in POGIL could be studied.

3.4 Analytical Framework

Kilpatrick et al.'s (2001) framework on mathematical proficiency provides a way to think about learners' proficiency as it encompasses the key features of knowing and doing. Three strands of Kilpatrick et al.'s (2001) framework (Section 2.3) are adopted to form the analytical tool for this study: *Conceptual understanding, procedural fluency* and *strategic competence*. These three strands were used to assess learners' proficiency in stoichiometry as they participated in the POGIL activities. Fraser's (1981) indicators of attitudes were used to analyse learners' attitudes towards science. These indicators of attitudes are included in the TOSRA questionnaire (Fraser, 1981) which was used to assess learners' attitudes towards science in this study. This study adopted these indicators and made modifications based on the definitions of attitudes as they related to this study (see Section 2.4) and data gathering tools.

Kilpatrick et al. (2001) highlight that these strands of proficiency are a social learning process grounded within an individual. This means that proficiency in stoichiometry occurs through shared action or interaction, in congruence with Vygotsky's theory that highlights social interaction as an important factor in learning (Schunk, 2012). Kilpatrick et al.'s (2001) analytical framework relates to Vygotsky's socio-cultural theory as they both postulate that learning is effective and meaningful when learners engage in collaborative processes of knowledge construction (Kilpatrick et al., 2001; Schunk, 2012).

Therefore, Kilpatrick et al. (2001) and Fraser (1981) were used as the analytical framework focusing on the concepts of social interaction, self-regulation, mediation, and ZPD from the socio-cultural theory of Vygotsky (1978). These concepts speak to learning (proficiency) and development – ways of being (attitude).

Table 3.1: Indicators of learners' proficiency and attitudes towards science

	Proficiency
CU	Using appropriate and comprehensible definitions and language of stoichiometry
	Providing an accurate explanation of stoichiometry concepts and connections
PF	Accuracy and efficiency in using appropriate procedure, and formulae for solving stoichiometry problems or stoichiometry task
	Computing fluently and procedurally
SC	Correct representation of problems with formulae, or symbols to solve problems
	Applying knowledge of concept to solve problems in creative ways
	Attitudes towards science
Attitude	Describing their ability in learning science as they participate in POGIL activities, perceived value and evidence of learning science, their perception of science during stoichiometry POGIL activities
	Describing their enjoyment of science learning during their participation in POGIL activities
	Describing their interest in science, science-related activities, and pursuing a career in science or related fields

3.5 Chapter Summary

In this chapter, I discussed the theoretical and analytical framework that I used to support this study. I discussed how Vygotsky's socio-cultural theory proffers that the learning environment and experience, specifically outlining active engagement and social interaction, are central to true comprehension, long-term retention of knowledge, and evolving ways of being (attitude). This chapter, with the earlier ones, influenced the research methodology employed in this study which is discussed in the next chapter.

CHAPTER FOUR: RESEARCH METHODOLOGY

Research methodology concerns 'how we find out about the phenomenon, the approach to be used, the principles which underpins it and the justifications for using the kind of research approach adopted, the type of study to be conducted, how the research is undertaken'. (Cohen, Manion, & Morrison, 2018, p. 186)

4.1 Introduction

The research methodology is the procedure by which researchers go about their work of describing, explaining, and predicting phenomena. It is the plan and structure of the investigation used to obtain evidence to answer the research questions (Kivunja & Kuyini, 2017). Considering this, this chapter gives a clear description of the participants, details of the research paradigm, and the data gathering procedures in this study. The research design, methods, sampling, and tools are subsequently discussed. It also includes a discussion of the data analysis process, validity, reliability, and ethical issues before, during, and after the research. Finally, this section is concluded by a chapter summary.

The primary aim of this research was to explore learners' evolving proficiency in stoichiometry and attitudes towards science through their participation in the Process Oriented Guided Inquiry Learning (POGIL) instructional strategy. To accomplish this goal, the following research questions were addressed:

1. What enabled and/or constrained learning of stoichiometry concepts by learners in the senior secondary school prior to the POGIL intervention?
2. How do learners' proficiency in stoichiometry change (if at all) over the period of participation in the POGIL intervention?
3. How do learners' attitudes towards science change (if at all) over the period of participation in the POGIL intervention?
4. What experience do learners value (if any) during their POGIL lessons?

One of the objectives of the research methodology is to follow a set of methods or procedures to answer the research questions or test the research hypothesis. The structure and approach to conducting research are guided by a set of principles known as a paradigm. It is therefore important to discuss the research paradigm in this study.

4.2 Research Paradigm

A research paradigm, also known as the researcher's worldview, is a lens through which a researcher perceives or experiences the world (Cohen, Manion, & Morrison, 2018; Kivunja & Kuyini, 2017; Morgan, 2007). Kivunja and Kuyini (2017) explain that research paradigms are not simply methodologies but perspectives, shared beliefs, or schools of thought that inform the meaning and interpretation of research data. In this sense, the research paradigm gives an understanding of the individual world views on the 'why and how' of the methodologies of research in determining the research methods to be used and how data will be analysed (Kivunja & Kuyini, 2017; Morgan, 2007).

There are four commonly agreed-upon paradigms: positivism or post-positivism, constructivism, transformative, and pragmatism (Creswell, 2014; Kivunja & Kuyini, 2017). In the context of this study and to answer the research questions (see Section 4.1) posed, both quantitative and qualitative research approaches were considered. It would be inappropriate to position this study as either purely quantitative or qualitative. I, therefore, considered pragmatism as an appropriate approach for this study. Pragmatism integrates both quantitative and qualitative approaches and data where relevant (Cohen et al., 2018). It is the most compatible with mixed-methods research as it seeks to utilise the best approach to address the questions being investigated (Cohen et al., 2018; DeCuir-Gunby & Schutz, 2017; Morgan, 2007).

Beyond the integration of quantitative and qualitative approaches or data types, mixed-methods research considers the pragmatist blend of paradigms, ontological, and epistemological assumptions in order to give a complete view of the phenomenon being investigated (Cohen et al., 2018). Ontology refers to ones' view of the nature of reality, which give rise to how we understand or ways of researching the reality – the epistemology (Cohen et al., 2018; Rehman & Alharthi, 2016).

According to Rehman and Alharthi (2016), alignment to a particular ontological assumption leads to a certain epistemological assumption. This is the case with both positivism and constructivism, unlike pragmatism which embraces the similarities of positivism and constructivism paradigms rather than the differences that place them apart (Cohen et al., 2018). In this sense, pragmatism advocates the necessity of choosing the best research method which ultimately helps to investigate what the researcher wants to know (Creswell, 2014; DeCuir-Gunby & Schutz, 2017). Cohen et al. (2018, p. 36) analysing the philosophical stances of pragmatism state: "What works is what helps us to understand, research and solve a problem. Our frames of references, conceptual schemes, and categories for understanding the world are not immutable or eternal, but are our creations, our artefacts, useful in so far as they solve practical problems".

Morgan (2007) in his argument for preference of the pragmatic approach, enlightens that a pragmatic stance does not disregard the concepts of the two main methodological stances, it does however provide the framework for the purpose and procedures of our pursuit. Pragmatism is primarily concerned with what is practical rather than the ideal (Denscombe, 2010). In other words, it is more oriented towards the solution of practical problems in the real world rather than engaging in the debate over the quantitative or qualitative divide (Cohen et al., 2018). In this sense, pragmatism highlights the centrality of identifying the most appropriate method to find out what the researcher wants to know, regardless of whether the data or methodologies are quantitative or qualitative, in as much as they address the research purpose or questions (Cohen et al., 2018; Morgan, 2007). This implies that the research is driven by the research questions.

For instance, in the connection of theory and data, the pragmatic approach adopts an *abductive* reasoning rather than exclusivity of induction or deduction. In this sense, a pragmatic approach flexibly moves back and forth between deductive and inductive reasoning to investigate multiple views of the problems and research questions (Cohen et al., 2018; Morgan, 2007). In the context of this study, the abductive process involved the use of deductions from the quantitative approach as an input to the inductive goals of the qualitative approach and vice versa. Thus, this process provided the flexibility for back-and-forth consideration of the knowledge generated with the qualitative and quantitative methods.

The pragmatist approach argues against the possibility of complete objectivity or subjectivity and regards reality as both objective and socially constructed based on the view that suitability and applicability is the most useful approach to research (Cohen et al., 2018). Thus, pragmatism favours an *intersubjective* approach against the dichotomy of objectivity or subjectivity as it concerns the relationship between the researcher and the research process. The intersubjective approach suggests the duality that involves the back-and-forth movement between the objectivity and subjectivity while emphasising the shared meaning in a social context. Therefore, in the context of this study, my pragmatic approach was a reflexive orientation that focused on the social process responsible for both the unique and shared meanings of participants. In this sense, the pragmatic approach allowed the flexibility of taking a subjective approach to interacting with the research subjects to construct reality while at another phase, an objective approach of not interacting with the subjects. This approach, according to Cohen et al. (2018) provides the most practical way to address the research question by generating multiple realities from both methods.

Furthermore, with this position, I therefore emphasised *transferability* while making meaning of the results from this study rather than contextualisation (constructivism) or generalisation (positivism) (Cohen et al., 2018; Morgan, 2007). To achieve transferability in this research, the information of the research context and process were provided, which could enable reliable inference with regards to the relevance and applicability of the findings of this study.

The goal of this study was to explore the influence (if any) of participation in the POGIL instructional strategy on learners' proficiency in stoichiometry and their attitudes towards learning science. The socio-cultural theory underpinning this study explains how an individual's competency and ways of being are influenced as they interact with other members in a social setting. Using both quantitative and qualitative methods allowed a detailed description of learners' proficiency in stoichiometry and their attitudes towards science before and after participation in the POGIL. It helped me understand, describe, and interpret the meanings individual learners made of their experiences. I gained insight into what factors or activities experienced in POGIL impacted on learners' proficiency in stoichiometry and their attitudes towards science.

Therefore, the aim of this study and the theoretical background informing it supported the use of mixed-methods research as choosing either the quantitative or qualitative approaches alone would not have been adequate to effectively achieve the desired goal of this study. Hence, I aligned more to the pragmatic research paradigm which allows multiple forms of data collection and analysis that provide a greater understanding of the problem in question. In essence, this study drew on both the quantitative and qualitative methods to examine how learners' proficiency in stoichiometry and attitudes towards science changed over the course of the study.

4.3 Research Design

As alluded in Section 4.2, this was a mixed-methods using two senior secondary schools with data collection occurring at the same period throughout the study. Creswell (2014) defines mixed-methods research as a research method in which both qualitative and quantitative data are collected, integrated, analysed, and interpreted based on two data sets to address the research question in a single research. Quantitative research makes use of the empirical approach in testing and verifying theories that explain a phenomenon (Ary, Jacobs, & Sorensen, 2010).

Quantitative tools such as questionnaires, surveys, and scales are usually employed in quantitative research. To control variables that may influence findings, quantitative studies typically use a random sampling method of selection (Ary et al., 2010; Creswell, 2014). In this study, the Test of Science Related Attitude (TOSRA) questionnaire (Fraser, 1981) was used to assess learners' attitudes towards science. Learners' proficiency in stoichiometry was also examined quantitatively using the Stoichiometry Achievement Tool (SAT). The Stoichiometry Learning Questionnaire (SLQ) developed by the researcher also involved a quantitative section to generate data on learners' views on each of the stoichiometry units being taught in the senior secondary school.

Qualitative research, on the other hand, is viewed through the subjective world of human experience which is bound by the context in which it occurs (Christensen et al., 2015). Qualitative research entails participants involved in a particular event constructing meanings attributed to their experience (Ary et al., 2010; Christensen et al., 2015). This study's theoretical framework (see Section 3.2) emphasises participation and interaction as significant during the learning process. Thus, it seemed logical to use qualitative methods that account for the experience of the participating learners.

One of the techniques for generating data qualitatively is interviews (Christensen et al., 2015; Cohen et al., 2018). The change in learners' proficiency in stoichiometry and attitudes in science concerning their participation in POGIL could not be better explored than through the direct experience of the learners involved qualitatively. In this study, semi-structured individual interviews, learners' reflective journals, and the SLQ were employed as qualitative instruments to generate data to answer research questions 1 and 4 as well as gaining insight into research questions 2 and 3.

Cohen et al. (2018) accentuate that the core assumption of using mixed-methods research is rather to combine the strengths of both quantitative and qualitative methods in a study which provides a complete understanding of a research problem, than either approach on its own. Mixed-methods research enables the researcher to answer confirmatory or exploratory questions and gain a better understanding of the research problem (Cohen et al., 2018; Creswell, 2014). Some of the advantages of mixed-methods research include: i) the opportunity to obtain a complete picture of the phenomenon under study, thus overcoming the weaknesses of a single approach, ii) the opportunity to elaborate and clarify findings, iii) increase data accuracy, and iv) increased validation of data by the multiple sources and methods of data collection involved (Ary et al., 2010; Christensen et al., 2015, Cohen et al., 2018).

Schoonenboom and Johnson (2017) opine that the use of mixed methods must align with the nature of specific research questions and contribute to answering the research questions. In other words, mixed-methods research is driven by the research questions. In this study, the first research question sought to gain an understanding of what constrains or enables the learning of stoichiometry, therefore both quantitative and qualitative approaches to the question were considered appropriate. The quantitative section of the questionnaire allowed learners to score each of the stoichiometry units based on their feelings or experiences about it while the qualitative questionnaire enabled the identification of challenges or prior experiences of learners with learning stoichiometry.

Furthermore, research questions 2 and 3 of this study aimed at examining how learners' proficiency in stoichiometry and attitudes towards science develop (if at all) as they participate in the POGIL intervention. The post-test results were compared with the pre-test to examine how the learners' proficiency in stoichiometry and attitudes towards science shifted over the period under study. In these processes, quantitative data were generated to provide answers to the two research questions. More so, learners' semi-structured interviews and their journal entries provided qualitative data on what facilitated or constrained the progression in proficiency and attitude towards science in the POGIL classroom. The data generated provided answers to research question 4 as well as providing support or clarifying the result of other research questions. Overall, the data generated in this study, in response to the research questions, were both quantitative and qualitative.

Furthermore, time order and paradigm emphasis must be indicated in mixed-methods research (Cohen et al., 2018; Schoonenboom & Johnson, 2017). Cohen et al. (2018) address this as mixed-methods design or typologies. The time order in mixed methods research is either concurrent or sequential. In a concurrent (parallel) design, both the quantitative and qualitative components are executed simultaneously but independently, it is indicated with a plus sign '+' between the components (for example, Quant + Qual) (Schoonenboom & Johnson, 2017). While in a sequential design, the qualitative component precedes the quantitative, or vice versa, as the study requires and is indicated with an arrow sign '→' (Cohen et al., 2018; Schoonenboom & Johnson, 2017). For instance, Qual → Quant indicates that the qualitative phase precedes the quantitative phase.

The paradigm emphasis is 'equal' or 'dominant' statuses. Equal emphasis has both components with the same lower cases. For example, 'Quant' 'Qual' means both the quantitative and qualitative components have equal emphasis, whereas the dominant status shows components with both lower and upper cases to illustrate greater or lesser emphasis given to a method. For instance, 'QUANT' 'Qual' shows that the quantitative components are given greater or dominant emphasis more than the qualitative method.

This study employed the Quant + Qual concurrent mixed-methods design. This (Quant + Qual) design depicts that: a) it is mixed methods with quantitative and qualitative equally important b) the quantitative and qualitative data collection and analysis were conducted simultaneously. For example, the TOSRA and SAT (pre-tests) were used to generate quantitative data while the SLQ generated both quantitative and qualitative data at the first phase of the research. The concurrent mixed-methods suggest that the quantitative and qualitative findings were integrated for discussion which is an identified feature of mixed-methods research as shown in Figure 4.1 below (Creswell, 2014; Schoonenboom & Johnson, 2017). The data from one approach could support the other or give an insight for further investigation (Figure 4.1) and possibly contribute to trustworthiness (Christensen et al., 2015; Schoonenboom & Johnson, 2017).

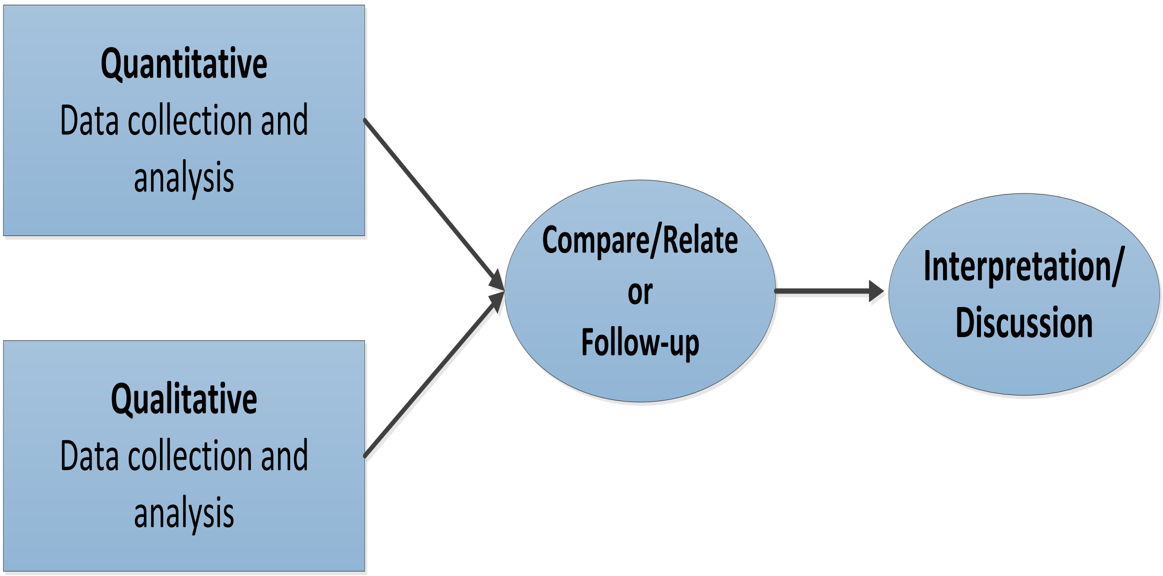


Figure 4.1: Quant + Qual mixed-methods design adapted from Creswell (2014, p. 242)

4.4 Research Site and Sampling

Defining the study population is paramount in research (Ary et al., 2010; Christensen et al., 2015). According to Cohen et al. (2018), the quality of research is determined by the tools used, the appropriateness of the sampling technique as well as the definition of the study population with the specific characteristics required for the research. This study was carried out in the Ilorin metropolis of Kwara state, Nigeria. Kwara state is in the north central part of Nigeria as seen in Figures 4.2 and 4.3 on the following page. This is where the two participating schools are located. As mentioned in Section 4.3, these learners are unique in some respects, but an example of a broader class of learners.

Figure 4.2: Map of Nigeria indicating the zones (https://s2.thingpic.com/images/Xc/foeKACBEtemtgcVCxE323FR2.jpeg)

Figure 4.3: Map of the North central zone of Nigeria (https://i0.wp.com/media.premiumtimesng.com)

The target population of this study was learners in the senior secondary school year two (SSS 2) phase in Ilorin metropolis. These learners have completed one year and are in the second of the three years of senior secondary schooling. Learners in this group range from 13 to 15 years old and is also the age range/phase in which learners begin to develop their attitudes towards science (see Section 2.5) (Bae & DeBusk- Lane, 2019; Juan et al., 2018). Also, SSS 2 learners can choose between science, social sciences, or art courses leading to the final senior certificate examination (Nigerian context) (see Sections 1.3 and 1.4). Their science experience at this stage influences whether they choose science courses at the final senior secondary school examination conducted by WAEC or NECO, or even change to other courses as they progress through the tertiary institution. Lastly, these learners would have been introduced to stoichiometry topics in the previous school year (SSS 1) and in the first term of their current school year. Thus, in the second term of the senior secondary school (SSS 2), learning of stoichiometry concepts are extended and reinforced. Since the focus of this study is on stoichiometry, this sample of learners was considered suitable to provide some valuable insights into the research topic.

Christensen et al. (2015) enlighten that sampling connotes having a representative subset of a larger population for a study. Thus, the sample is similar to the larger population in all characteristics and must be purposive and not just a random representation. Purposive sampling focuses on a small sample element judged to be relevant or knowledgeable on the issues being investigated (Ary et al., 2010; Denscombe, 2010). As the name suggests, in purposive sampling, researchers handpick the sample for a specific purpose based on particular characteristics being sought (Denscombe, 2010; Christensen et al., 2015). As it relates to this study, learners in SSS 2 were chosen as this study was on the proficiency of learners in stoichiometry and attitudes towards science. As alluded to in the previous paragraph, these groups of learners would suitably provide in-depth information as they were currently involved with the matter of interest in this study.

Furthermore, Ary et al. (2010) affirm that it would be expensive and time-consuming to sample the total population, but researchers can draw a sample from the population accessible to them. This involves using available cases for the study, also known as convenience sampling. Cohen et al. (2018) define convenience sampling as choosing a sample based on availability, time, location, or ease of access. This sampling is considered suitable because of the nature of this study in which time and availability of teachers and learners for the intervention phase are important. Both purposive and convenience sampling techniques suggest that the sample represents itself and not any group and does not seek to generalise to the wider population (see Section 4.3) (Cohen et al., 2018). However, the primary concern in this approach is to gain access and acquire in-depth information from those who could provide it (Cohen et al., 2018). Therefore, convenience and purposive sampling were used to choose SSS 2 science learners in two senior secondary schools in the Ilorin metropolis of Kwara state. Cohen et al., (2018) alluded that is based on easy access to research participants. The primary researcher of this study is physically located in Ilorin, Kwara State and choosing to conduct the research in Ilorin allows easy access to the study participants

The sites of this study were senior secondary schools T and C (pseudonyms). Schools T and C have 25 learners and 28 learners respectively in their SSS 2 science classes. In other words, a total of 53 learners participated in this study. Fifty-three SSS 2 learners who assented to and whose parents consented to their participation in the study, completed the pre-test questionnaires which were administered before they participated in the POGIL. The same 53 learners also completed the post-tests after 10 weeks of participation in the POGIL intervention indicating that there was no dropout. Thus, the data for this study were analysed based on the 53 learners that completed both the pre-and post-tests.

The chemistry teachers of the learners in Schools T and C were facilitators in the POGIL classrooms, but no data were generated from them as they were not the focus of this study. School T had five learning teams with five learners in each team, while school C also had five learning teams, having five or six learners in each team. The profile of sampled learners is shown in Table 4.1 below.

Table 4.1: Profile of study participants

	Participants	**No. of Males**	**No. of Females**	**Learning Teams**
School T	25	14	11	5
School C	28	12	16	5
Total number of participants	53	26	27	10

Seven learners were selected purposively for the semi-structured interviews; four females and three males. Learners were selected from: 1) the attitude groups, based on their scores from the

TOSRA pre-test and post-test; 2) proficiency levels, based on their scores from the SAT pre-test and post-test. Learners were also selected based on entries in their journals as well as their willingness and availability for the WhatsApp interviews conducted at the later phase of the study (see Section 4.5.4). The profiles of sampled learners for semi-structured interviews are shown in Table 4.2 below.

Table 4.2: Profile of interview participants

Participants	Gender	Attitude Pre-test (TOSRA-2)		Attitude Post-test (TOSRA-2)		Proficiency (SAT) Pre-test		Proficiency (SAT) Post-test	
		Score	**Group**	**Score**	**Group**	**Score**	**Level**	**Score**	**Level**
L15	Female	81	L	115	A	15	BP	24	AP
L40	Male	47	L	70	L	9	BP	36	AP
L44	Female	115	A	140	H	27	AP	36	AP
L45	Male	103	A	139	H	27	AP	33	AP
L2	Male	70	L	115	A	12	BP	24	AP
L19	Female	94	A	116	A	15	BP	18	AP
L31	Female	139	H	127	A	42	P	45	P

* A= Average attitude　　L = Low attitude　　H = High attitude
* P = Proficient　　AP = Average proficient　　BP = below proficient

4.5 Data Collection Methods

Selecting research instruments for a study is based on suitability and fitness for purpose (Ary et al., 2010). The research tools used in this study were chosen based on the research questions to be answered, the nature of the study, and its theoretical frameworks. This was a mixed-methods research in which both quantitative and qualitative data were obtained.

Quantitative data were obtained using the SLQ, TOSRA, and SAT questionnaires. Questionnaires are self-reported data collection tools which can be closed- or open-ended (Cohen et al., 2018). In a closed-ended questionnaire, respondents pick from responses provided by the researcher while in open-ended, respondents provide answers in their own words (Christensen et al., 2015). Questionnaires are widely used and comparatively straightforward to analyse (ibid.). Questionnaires can include either (or both) closed-ended items where respondents have to choose from responses given by the researcher or open-ended where respondents must give answers in their own words (Ary et al., 2010; Christensen et al., 2015).

The questionnaires used in this study were both closed- and open-ended. The first section of the SLQ contained closed-ended questions where learners had to select their responses from the options provided in the questionnaire, while the second section were open-ended items (see Section 4.5.1). The TOSRA is a closed-ended questionnaire designed to assess learners' attitudes towards science (detailed in Section 4.5.2). The SAT was open-ended, designed to assess learners' proficiency in stoichiometry (detailed in Section 4.5.3). The qualitative data sources were the SLQ, semi-structured individual interviews with learners, and their weekly journal entries (see Sections 4.5.1, 4.5.4, and 4.5.5 respectively).

4.5.1 Stoichiometry Learning Questionnaire

The stoichiometry learning questionnaire (SLQ) was an exploratory questionnaire directly administered to the respondents for collecting both quantitative and qualitative information. A questionnaire is a data collection instrument consisting of a series of questions to be completed by the research participants (Christensen et al., 2015). It provides pieces of self-reported information, opinions, and perceptions of the research participants related to the research objectives (ibid.). Items in questionnaires are to be short, clear, and written in simple language that can be easily understood by respondents, otherwise, the respondents might interpret questions differently or provide ambiguous answers (Ary et al., 2010).

The SLQ included closed-ended items as well as open-ended items. The first part of the questionnaire included scaled items where respondents were expected to rate their experiences with each sub-topic in stoichiometry. The perception levels were: Not Sure (NS), Very Difficult (VD), Difficult (D), Easy (E), and Very Easy (VE). The second part of the questionnaire, which was open-ended, allowed the learners to give free responses to the reasons for their perceptions in section one of the questionnaire.

In addition, the SLQ was directly administered to respondents. According to Ary et al. (2010), a directly administered questionnaire is filled out by a group of people assembled at a certain place for a specific purpose. Directly administered questionnaires have some advantages such as high response rates and the presence of the researcher to answer questions or provide necessary assistance to respondents.

The SLQ (see Appendix G) was designed for this study based on procedures obtained from relevant literature (Descombe, 2010; Cohen et al., 2018). Content validation was done as follows. Chemistry teachers with more than six years of teaching experience and who were not included as facilitators in this study, were involved as an expert panel. They were requested to scrutinise the SLQ items and offer a second opinion. A complete draft of the questionnaire was sent to both teachers, with instructions to further review and validate the instrument using the SLQ validation checklist (see Appendix H). This method has been effectively utilised in many studies (Descombe, 2010).

Following this, I scheduled an online Zoom meeting with the two teachers because they were in different locations and it was difficult to meet face-to-face. Their comments and ratings from the validation checklist were used to revise the questionnaire. For example, the initial draft sent out did not include the 'Not Sure' (NS) rating, but one of the teachers raised that this should be included as some of the topics might not have been taught in depth in some schools at the time the questionnaire would be administered. Also, the heading of the initial draft was 'stoichiometry difficulty questionnaire' and was revised to 'stoichiometry learning questionnaire'. This was because one of the teachers pointed out that using the word 'difficulty' might already give the learners the idea that stoichiometry is difficult. Besides, my supervisors provided invaluable suggestions in the rewording and order of the items in the questionnaire. Based on the input from the experts and my supervisors, several changes were made to the first draft of the questionnaire. A pilot study was carried out before utilising the tool (see Section 4.7).

The SLQ questionnaire was designed to collect data on learners' perspectives on stoichiometry and understand their experiences with learning stoichiometry before the POGIL intervention. This was intended to meet an objective and provide answers to research question 1:

> *What enabled and/or constrained learning of stoichiometry concepts by learners in the senior secondary school chemistry curriculum prior to POGIL intervention*?

4.5.2 Test of Science Related Attitude Questionnaire (TOSRA)

The Test of Science-Related Attitude (TOSRA) questionnaire was developed by Barry Fraser (1981). TOSRA was designed based on Kloper's table of classification of affective behaviour for scientific education (Fraser, 1981). In its original form, TOSRA included 70 response items for learners from middle and high schools. These responses were related to the learners' general feelings towards science (Fraser, 1981). In its modified form, TOSRA-2 divided the TOSRA into 35 questions each for the pre-test and post-test (Ledbetter & Nix, 2002).

The TOSRA questionnaire consists of seven focused scales to measure the sub-constructs of attitude towards science which are: the social implication of science; normality of a scientist; attitudes to scientific inquiry; enjoyment of science; leisure interest in science; career interest in science; and adoption of scientific attitudes (Fraser, 1981). Some previous studies (Anwer, Igbal, & Harrison, 2012; Welch, 2010) showed that TOSRA could be scored independently for different sub-constructs of attitudes as opposed to yielding an overall score for attitude. This gives TOSRA an advantage over other attitude questionnaires. Some other studies also excluded (Alharbi, 2012; Ledbetter & Nix, 2002) or merged (Fraser, Aldridge, & Adolphe, 2010; Madu, 2010) some of the scales from TOSRA sub-scales to measure attitude based on what was relevant to their studies.

In the case of this study, the TOSRA-2 pre-test and post-test were modified and adapted from Agunbiade (2015) for this study. Overlapping scales were merged and were renamed as follows to adapt meaningfully to this study: interest in science and science-related careers (from leisure interest and career interest in science scales) and perception of science (from the social implication of science, normality of science, and adoption of scientific attitudes scales) (Agunbiade, 2015). Hence, the sub-scales adapted for use in this study were enjoyment of science, interest in science and science-related careers, and perception of science or scientists. Enjoyment of science measures the enjoyment of science learning experience. Interest in science measures the development of interest in science and science-related activities or pursuing a career in science. The perception of science measures the recognition and understanding of the value of science regarding its role in society.

TOSRA-2 consists of 35 items each in the pre-test and post-test, with each item having a five-point Likert scale. Respondents are to express their degree of agreement with each item with possible responses ranging from 'Strongly Agree' (SA), 'Agree' (A), 'Not Sure' (NS), 'Disagree' (D), and 'Strongly Disagree' (SD). For analysis purposes, these scales have been given numerical values: 5, 4, 3, 2, and 1, respectively for positively worded items and reversed for negative items (Fraser, 1981). TOSRA has been extensively used in different countries and shown to be highly reliable (Agunbiade, 2015; Alharbi, 2012; Ali, Mohsin, & Igbal, 2013; Anwer, Igbal, & Harrison, 2012). For this study, the Cronbach alpha coefficient measured (using SPSS, version 25) was 0.88. A good and acceptable coefficient alpha should be 0.7 or higher, with a higher value indicating that the items are consistently measuring the same thing (Christensen et al., 2015). The internal consistency reliability of each was enjoyment of science (0.91), interest in science (0.89), and perception of science (0.84). This is a measure of the consistency of a test and shows that TOSRA-2 was reliable for respondents of this study (Cohen et al., 2018). The TOSRA-2 questionnaire used in this study is shown as Appendix F. The number of items retained for each sub-scale with its reliability coefficient value after piloting, is also shown in Appendix F.

The tool was revised after piloting (see Section 4.7). The revised TOSRA-2 instrument allowed the generation of the profile of the learners' attitudes towards science based on their responses to each of the three sub-scales studied. These sub-scales are mentioned in my description of learners' attitudes towards science (see Section 2.4) and made this instrument suitable for assessing the attitudes of learners in the study. The instrument was used to generate answers to research question 3:

> *How do learners' attitudes towards learning science change as they participate in the POGIL intervention?*

The pre-test questionnaire was administered by me, with the help of their teachers, to a total of 53 learners from the two participating schools. This was the first questionnaire that was completed by the participants at the beginning (first week) of this study. The post-test was administered to a total of 53 learners from the two schools that completed the pre-test after 10 weeks.

4.5.3 Stoichiometry Achievement Test (SAT)

Ary et al. (2010) describe the achievement test as a set of standard questions presented to an individual which requires completion of a cognitive task to measure mastery or proficiency in a specific area. It is usually characterised as either a standardised or a teacher/researcher-made test (Ary et al., 2010). For this research, the Stoichiometry Achievement Tool (SAT) was a teacher/researcher-made test. It was modified and adapted from the study of Denuga (2019) and Tigere (2014). One of the advantages of the researcher-made test is that it can be developed to closely match the content covered in the research study (Ary et al., 2010). This method seemed suitable because I could focus on the particular proficiency strands that the research aimed to assess.

SAT is a 2-tier test consisting of 1) multiple-choice questions based on the stoichiometry concepts with three or four alternatives and 2) open-ended questions which require explanations or calculations. Multiple-choice questions have been widely used to test the knowledge of learners and the results can be evaluated easily even with a large number of respondents (Klufa, 2012). One of the disadvantages of multiple-choice questions is the lack of explanation to answers and limited types of knowledge that can be assessed (Klufa, 2012). However, this was offset by the open-ended question section included in this questionnaire.

SAT questions were drafted from chemistry textbooks and past secondary school chemistry exam papers and have been validated to test learners' achievement in stoichiometry (Denuga, 2019; Tigere, 2014). The SAT consists of items on the mole concept, solution and mole calculations, % yield, molarity, limiting reagent, coefficient ratio chemical equations, empirical and molecular formulae, and gravimetric analysis. Learners were introduced to these units in their previous school year, the first term of the current class as continuation for reinforcement in the current syllabus. These items were used to assess learners' conceptual understanding (CU), procedural fluency (PF), and strategic competence (SC). These strands defined proficiency in this study as outlined in the analytical framework (see Table 3.1). The SAT items and proficiency level being assessed are shown in Appendix I.

The SAT was reviewed by the primary researcher, three chemistry teachers (expert panel), and my supervisors before piloting, with subsequent adaptation to this study. The chemistry teachers (expert panel) were not included as facilitators in this study, and each had more than 10 years of experience teaching chemistry at the senior secondary school, with postgraduate degree teaching qualifications. This exercise was to ascertain the appropriateness of the tool for the study participants and the purpose of this study. A draft of the test and its memo were sent to the expert panel and they were requested to validate the instrument using a checklist (Appendix J). This process ensured the validity of the questionnaire.

Following this, I scheduled a meeting with the expert panel (teachers) to discuss each item and revise the questionnaire and memo accordingly using their completed validation checklist as a guide. Also, my supervisors assisted in revising some of the questions before piloting the questionnaire (see Section 4.7). Cohen et al. (2018) enlighten that it is important to establish the degree to which an instrument consistently measures whatever it measures, also referred to as the reliability coefficient. After the pilot test, the reliability of the SAT was obtained using SPSS and it yielded a coefficient value of 0.91.

The pre-test of the SAT was administered to 53 learners at the beginning of the study before the POGIL intervention. This provided the baseline for monitoring their proficiency in stoichiometry as they engaged with POGIL instructions. The post-test was a similar test to the pre-test in structure and content, but some items were re-ordered and figures in some of the questions were changed. The SAT post-test was administered to the same 53 learners who had completed the pre-test. This was to respond to research question 2:

> *How do learners' proficiencies in stoichiometry change as they participate in the POGIL intervention?*

4.5.4 Semi-structured interviews

Interviews are the most widely used qualitative instrument that provide a richer and more reliable understanding of the phenomenon under investigation (Christensen et al., 2015; Cohen et al., 2018). They provide data about people's opinions, feelings, and experiences in their own words (Ary et al., 2010). One of the qualitative research instruments employed for this study was online individual semi-structured interviews with individual learners. Semi-structured interviews are designed to provide the opportunity for flexible, open-ended questions that allow further probing to obtain clarification on participants' responses in the area of interest by the interviewer as the interview progresses (Cohen et al., 2018).

Semi-structured interviews involve the use of an interview guide with open-ended questions (Cohen et al., 2018). The interview guide usually consists of a schedule of questions that are prepared in advance relating to the research goals. However, it allows for follow-up questions based on the interviewee's responses (Ary et al., 2010). Often, data obtained from the semi-structured interview will not just provide direct answers but reasons for the answers given (ibid.). The interview guide for this study was prepared based on items of the TOSRA-2 questionnaire and learners' journal entries. This was further improved by pilot testing with two learners who participated in the study but not included in the interview sampling (see Section 4.7). The interview guide is shown in Appendix K. The interview was to find out how the learners experienced POGIL, how or what influenced (if any) their understanding of stoichiometric concepts and attitudes towards learning science. This was aimed at providing the response to research question 4:

What experience do learners value (if any) during their POGIL lessons?

At the initial stage of the study, I had intended to conduct focus-group interviews. However, due to the novel coronavirus (Covid-19) pandemic, the school structures and schedules were disrupted, and it was unclear when there would be an end to the pandemic. Thus, face-to-face focus group interviews were not advisable considering the social distancing rules in force during the pandemic. The individual interviews were considered more suitable as opposed to the focus group interviews. This allowed honest and personal responses to emerge concerning their attitudes or proficiency, bearing in mind that learners may be apprehensive or self-conscious, or may not be able to speak out in the presence of other learners if done within a group. The individual interviews also seemed suitable since they allowed for probing of learners' thoughts based on the uniqueness of the data generated from the other instruments. For example, I could ask a series of follow up questions based on learners' remarks in their journals. Also, Cohen et al. (2018) inform that a 'public line' may be presented in a group interview instead of an individual honest response. This phenomenon, known as 'group think' was also avoided by individual interviews. 'Group think' discourages individuals to voice their opinions if they have a different view from other members in the group (Cohen et al., 2018).

Furthermore, due to the impact of the Covid-19 pandemic, individual online interviews through the form of WhatsApp video calls were adapted for this study. An online interview is a two-way interaction between the interviewer and the interviewee on a topic of mutual interest conducted remotely and can take several forms such as SMS, emails, WhatsApp, Skype among others (Cohen et al., 2018). The WhatsApp online platform was frequently used by the schoolteachers and learners to communicate with each other during the Covid-19 crisis.

Therefore, WhatsApp was considered a suitable platform to conduct the interviews after obtaining permission from the school heads and parental consent. The WhatsApp interviews provided flexibility with scheduling the interview time and reduced the potential interviewer effect (Cohen et al., 2018). In addition, it allowed for the visibility of non-verbal cues and gestures from learners that may have been absent with audio interviews (Cohen et al., 2018). Een though there were disadvantages such as interrupted calls from poor network coverage, these were easily managed by rescheduling interrupted calls.

4.5.5 Learners' reflective journals

A reflective journal is a recognised means of expression which provides an avenue for learners to identify and document their experiences or beliefs about a particular situation (Bashan & Holsblat, 2017; Towndrow, Ling, & Venthan, 2008). Reflection helps to identify one's needs, shifts in attitudes and knowledge, as well as discovering one's strengths and weaknesses (Towndrow et al., 2008). The reflective journal provides the opportunity for individuals to critically reflect on their actions and activities and also provides qualitative evidence of stages in the development of teamwork among learners (Bashan & Holsblat, 2017).

Learners in this study were engaged in reflective journaling activity. They were required to reflect on and describe their experiences and activities of POGIL in relation to their learning and the learning teams throughout the study. It was initially challenging to get some of the learners to write in their journals. Through interaction with them, I discovered that many of them forgot to write it up and some even thought their written English was not good enough to describe their experiences and they did not want to be laughed at. In retrospect, learners should have been prepared and encouraged to do reflective writing on what they were learning before the study began.

Nevertheless, four solutions were proffered for these; 1) journal entries were done immediately after each POGIL class (chemistry lesson) by each learner, 2) learners could choose to write short statements/phrases or even draw a picture to express themselves, 3) learners could choose not to show their journal to anyone except myself (the primary researcher), and I would accept their written English not minding if it was good or bad, 4) we agreed to use pseudonyms in the journals which learners assigned to themselves. These pseudonyms were merged with learners' assigned numbers in the quantitative tests and used as the identifier for each learner in the study. The journals were meant to capture learners' feelings and views as they engaged in POGIL activities with their peers, and were not meant to be perfect pieces of writing.

I could not ask learners to write in their mother tongue even if they were more comfortable doing that. Nigeria is dominated by three major tribes with these languages: Yoruba, Igbo, and Hausa. However, English is an official language in Nigeria and the official language of instruction in senior secondary schools and the universities. This was also the reason why the interviews were conducted in English.

The journals were collected and returned with learners' permission to capture and record their comments that provided relevant information for this study. Learners that were participants in the interviews were asked to bring along their journal to the interviews so that it would help in further discussions/clarifications of their write-ups. I also took copies of some journals with unique or unclear comments to obtain further clarification. Learners' journal entries were utilised to further reinforce data generated from semi-structured interviews, the SLQ, TOSRA, and SAT research tools.

Table 4.3: Summary of data collection techniques

Research Tools	Purpose	Research Questions	Nature of data collected	Time of data collection
SLQ	To obtain data on learners' perspective on/ experiences with learning stoichiometry before the POGIL intervention	Question 1	Quantitative & Qualitative	1st week of study
TOSRA-2 Pre-test	To obtain the profile of the learners' attitude towards science before POGIL intervention	Question 3	Quantitative	1st week of study
TOSRA-2 Post-test	To obtain the profile of the learners' attitude towards science after engaging in POGIL			After 10 weeks of POGIL activities
SAT Pre-test	To obtain a baseline for learners' proficiency in stoichiometry as they engage with POGIL	Question 2	Quantitative	2nd week of study
SAT Post-test	To examine the influence (if any) of POGIL on learners' proficiency in stoichiometry			After 10 weeks of POGIL activities
Semi-structured interviews	To obtain contributing factors to learners' stoichiometry proficiency and attitudes towards science in the POGIL classroom	Question 4	Qualitative	After 10 weeks of POGIL activities
Learners' reflective journal	To obtain learners' experiences with POGIL in relation to stoichiometry proficiency and attitudes towards science	Questions 2, 3 & 4	Qualitative	1st week – 10th week of study (ongoing)

4.6 Research Procedure

This study was conducted in three phases. To conduct this research and collect research data successfully the following procedures were followed: gaining access, support and permission from the research site and participants, obtaining permission for the POGIL materials, conducting a POGIL workshop with POGIL facilitators, and conducting the three phases of the research.

4.6.1 Accessing the research site

To begin the research, it was necessary to discuss the scope and requirement of the research at the initial stage. I discussed this with four chemistry teachers at the anticipated schools. I have met these teachers many times in our State organised teachers' professional development programmes. The discussion was to find out the feasibility of conducting the research in their schools considering the structure and nature of the study. Only three of these teachers were enthusiastic and agreed to participate in the study. The school authorities of the selected schools (schools where the three teachers were teaching) were visited and I sought their permission to undertake the study. The school head of one of the schools declined because of their school structure and that the timing of the study would not be convenient. The two other school heads granted permission for the study (see Section 4.10 on ethical considerations).

Following this, I had a discussion with the chemistry teachers at each of the two schools to schedule a convenient time for the POGIL training workshops. The handbook, *Instructor's guide to process-oriented guided inquiry learning* written by Hanson (2006), and other online resources were used as a guide in the workshops. Though Hanson's handbook is readily accessible online, the teachers requested a hardcopy so they could easily access it whenever the need arose for more understanding of POGIL. I therefore contacted David Hanson who was the writer of the book to obtain permission to make four hard copies of the book.

4.6.2 POGIL training workshop

The first two sessions of the POGIL training workshops organised by myself were attended by the teachers who agreed to take part in the study. Three chemistry teachers (the facilitators in the study) participated in these initial training workshops: one teacher from school T and two from school C. It was intended for the POGIL strategy to be implemented in the 12 weeks from the onset of school term two. The first two workshops took place in the laboratory at one of the schools while subsequent meetings were arranged as convenient for all attendees. The first workshop took almost three hours and teachers were provided with a POGIL booklet. The booklet was adapted from the David Hanson (2013) instructor's guide on POGIL with his permission as explained in Section 4.6.1 above (see Appendix O).

In the workshops, teachers were exposed to what POGIL entails and their role definition. We looked at the structure of POGIL and how it could be fitted into the term's chemistry curriculum. The benefit of the learning teams cannot be achieved by simply telling learners to form teams. Hanson (2006) suggests that the composition of the learning teams determines POGIL's effectiveness and dynamics. Thus, the facilitators were also instructed on how to assign learners to the learning teams correctly. We agreed to form learning teams of four or five learners to achieve diversity of perspectives and skills, leading to a rich exchange of ideas among the learners. We deliberated on team formation and agreed on having at least a high-achieving learner and a low-achieving learner with two others in each group to provide such diversity. Each learning team also included both male and female learners.

In this study, the worksheets were specifically designed for the POGIL implementation but depending on the stoichiometry unit to be learned, some of the POGIL worksheets did not consistently include the three cycles but had at least two cycles. Thus, adaptation was made concerning the POGIL activities and worksheets to fit the curriculum and the time of each lesson. The most important issue was that the key characteristics that describe POGIL were implemented:

- learners worked collaboratively in groups of three or four with a facilitator present in the class;
- the facilitators mainly served as facilitators in learning stoichiometry concepts;
- the activities were specifically designed for POGIL implementation;
- learners worked on the activities during the scheduled stoichiometry lesson period; and
- learners had assigned roles in their learning teams.

A sample of POGIL worksheets is shown as Appendix P. More so, some of the resource materials for the stoichiometry lessons were provided. The activity worksheet for the first two weeks' lessons was prepared during our second meeting. Figure 4.4 below represents the agreed model adopted for stoichiometry calculations at the workshop.

After the first two training workshops, it was easier to reschedule meetings as we communicated regularly using social media when any of us were not available for the scheduled time. I also checked on each teacher regularly to assess their commitment and address any challenges they might be facing. After our third meeting, two other chemistry teachers that were not facilitators in this study decided to join us. Their reason for attending was that the participating teachers explained how the workshops had enhanced their stoichiometry teaching experiences. During these meetings, teachers came with their concerns or questions on delivering their lessons through POGIL. For example, one of the teachers asked what she could do if any of the learning teams were not collaborating or interacting as they should in completing their tasks. According to Hanson (2006), learners must understand the essence of the learning teams in which their collaboration supports not only the group success but also individual achievement. Thus, simply putting learners into teams is insufficient for their learning in POGIL. We deliberated on the issue and resolved what could help collaboration in the learning teams. Subsequently, I discussed with the chemistry teachers from the participating schools to organise a suitable time for the administration of the questionnaires – this was phase one of this study.

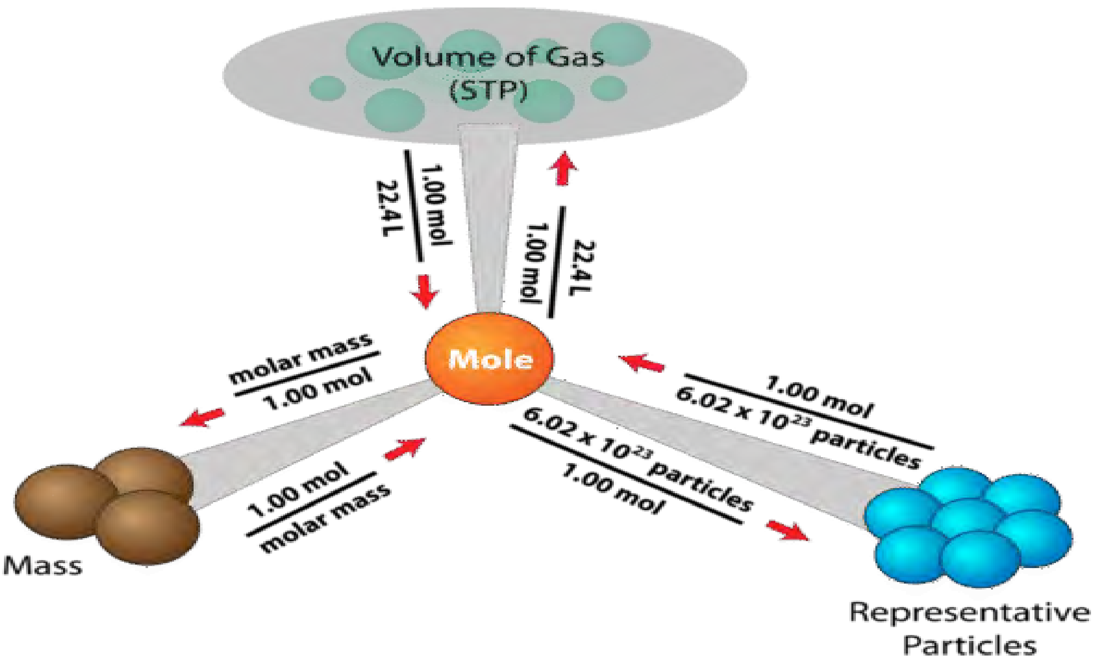


Figure 4.4: Representative model used for stoichiometry calculation (chem.libretexts.org)

4.6.3 Phase 1

Phase one was the pre-intervention when the research tools, TOSRA-2, SAT pre-tests, and SLQ were administered to the learners in the two schools before they participated in POGIL. The questionnaires (SLQ, TOSRA-2, and SAT pre-tests) were administered to a total of 53 learners from the two participant schools. These were administered at the two schools on different days. Consent for learners' participation in the study was obtained from their parents/guardians (see Section 4.10). Learners were given an explanation on how to complete the questionnaires. They were informed that there were no wrong or right answers to the items on the questionnaires. The tools were administered by me with the assistance of their respective chemistry teachers in their classrooms. It took the learners 15-20 minutes to complete TOSRA-2 while they completed SLQ within 10-15 minutes. TOSRA-2 and SLQ tools were administered the same day in the first week of the study. This was after the first two sessions of the POGIL training workshop.

SAT was administered the following week after the first questionnaires were completed. This was done intentionally. Firstly, I did not want to bore learners with completing many questionnaires at the same time which might make them provide information that did not reflect their true feelings or drop in performance on the SAT questionnaire. Secondly, administering all the questionnaires at the same time would have disrupted the learners' lesson periods because of the time needed to complete them. Learners were told to complete the questionnaire to the best of their knowledge and show all necessary calculations. Answer sheets were provided to the learners to complete the questionnaire. Learners took 25-40 minutes to complete the SAT pre-test. The answer sheets were collected and marked by two chemistry teachers using the prepared memorandum. The verification of the marked scripts was done by me and a critical friend.

All the questionnaires were collected and analysed. The SAT and TOSRA-2 pre-tests provided a baseline for monitoring shifts in learners' proficiency and attitude respectively as they participated in POGIL activities in the intervention phase. The SLQ provided the answer to research question 1 on learners' experiences with learning stoichiometry before they participated in POGIL.

4.6.4 Phase 2

The pre-intervention phase was followed by the intervention phase. This was the phase where the chemistry teachers adapted the POGIL instructional strategy in the teaching of stoichiometry. Before the intervention phase with the learners began, the teachers and I had two POGIL workshops. The intervention phase spanned 10 weeks. The units that were taught within the 10 weeks of this study using POGIL were:

- Balancing chemical reaction, mole ratio, and mass relationships;

- Mass-volume relationships;
- Calculation of concentration, molar mass, moles, and volumes;
- Stoichiometry of reaction;
- Acid-base titration;
- Acid-base tritration & calculation;
- Qualitative comparison of conducting of molar solution of strong-weak acid and base;
- Titration – application;
- Determination of percentage purity, percentage yield; and
- Water of crystallisation.

There were four periods per week in both schools with a duration of 40 minutes per period. The following account was from my observations of the POGIL class at each site.

Typically, the chemistry teachers (facilitators in this study) started each lesson period by writing the lesson topic and objectives on the board to orientate learners on the activity for the day. Learners worked in teams, interacting, discussing, and supporting each other to complete their class activities/tasks based on the learning cycles: exploration, concept invention, and application phases. The facilitators provided support and guided each learning team through these cycles. Learners were instructed on the first part of the activity, usually labelled the 'starter activity' on the worksheet – the exploration phase. The starter activities were usually quizzes, series of questions/activities (including laboratory experiments), or a review of the extended activity from the previous lesson that could lead to the current lesson's objectives. Learners were each given worksheets which contained the activities/tasks, but they worked in their teams to complete the worksheets. They were usually given 10 minutes to discuss and work together as a team.

The second section included activities to encourage critical thinking to develop learners' understanding of the concepts – the concept formation/invention phase. While the teams were working, the facilitators moved around each team to keep learners on task, monitor the team interaction, and listen to their conversations. This gave the facilitators insight into how the learners understood the content of the lesson and how to mediate for learning to occur when necessary.

In the application phase, learners' understanding of concepts was reinforced or extended by engaging in problem solving activities. This process enabled transferability of knowledge to familiar contexts (Hanson, 2006; Sen et al., 2016). Learners were then given opportunities to ask questions and complete the extended activities individually. Some of them asked for help from the facilitator or team members once they realised that they were struggling to complete the task.

Depending on the task or activity, the facilitators asked the learning teams to share their findings or strategies with the whole class, while the facilitators built on/provided the correct approach or solution to learners' findings. The facilitators ended their lessons by summarizing salient points and guided learners with extended activities.

My initial intention was to video-record and observe some of the POGIL lessons. However, the videorecording was declined by the school authorities and I was allowed to observe the lessons once in school T and twice in School C. The reason given by the school authorities was to avoid any form of distraction during teaching and learning for both teachers and learners. Nevertheless, the teachers agreed to take pictures of some of the group activities for their reflections. We had opportunities to discuss their (teachers') observations and challenges in implementing POGIL in the classroom during our POGIL meetings.

I made notes of my observations which helped with reflection on the learners' POGIL experiences, and the teachers' adjustment to the facilitators' role. Some of my observations that could help the teachers were discussed with them personally after the lesson and those that would benefit other teachers, especially about the learners, were shared with other teachers with their permission. For instance, I observed that while trying to complete the task given some learning teams were loud and noisy. This was because some of the members believed they had the best strategy and solution to the problem and would not tolerate others' opinions, while those that could not argue with them were passive in the team or tried completing the task individually. Another key issue that we addressed based on my observations was that many of the learners that were assigned the role of recorder in their team were merely reporting and recording the activities without actively contributing to the teams' discussion. These issues were discussed with the teachers and addressed accordingly.

In addition, in this intervention phase learners were guided with entries in reflective journals concerning their experiences with POGIL. Learners had no previous experience of journaling and so many of them found the notion of writing up a reflective journal daunting. However, after explaining what it entailed and giving examples of what could be written in their journals, they were successful at writing up their entries which continued throughout the study (see Section 4.5.5). Learners' journals were collected, with their permission, after the first four weeks and during the tenth week of the POGIL intervention. Copies of the journals were made before returning the journals to the respective learners the same day they were collected. The journal entries provided insights into learners' proficiency in stoichiometry, attitudes towards science, and experience with POGIL while learning stoichiometry throughout the study.

4.6.5 Phase 3

The third and last phase of this study was the post-intervention phase. At this phase, the TOSRA-2 and SAT post-tests were administered to all 53 learners who had completed the pre-tests. The two questionnaires were administered following the same procedure as with the pre-tests after 10 weeks of their participation in POGIL. The post-tests were collected and analysed. The results of the two post-tests were compared with the respective pre-tests to examine the trend of change in learners' proficiency in stoichiometry and attitudes towards science.

After the completion of the post-test questionnaires, I had a conversation with the learners and teachers to schedule a convenient time for the focus group interviews. I observed that most of the learners were excited to participate in the focus-group interviews. They seemed eager to be interviewed to share their experiences. This statement supports the report of Cohen et al. (2018) that children are always excited when interviewed because they feel their opinions and experiences, which they do not always have the opportunity to share, are valued. I scheduled the focus-group semi-structured interviews with each focus group from the two schools at a convenient time agreed on by the school authority, their respective teachers, and learners.

However, just two days before the first scheduled interview, the schools were closed due to the Covid-19 pandemic. With the impact of the pandemic, it became impossible to reschedule the focus-group interviews, as the schools were closed to prevent the spread of the Covid-19 infection among the learners. At this juncture, I had to consult with my supervisors, critical friend, and the teachers involved in the study to devise the way forward. A suggestion of a virtual interview was unanimously agreed upon and subsequently added to the methodology, as determined by the impact of the pandemic on the research process. The teachers and learners were using the WhatsApp platform for sending weekly lessons and other academic communications since the closure of schools due to the pandemic.

The WhatsApp video interview was considered a suitable and safe option to use with consent obtained from learners' parents/guardians. However, before contacting the learners that were interviewed, I obtained permission from the heads of the schools to conduct the interviews via this platform. Subsequently, the selected learners were contacted to explain how the interviews would be conducted because of the pandemic. They were also informed that they could choose not to participate in the interviews if they anticipated any risk or were not comfortable being interviewed. I allowed the learners to choose an appropriate and convenient time for the interviews between the hours of 10 am - 4 pm from Monday - Friday.

The intended sample contacted for the interviews was nine learners based on their proficiency/scores and journal entries as described in Section 4.4. However, one of them was not willing to participate in the interviews thus the learner's feelings were respected, and the learner was exempted. Another learner, though enthusiastic, was exempted from the interviews because of the inaccessibility to a suitable device and technology. It impossible for this learner to participate in the WhatsApp interviews as there was the need to maintain physical distancing and schools were shut, as a result of the Covid-19 pandemic.

The WhatsApp online interviews were thus conducted with seven learners. The seven learners were from seven of the 10 learning teams in this study. The profile of interviewed learners was shown in Table 3 of Section 4.4. The interviews were conducted in English and audio-recorded with the consent of each of the participants. All these learners consented to be interviewed via video WhatsApp. An interview guide was employed but learners could express themselves freely as it related to the study. The interview lasted between 20 and 30 minutes. Besides, I had copies of each participant's journal entries with me at their interview and probed further on some of their comments. For example, L2 wrote in his journal: "*now, it is making sense, let's ride onn (sic)*" (L2). I was able to obtain clarification on what he meant by the statement during the interview. Also, another learner, L40, had a drawing in his journal that I could not interpret and I asked for the interpretation of the drawing during the interview.

In two of the sessions, the learners were keen to talk more at the end of the interview emphasising their excitement to share their experiences. Some even asked if there would be more sessions. They were pleased with the opportunity to share their learning experiences with somebody. Correspondingly, Cohen et al. (2018) aver that children feel positive when interviewed as they feel that their opinions are valued. The interviews allowed the description of how learners' proficiency in stoichiometry and attitudes has shifted, as well as providing the experience they valued in POGIL in responding to research question 4. This also strengthened the answers provided to research questions 1, 2, and 3 by the SLQ, TOSRA, and SAT research tools. Figure 4.5 below outlines the timeframe over which the study was carried out.

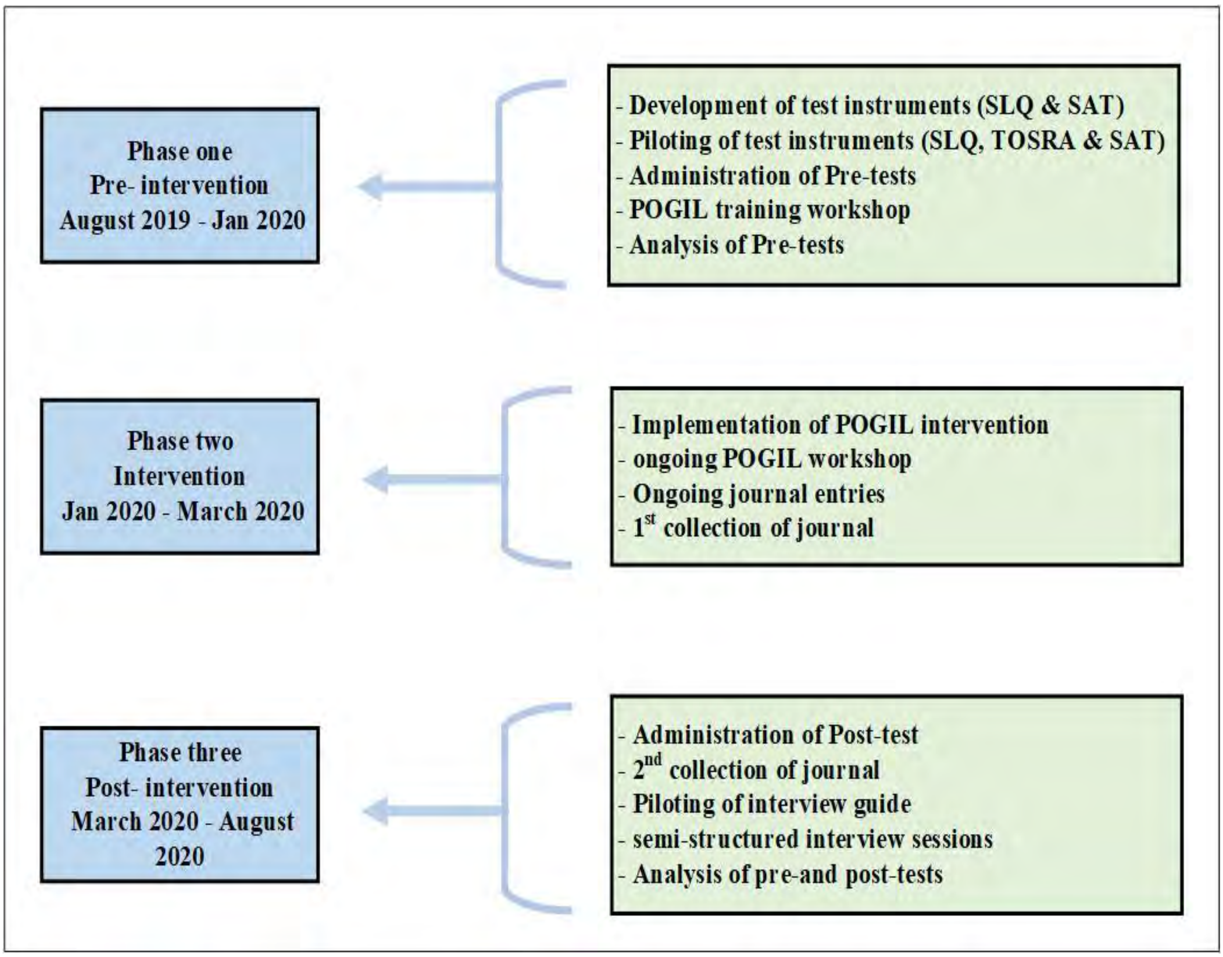


Figure 4.5: Outline of the timeline of the study

4.7 Pilot Study

Pilot tests are usually done in advance before a research tool is used in the field (Cohen et al., 2018). Cohen et al. (2018) assert that pilot tests increase the reliability, validity, and practicability of a study. Pilot studies of the SLQ, TOSRA-2, SAT and the interview guide were carried out with 36 SSS 2 learners who were not participating in the study. This occurred after the tools were validated and revised by both the expert panel and my supervisors as described in Section 4.5. The tests were conducted using the same protocol and setting as the study sample. The purpose of the pilot was to verify if the items on the research tools, the instructions given, and the response format were clearly understood by the learners.

Subsequently, several items were rephrased or expanded to avoid ambiguity, some were re-ordered while some were considered inappropriate for the learners. The modified version of these questionnaires (SLQ, TOSRA-2, and SAT) were adapted for this study. Likewise, the interview guide was pilot tested initially with one of the learning teams of this study. The pilot testing allowed me to reassess the process: what went well, what needed to be modified, the sequence of questions, and the strategies to employ for eliciting responses. Some vague and leading questions were also reworded. For example, the question "has the method used by your teacher in teaching stoichiometry helped you in understanding stoichiometry?" was rephrased to "how would you describe the method used by you teacher in teaching stoichiometry in relation to your understanding of the topic?" Also, the interview guide was modified following suggestions from my supervisors as appropriate.

More so, before the WhatsApp interviews, I carried out a pilot testing of the process with two learners that were not participants in the study but had similar characteristics with the study sample. The pilot testing allowed me to assess the practicality of using WhatsApp video and audio-recording the interview session as well.

4.8 Researcher Positionality

The issue of positionality and its influence on research is an important aspect of educational research that must be addressed. According to Cohen et al. (2018), positionality describes an individual's world view and the position they adopt in a research setting. Researchers occupy different social and power positions from participants in all educational research. This stance impacts the way the researcher conducts their research and how the participants of the research perceive them (ibid.).

Given my position as the head of the science department in my school, I have attended or been involved in the organisation of workshops for science/chemistry teachers within the province. This created an environment where I interacted with many science teachers and resulted in the development of relationships. This study involved an intervention phase in which the input of chemistry teachers was essential in implementing POGIL in the stoichiometry classrooms.

Before obtaining consent from the school authorities, I informally had discussions with anticipated chemistry teachers to assess their willingness to be engaged with this study. Most of them were interested but because of the nature of their school system and time, they could not commit. Being a chemistry teacher for more 10 years, I understood the potential challenges. If the school authorities had permitted the study to be carried out without appropriate consultation with the teachers, they might feel compelled to participate in the study. Thus, I ensured that all chemistry teachers in this study were not forced or obliged to participate. Besides, these teachers were my junior colleagues and facilitators in POGIL classrooms.

When the study began, my role was to collaborate with the teachers to organise suitable times to meet for workshops and collect data, having explained the data collection procedures. During the workshops, I was aware of the dynamics resulting from my positionality in comparison to my colleagues. I had previously attended a workshop on POGIL, so consequently I ensured a balance between giving guidance, advising, and telling them what needed to be done. If not handled well, this could inadvertently inhibit creativity, or negate their thoughts and ideas which were crucial for the research.

My objective was to make sure all the teachers understood this as a research that supported their teaching. During the research process and workshop, I made sure that individual voices were heard and that they all had a part to play. As already stated above, although I occupied a more senior position to the teachers, I assumed the position of a researcher, as I had taken up more administrative responsibilities as head of the science department over the years. Thus, the teachers had more current practical experience of teaching chemistry. I, therefore, positioned myself as a co-learner with these teachers in the POGIL workshops and encouraged their input at co-developing the stoichiometry learning materials and encouraged feedback from the teachers. Consequentially, we were all members of a community of practice (CoP)[3].

Cohen et al. (2018) suggest that one of the strategies to reduce power differentials in research with children is to allow them to have a *voice* in decision making. The participants involved in this study were more vulnerable, as they were children between the ages of 13 and 15 years.

[3] CoP is a context which enables interaction, collaborative activities, and relationship building among members in a sustained pursuit of a shared enterprise (Wenger, 1998).

To reduce the power imbalance and to put learners at ease, I allowed them to have input concerning the scheduling of the dates and times for the interviews.

Also, throughout the interviews, I allowed participants to discuss freely so that the interview was not another question-and-answer session. This process was positively reinforcing and enjoyable for most of the learners. Also, I made sure that participants did not feel that they were obliged to explain themselves or give answers to every question. For example, when I probed further or asked for reasons why they gave a particular answer to a question, I was sensitive to their willingness to express their views without them feeling I was putting them on the spot.

As Cohen et al. (2018) remark, there is no research that is completely neutral and objective but the researcher should aim for neutrality as much as possible. Thus, I became increasingly aware of areas with potential bias, and made sure I took those into account. Hence, I strived to avoid obvious and conscious bias in the process of data collection, interpretation, and presentation. This is further discussed in Section 4.10

4.9 Data Analysis

Cohen et al. (2018) describes data analysis as a process of reducing large amounts of data to make some sense through organising, sifting, sorting, and reviewing. Data that were generated with the research tools go through data analysis to provide answers to research questions (Christensen et al., 2015; Cohen et al., 2018). According to Denscombe (2010), quantitative research uses numbers as the unit of analysis while words or visual images are the units of analysis for qualitative research. This was a mixed-methods research, thus both quantitative and qualitative data were generated and analysed to provide answers to research questions 1, 2, 3, and 4. Cohen et al. (2018) suggest that in mixed-methods research, the quantitative and qualitative data can be analysed separately and independently. Thus, the approach to the quantitative and qualitative data analysis is given below.

4.9.1 Approach to quantitative data analysis

The quantitative data were entered and analysed using the Statistical Package for Social Science (SPSS) version 25. Cohen et al. (2018) opine that in quantitative data processing and analysis, researchers will need to decide on the scale of the data being used (categorical, ordinal, interval, or ratio) and the kind of statistics to be used (either inferential or descriptive), among others. In this study, the quantitative data were described using descriptive data analysis methods such as frequencies and percentages. Descriptive data analysis simply involves understanding, describing, summarising, and reporting data itself without making inferences (Christensen et al., 2015; Cohen et al., 2018. It usually presents data making use of frequencies or graphical representations such as bar charts, scatter plots, histogram among others, to describe characteristics of a data set (Christensen et al., 2015; Cohen et al., 2018).

The perception rating section (close-ended) of SLQ were: Not Sure (NS), Very Difficult (VD), Difficult (D), Easy (E), and Very Easy (VE). The percentage of learners' ranking of each stoichiometry unit were shown on a bar chart, while the percentage of stoichiometry units that were rated difficult, easy, and not sure was also shown on a pie chart. This presented an overall trend of stoichiometry units as perceived by the participants.

Positive items in the TOSRA-2 were scored 5, 4, 3, 2, and 1 for the responses SA, A, NS, D, and SD respectively (Fraser, 1981). Negative items were reversed scored, which is 1, 2, 3, 4, and 5 for responses SA, A, NS, D, and SD (ibid.). The trend of learners' responses to each item was shown using a bar chart. Moreover, items ratings in the same subscales were added together, that is, learners' scores in each of the attitude subscales. According to Fraser (1981), higher scores in TOSRA indicate a better attitude towards science. The total possible attitude score for this study ranged from 35-175 points.

Learners were profiled into three main attitude groups according to their scores: high, average, and low. This was done using the class interval formula: the range of scores / number of groups = (175-35)/3 = 46. The class width was 46. The high scores between 175-129 were grouped as high attitude, scores of 128-82 were grouped as average attitude while scores from 81 and below were the low attitude group. These groups provided the opportunity to analyse how learners moved within the groups before and after their participation in POGIL.

Descriptive data analysis was also carried out on the SAT pre-test and post-test scores. The total scores for each participant and overall means were calculated for both pre-test and post-test. Learners' responses were marked and analysed according to the indicators for each of the proficiency strands in the analytical framework (see Table 3.1). The total possible scores for SAT ranged from 0-60. A learner's proficiency was calculated based on the responses to the items assessing each strand of proficiency. The scores on each strand were added and learners were assigned a level of proficiency based on their overall score: ‘proficient’, ‘intermediate proficient’, and ‘below proficient’ learners.

The class interval formula was also used to profile learners. The highest and lowest proficiency scores of learners for both pre-test and post-test were compared. The total scores on each proficiency strand – conceptual understanding (CU), procedural fluency (PF), and Strategic competence (SC) were represented using bar charts. In addition, the percentage of learners in each category of each of the strands was also shown with bar charts.

The difference between the pre-test and post-test data were measured using the paired sample *t*-test. A paired sample *t*-test is used to compare the statistically significant difference between means of data from the same individual or units measured at two different points in time (Cohen et al., 2018). Both the pre-tests and post-tests of TOSRA-2 and SAT were analysed using the paired samples *t*-test to establish any statistical differences between their means. The level of significance for this study was set at $p = 0.05$ (Cohen et al., 2018).

4.9.2 Approach to qualitative data analysis

As Cohen et al. (2018) remark, the ‘one-size-fits-all’ formula does not apply to qualitative data analysis and presentation but is more concerned with *fitness for purpose*. With qualitative data analysis the researcher focuses more on the rich, context-specific, and subjective situation or data meaning-making and interpretation through the process of data reduction, display, analysis, drawing, and verification of conclusions (Cohen et al., 2018; Merriam & Tisdell, 2015). An inductive approach to data analysis was used for the qualitative data generated from the SLQ, interviews, and learners’ journal entries based on the research objectives. Inductive analysis is a form of pattern recognition through reading, re-reading, and interpretation of raw data to make meaning without preconception from a given framework (Cohen et al., 2018; Merriam & Tisdell, 2015). It allows research findings to emerge from the frequent or significant themes derived from the data (Cohen et al., 2018).

The SLQ qualitative data were analysed first, as the data were generated at the beginning of the study, but this was re-examined when the other data were available. The qualitative data analyses were in five stages as described by Cohen et al. (2018).

The first stage was data preparation. This stage involved transcribing and organising data from the audio-recorded interviews and journal entries. This was followed by reading through texts from journals, the SLQ, and transcripts of the interviews where key points or statements relevant to the study objectives were identified and highlighted in the texts. Multiple readings of the transcripts were done to identify patterns in the way learners responded to key questions guided by the analytical framework (see Table 3.1) and to be sure no statement was missed. The highlighted statements were compared to determine their meanings in the sentences.

In the second stage, short word descriptions and codes were generated for the highlighted statements. Trends, similarities, and contradictions were checked during the process of coding. Cohen et al. (2018) recommend that codes and categories that are generated can be reviewed and validated by processes such as stakeholder or member checks, blind parallel coding, and checking of clarity of categories by a second researcher. The stakeholder or member check and checking of clarity of categories were employed in this study. Firstly, the transcriptions of individual interviews and some journal entries were checked and validated by the participants to ensure credibility with data interpretation. Secondly, the audio-recorded interviews were transcribed and cross-checked with a critical friend. Also, the codes and categories were given to the critical friend to assign to the transcripts. This was checked and reconciled afterwards with my first allocation.

In the third stage of analysis, similar codes were combined to generate a theme. The themes were derived from codes from the interview transcripts and journal entries. The themes were checked for overlaps and divergence. Names were generated for each theme based on the emerged data. Single statements or data outside the broad themes were discussed rather than eliminating them as irrelevant. In the fourth stage, the themes were used to form the analytical memo with all its corresponding codes organised. Data were recorded across the participants and across the data sources – journal entries and interviews – in an analytical memo. The analytical memo served as a means of conceptualising and organising the themes that were generated.

The fifth stage primarily involved reporting the research findings or providing meaning to the data. According to Cohen et al. (2018), qualitative data can be presented in many ways. One of these ways is by organising and analysing data by research questions (Cohen et al., 2018). With this approach, relevant data from all instruments are collated and presented systematically to provide a collective answer to the research question (Christensen et al., 2015; Cohen et al., 2018). Relevant data from the SLQ, interviews, and journal entries were drawn together to answer the research question. This approach enabled the exploration of patterns and relationships across research instruments. Thus, results from the qualitative analysis were checked with quantitative data to support or counter the findings. For instance, learners' written answers and problem-solving strategies applied to the pre- and post-test were described when discussing the SAT findings and used as the basis for relevant arguments in the qualitative data discussion. Emerged themes were discussed with reference to the literature and theoretical frameworks. More so, excerpts from the SLQ, interviews, or journal entries were used to increase the internal reliability of the study. Figure 4.6 below shows a summary of the qualitative data analysis stages.

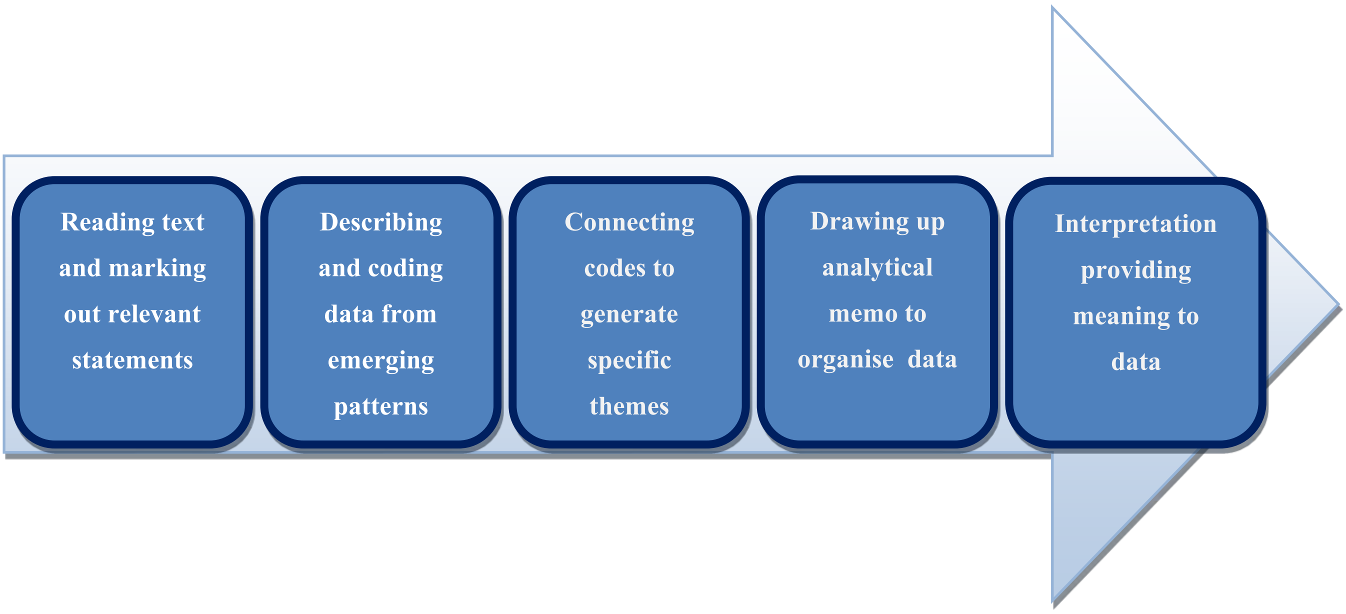


Figure 4.6: Stages of qualitative data analysis (adapted from Agunbiade, 2015)

4.10 Research Validity and Reliability

Research quality and credibility are important dimensions that must be clarified as part of the research process itself (Cohen et al., 2018). Cohen et al. (2018) elucidate that any research without credibility is worthless. Thus, researchers must strive to "minimize invalidity in their studies and maximize validity" as it is impossible to obtain absolute validity from any research (Cohen et al., 2018, p. 245). These authors enlighten that four criteria can be used to establish the authenticity of qualitative research: credibility, transferability, dependability, and confirmability. These enable shifting the research from a study of questionable value to a quality study that meets its purpose (Cohen et al., 2018). Thus, these four criteria were used to establish the credibility of this study.

Credibility, also referred to as the "truth value" (Cohen et al., 2018, p. 248), is the extent to which researchers demonstrate that their research findings are believable, accurate, and appropriate (Cohen et al., 2018; Denscombe, 2010). Credibility involves the degree of honesty, depth, richness, and scope of data achieved, the extent of triangulation, and researchers' objectivity in qualitative research (Cohen et al., 2018; Merriam & Tisdell, 2015). To ensure credibility in this study, I have used multiple data sources referred to as triangulation. Triangulation is the reflection of ideas gleaned from different sources and procedures to corroborate information.

In this study, different methods of data collection were used namely questionnaires (SLQ, TOSRA-2, SAT), semi-structured individual interviews, and journal entries. For example, learners' responses in the interviews were checked against their comments in their respective journal entries. Data recorded across different participants and the agreement between responses of different participants to the same questions ensured triangulation through multiple sources. Merriam and Tisdell (2015) inform that triangulation is a significant approach to increasing the credibility of any research. Similarly, Cohen et al. (2018) point out that credibility in mixed-methods research involves weakness minimisation. This is the extent to which the weakness of one approach is compensated by the strength of the other (Cohen et al., 2018). In this study, data that were generated through quantitative methods were clarified or supported by the qualitative data or vice versa.

In addition, Merriam and Tisdell (2015, p. 245) suggest "triangulating analyst" as a strategy to obtain credibility. This involves having more than one person independently analysing the same data to compare their findings. One of my colleagues in science education played this role as my critical friend. The quantitative analysis, audio-recorded interviews, copies of learners' journal entries, and coding of the data were checked by my critical friend. My critical friend also asked questions that helped me to consider alternative ways to look at the data.

Another strategy often deployed to enhance the credibility of a study is "respondent validation" or "member checks" (Merriam & Tisdell, 2015, p. 246). Respondent validation is the process of ruling out misunderstanding or biases in preliminary findings by obtaining feedbacks from respondents (Merriam & Tisdell, 2015). The findings of individual interviews and some journal entries were checked with participants to determine whether I had accurately interpreted their viewpoints. Modifications were made based on their feedback. Moreover, the interview guide, SLQ, and SAT questionnaires were reviewed by my supervisors and piloted to ensure their appropriateness for the study.

Dependability involves providing an explicit account of the methodological procedures, analysis, and decisions taken in research (Cohen et al., 2018). This entails mapping out an audit trail of the research from conception to the conclusion and this acts as a proxy for being able to replicate research (Denscombe, 2010). In this study I have given a detailed account of the procedures, decisions taken, and challenges during the research process. In addition, my supervisors and fellow education researchers provided the evaluation of the research process by asking questions about the objectives, procedures, and interpretation of the research.

I also kept and consistently recorded each process and the decisions taken in my research journal. This allowed for accurate data reporting and detailing of the research procedures. More so, excerpts from the interviews, learners' journal, and SLQ provided a rich description of learners' viewpoints. Raw data such as written answers in the tests were used in describing learners' ideas/understanding. This also enhanced data corroboration.

Transferability refers to the extent to which the findings of research can be transferred to other settings, across different participants or situations (Denscombe, 2010). Merriam and Tisdell (2015) argue that transferability in research is concerned with readers being able to concur with the findings of the study as consistent with the data collected rather than replicating the result in other studies. To achieve transferability in research, the researcher must supply information enabling others to reliably infer the relevance and applicability of the findings to make the comparison (Denscombe, 2010; Merriam & Tisdell, 2015). For this study, I have provided the details of the learners who were participants of the study, the study context, my role in the research, and a rich description of procedures undertaken to complete the study. I was also able to compare findings across the research instruments. These would enable readers to infer the relevance and applicability of the findings of this study.

Confirmability, which is also objectivity, is the extent to which research findings are free from the influence of the researcher who conducted it. Cohen et al. (2018) argue that qualitative data are the product of the researcher's interpretation, thus, it is difficult to produce a research free from their (researchers) personal prejudice. An effort was made to reduce the effect of my contribution as the researcher in the collection of data, analyses, and inferences. The process of data analyses as outlined in Section 4.9 and the analytical memo demonstrates how themes were supported by excerpts from the raw data. This ensured that data interpretation can be directly linked to the words of participants. In addition, the quantitative analysis, and transcripts generated from journals and learners' interviews were compared and cross-checked with a critical friend.

4.11 Research Ethics

Research ethics concerns the code of professional conduct for researchers (Cohen et al., 2018). Qualitative research requires ethical considerations regarding data collection and dissemination of findings (ibid.). The sources of data in this study require obtaining informed consent from participants and institutions that were involved. In the first instance, permission to conduct this study was given by the Rhodes University Standard Ethical Committee (Human Ethics Sub-committee) (see Appendix A). Also, I obtained gatekeeper permission to the research site and participants (see Appendix B).

In addition, I completed the Rhodes University Faculty of Education Ethics Approval Application form. This was submitted with the research proposal to the Rhodes University Education Higher Degrees Committees. In completing the form, I outlined my research and ethical approach. Therefore, in conducting this study, the following ethical principles were defined and considered.

Respect and dignity: The participants of this study were young children therefore, consent from learners and their parents or guardians was sought by giving out informed assent and consent letters, respectively. The parental consent letters were written in English and three other major languages that are spoken by learners in the metropolis (Yoruba, Hausa, and Igbo). This was to ensure that parents who were not literate in the English language had access to other languages spoken in the metropolis. The letters were sent through the learners to their parents or guardians. The letters explained the purpose of the research, the anticipated participants' involvement, and participants' voluntary withdrawal at any time without any consequences. They were required to sign and return the reply slip indicating whether they gave consent as was appropriate. Hence, participants of this study were learners whose parents consented to their participation (see Appendices D, D1, D2, and D3 - parental consent letters).

Afterwards, learners were asked to read and sign the participant's assent form. They were verbally informed that their participation in this study was voluntary and that they could withdraw anytime without consequences. Their role and rights as participants in this study were also discussed with them. The form detailed the research purpose, participants' involvement, and assessed learners' understanding of what they were required to do. The form also indicated that learners could disallow the use of any media (see Appendix C - Consent Form). I also made the learners aware of the major phases of the research process and that their participation was not in any way tied to their grades or other academic work.

The issue of confidentiality and anonymity was explained in the letters and verbally to the learners before the study began and during the study. They were assured that the data collected would be used for research only and would not be revealed to their parents nor their teachers. In addition, only learners who consented to be interviewed via WhatsApp were interviewed (see Section 4.6.5). During the WhatsApp video interviews, I sought participants' permission for the audio recordings and the use of videos.

Moreover, the schools' rules, interest, and learners' interest and privacy were respected and protected throughout the study. The questionnaires were administered, and interviews were conducted at a convenient time with premises agreed upon by the participants and school authorities. The schools and learners were guaranteed anonymity as pseudonyms were used in reporting the findings of the study. All other means of identification were also removed in compiling the study. Learners were assigned identification numbers from 1-53 in the quantitative data while these numbers were linked to learners' pseudonyms in the qualitative phase. Learners volunteered to give themselves pseudonyms and this was used as identification in their journals. The assigned numbers were used in the reporting of the data to ensure anonymity. The pseudonyms were also used to indicate the schools as seen in Section 4.4.

Cohen et al. (2018) note that it is uncertain that children would share their experiences with someone with whom they have had no interaction or relationship with. Thus, it is important to gain their trust and help them feel at ease. At the beginning of the study, I interacted with the learners to help them feel at ease before administering the pre-test questionnaires. I also consistently visited their classrooms when permitted to encourage them to write in their journals as well as reminding them of the research process and their non-obligatory participation. This process enabled me to create a good relationship with the learners. In addition, I sought the permission and agreement of the chemistry teachers to participate in the POGIL workshop and their cooperation in the POGIL implementation in their classrooms. This is shown in Appendix E.

Transparency and honesty: The purpose and procedures of this research were clearly explained to all stakeholders in this research – the teachers, learners, and school heads. This was to ensure that the study was conducted in an honest and transparent manner. I used simple English in communicating information to ensure participants understood. This is the accepted language of communication in a formal school setting in Nigeria.

Accountability and responsibility: This research was conducted in compliance with the research principles as stipulated by Rhodes University, and I was in constant communication with my research supervisors for guidance and clarity. In addition, while working collaboratively with the facilitators, the cost of producing the necessary POGIL materials was borne by me. I also ensured that the data generated from this study were handed carefully, recorded, transcribed, and stored by myself in a secure place.

Integrity and academic professionalism: As mentioned above, this research was conducted in a manner that respected the participants' integrity. The research design and procedures were clearly detailed. Hence, throughout the course of this study I strived to conduct the research in an academically professional manner by following research principles such as validation of research tools, and member checking so that potential researcher bias, ambiguity, and inaccuracies were minimised.

4.12 Chapter Summary

In this chapter, I explained the study as situated in the pragmatic paradigm. The research design in terms of mixed-methods, timescale, research tools to generate answers to the research questions, research site, sampling, research procedures, and approach to data analysis were also discussed. Lastly, I detailed the approach to ensure that the study was authentic and the ethical considerations as it related to this study. This next chapter presents the findings of this study.

CHAPTER FIVE: LEARNERS' EXPERIENCES OF STOICHIOMETRY BEFORE THE POGIL INTERVENTION

> *Constructive pedagogy is said to be the creation of classroom environment, activities and methods that are grounded in a constructivist theory of learning with the goals that are focused on individual learners developing deep understanding of the subject matter of interest and habits of mind that aid in future learning and teaching*. (Nhase, 2019, p. 56)

5.1 Introduction

Research question one: *What enabled and /or constrained the learning of stoichiometry concepts by learners in the senior secondary school prior to the POGIL intervention?*

The focus for research question 1 was to explore learners' experiences of learning stoichiometry concepts before they participated in POGIL activities. This chapter therefore presents, analyses, and discusses the data from the stoichiometry learning questionnaire (SLQ). The SLQ aimed to collect data on learners' perspectives on each stoichiometry unit and elicit their previous experiences learning stoichiometry.

As explained in Chapter Four, in order to answer the first research question, I present two views of the collected data: quantitative and qualitative. On the one hand the quantitative data were analysed using SPSS to reveal learners' opinions of each stoichiometry concept and the proportion of stoichiometry concepts that learners considered difficult or easy to understand before they participated in POGIL. As described by Cohen et al. (2018), combining scales to form categories shows a general trend of data. The perception rating section (close-ended) of the SLQ were: Not Sure (NS), Very Difficult (VD), Difficult (D), Easy (E), and Very Easy (VE). These ratings were combined into three main categories which were: Difficult (D), Easy (E), and Not Sure (NS). Using the combined categories, the percentage of learners ranking each stoichiometry unit as difficult, easy, or not sure was shown on a bar chart. While the percentage of stoichiometry units that were rated difficult, easy, or not sure was also shown on a pie chart. This presented a general trend of stoichiometry units as perceived by the participants.

These results were displayed with bar charts and a pie chart, respectively. On the other hand, the qualitative data presented learners' experiences learning stoichiometry concepts before they participated in POGIL. Learners' responses to the SLQ (n = 53) were collated and analysed to form broad categories. Subsequently, three main themes emerged: teacher/instructional characteristics, nature of the subject (stoichiometry), and learners' attributes representing learners' stoichiometry learning experience prior to the POGIL intervention. In the final sections of this chapter, I discuss the results presented based on the research question. Learners' excerpts were also integrated while discussing the results.

5.2 Data and Findings from Stoichiometry Learning Questionnaire (SLQ)

The SLQ data were analysed based on 53 learners that completed the questionnaire. As briefly mentioned earlier, the scales were combined into three main categories: difficult (difficult + very difficult), not sure, and easy (easy + very easy) to determine the overall learners' assessment of the stoichiometry concepts as easy or difficult. Learners' assessment of stoichiometry concepts represented in the SLQ (see Appendix G) before the POGIL intervention is shown in Figure 5.1 on the following page.

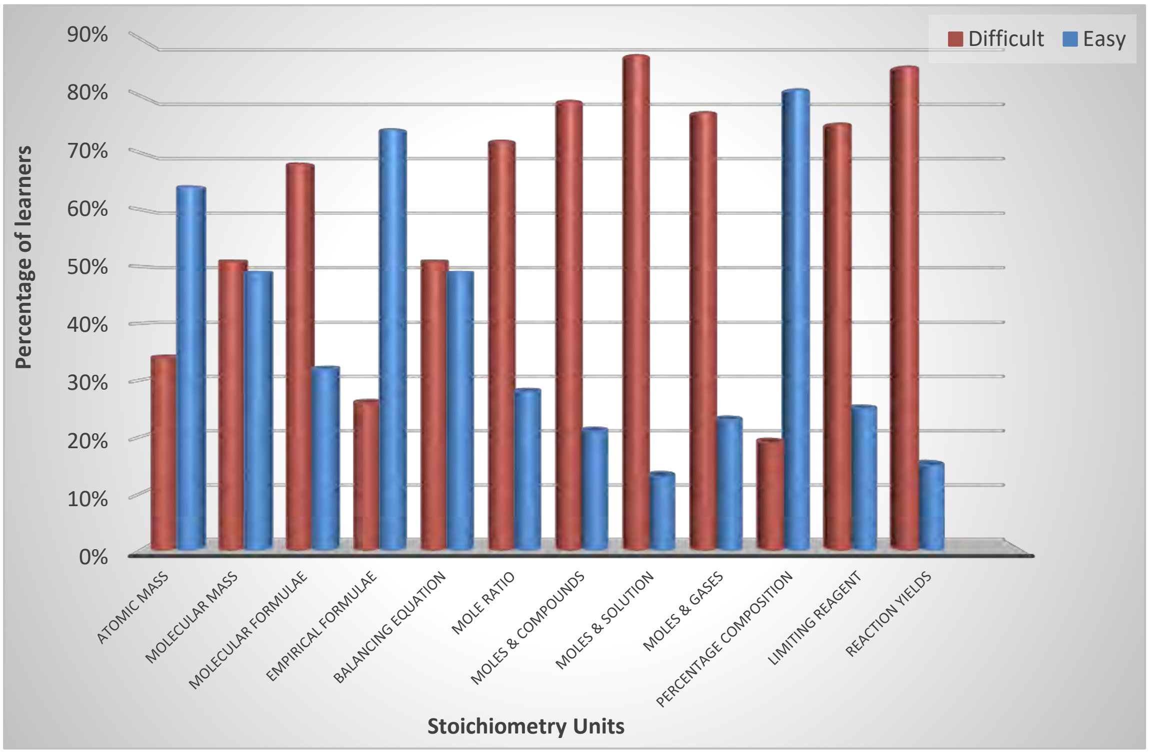


Figure 5.1: How learners feel about each stoichiometry unit

Figure 5.1 shows that only 34% of the learners surveyed rated atomic mass as a difficult stoichiometry concept while more than half (66%) of the learners felt that it was easy. This is similar to their opinion about empirical formula where 74% of learners identified it as an easy concept, and less than half (26%) found it difficult. A similar pattern was observed for percentage composition, where 81% of learners felt it was easy and only 19% considered it difficult. Surprisingly, there were no 'NS' ratings for any stoichiometry unit.

There was albeit a different perception about molecular formulae, mole ratio, mole & gases, moles & compounds, moles & solutions, limiting reagent, and reaction yields. Consistently, most of the learners (about or more than 70%) indicated that these units were difficult. This infers that most of the learners found these seven stoichiometry units difficult to understand or learn. However, a similar proportion of learners identified balancing chemical equations as an easy or difficult concept; 49% and 51% respectively. Likewise, an almost equal percentage of learners, 51% and 49% referred to molecular mass as a difficult and easy unit, respectively.

The level of difficulty ratings for stoichiometry concepts by learners is shown below.

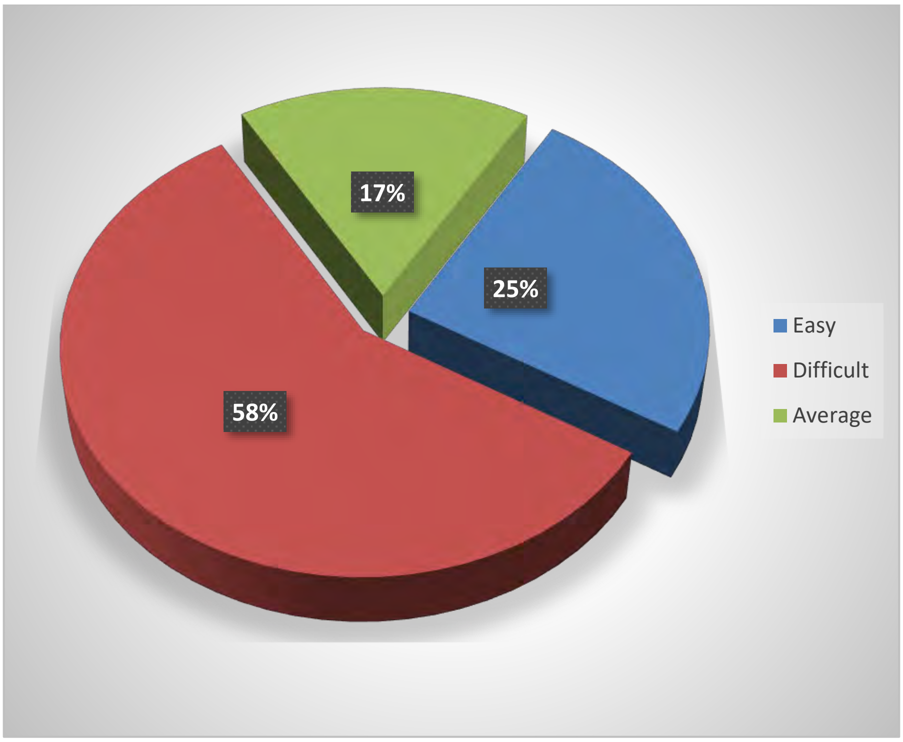


Figure 5.2: Learners' level of difficulty rating for the 12 stoichiometry concepts

Figure 5.2 shows that more than half (58%) of the 12 stoichiometry units were perceived as difficult while 25% of the units were identified as easy concepts. However, 17% of the stoichiometry concepts were perceived as moderately easy or difficult. This shows that learners perceived most of the concepts taught in stoichiometry as difficult to learn or understand.

5.2.1 Learners' experience learning stoichiometry before the POGIL intervention (SLQ)

Learners' responses to the items assessing what enabled and/or constrained the learning of stoichiometry concepts before the POGIL intervention from the second section of the SLQ were collated and analysed. Learners' responses were pulled together into categories. These categories were reviewed by checking for similarities, overlaps, and contradictions. Three main themes emerged from the categories representing factors responsible for learners' perceived difficulty with stoichiometry concepts.

The three themes are:

- Teacher/instructional characteristics.
- Nature of the subject (stoichiometry); and
- Learners' attributes.

Table 5.1: Learners' indication of factors responsible for their experiences with learning stoichiometry concepts before the POGIL intervention

Theme	Description
1. Teacher/instructional characteristic	• Teacher-centred teaching • Lack of appropriate teaching strategy • Fewer problem-solving exercises in the classroom • Lack of discussion in the classroom • Boring stoichiometry lessons • Loads of learning outcomes expected in a single lesson
2. Nature of subject/unit (stoichiometry)	• Confusing meanings of stoichiometry concepts • Abstract nature of stoichiometry topics • Too many calculations/mathematics involved in stoichiometry • Too many concepts with no meaningful connections between them
3. Learners' attributes	• The pre-conceived notion of difficulty of science/stoichiometry • Lack of interest in stoichiometry concepts • Interest in science/science careers • Preference for rote learning • Adequate/insufficient mathematical skills • Coaching from family members and friends

5.2.2 Factors influencing positive experiences when learning stoichiometry concepts

Learners' responses to SLQ items on what will make difficult concepts easier to learn were highlighted and arranged to form categories. These categories were reviewed to check for similarities and contradictions.

Only one theme emerged representing what learners view could influence positive experiences with learning stoichiometry:

- Instructional characteristics

Table 5.2: Factors influencing positive experiences when learning stoichiometry concepts

Theme	Description from highlighted text
Instructional characteristics	• Making abstract topics more concrete • Stepwise explanation by the teacher • Spending more time in learning concepts • Practical experience • Making connections between stoichiometry and learners' environment • Simplifying concept with examples

5.3 Discussion of SLQ Result - Learners' Experiences Learning Stoichiometry Concepts Before They Participated in POGIL

The first section of the SLQ instrument set out to determine the stoichiometry concepts that were perceived as either easy or difficult by learners before the POGIL intervention. Based on the SLQ, more than half (58%) of stoichiometry concepts were perceived as difficult. About a quarter of the concepts were considered easy, while 17% were considered neither easy nor difficult (see Figure 5.1). 'Moles & solutions', 'reaction yields', 'moles & compounds', 'mole & gases', 'limiting reagents', and 'mole ratio' were the six concepts perceived as being most difficult to learn. More than 70% learners indicated that these were difficult concepts to learn.

On the other hand, 'percentage composition', 'atomic mass', and 'empirical formulae' were perceived as easy concepts to learn by 87%, 68%, and 74% of learners respectively (see Figure 5.2). These figures suggest that a large proportion of the learners surveyed perceived a considerable number (58%) of stoichiometry concepts as difficult to learn. This is in keeping with observed problems with mathematics-based topics involving calculations.

Similar findings were reported by various studies on perceived difficult topics/units in chemistry. For instance, Childs and Sheehan (2010) report that chemistry topics that involve any form of mathematical calculations always appear higher in the difficulty list of chemistry topics. Chemistry units such as 'mole', 'volumetric calculations', and 'concentrations of solutions' were rated difficult topics on the list. This finding also supports that of Uchegbu et al. (2016) who found that 'mass-volume relationships' are perceived as difficult chemistry topics among others by SSS 2 learners in Nigeria.

Interestingly, in this study, both 'balancing chemical equations' and 'molecular mass' were perceived as difficult or easy concepts by a similar proportion of learners. This finding contrasts with Childs and Sheehan's (2010) which shows 'balancing chemical equations' is at the top of the list of difficult chemistry topics. Correspondingly, Uchegbu et al. (2016) found that learners find 'balancing chemical equations' an easy chemistry concept to learn.

The second part of the questionnaire was an open-ended section where learners were asked to indicate the reasons why they perceived a unit as being difficult or easy to learn. Three main themes emerged as factors enabling or constraining the learning of stoichiometry concepts (Table 5.1). These themes are further explored below.

5.3.1 Instructional characteristics

Learners seemed to dislike the traditional method used to teach them stoichiometry. For instance, most of them expressed that "*just sitting to listen to their teachers and taking notes without understanding what they meant*" is the usual practice in their chemistry classes. They considered this method quite boring. They made comments such as "*teachers do not give an adequate explanation to help with understanding the concepts"*. The following statements describe verbatim how learners felt while learning stoichiometry before the POGIL intervention. Considering this, three learners reflected that:

> *Because I don't understand many of these topics. I just copy what is written on the blackboard and the explanation from the teacher… I do not understand them. (L34)*

> *These topics are difficult to understand because the class is so boring, we just listen and copy notes or questions written on the board and I don't understand how it is done. (L15)*

> *Because we just listen to what I don't know, copy notes and try to memorise it for exams, I don't like stoichiometry at all. (L20)*

The above statements describe learners' disenchantment due to the lecture-driven stoichiometry class with no adequate support for learning. Their stoichiometry classes lacked activities, they watched their teachers solve problems without knowing 'how', and took notes without any supporting hands-on activities to follow-up when away from the learning environment. Thus, learners assumed a passive role while the teachers transmitted processed information to them without proper engagement in critical thinking. They felt that the difficulty in stoichiometry was associated with boredom emanating from the 'chalk and talk' method without engaging activities. Asheela et al. (2020) in their study, report that engaging learners in hands-on activities is of paramount importance in science learning. Hands-on activities make learning meaningful, fun, help learners internalise what they have been taught, and develop understanding of difficult scientific concepts (Asheela et al., 2020).

The ineffectiveness of the traditional teaching approach as opposed to other instructional strategies in science has been compared by many researchers (Ajayi & Ogbeba, 2017; Cardellini, 2012; Opara, 2014). Over time, the lecture method has been considered an inefficient way of engaging learners in the classroom. It is described as teacher-centered whereby learners are regarded as empty vessels who passively receive information from the teacher (Cardellini, 2012). This approach often makes learners complacent about learning. In essence, they find any task that requires a more thoughtful process as difficult. Learners' experiences with the instructional technique in learning stoichiometry had an adverse effect on their understanding of stoichiometry, hence their perception of stoichiometry as difficult.

According to Omiko (2017), one of the reasons responsible for learners' difficulties in chemistry is an inadequate explanation of basic chemistry concepts which often deter proper understanding. The use of appropriate teaching methods and local examples from the learners' environment aid their understanding and arouse their interest in chemistry (Omiko, 2017). Learners who are deficient in conceptual understanding perform poorly and consequently perceive these concepts as difficult (Agunbiade et al., 2017). This finding agrees with that of Agogo and Onda (2014) and Uchegbu et al. (2016) who, in their separate studies, report that learners find some chemistry concepts difficult to learn because of teachers not taking time to explain basic chemistry terminologies. As a result, learners develop a negative attitude towards chemistry generally.

Moreover, learners believed that there were fewer or no problem-solving activities in the classroom that could help them make sense of what the stoichiometry problem solving entailed. They felt that opportunities to practise or solve related questions in the classrooms were not adequate; this also influenced their undesired experience with learning stoichiometry. The statements below reveal some of the learners' comments.

> *I find it difficult because I do not understand what some of the topics mean or what type of question it is talking about, because we were taught the theory, but was not given question in the class. I hate it because we only see these hard questions in the exams. Most of the time I don't know what the question is asking me to do. It is so difficult. (L27)*

> *These topics are difficult for me because when we are taught we just copied some example and we do not understand how it is done. We just try to cram it for our test and exams. (L14)*

> *These topics are difficult because I get confused on how to solve the questions. Many topics have so many formulas that are similar and confusing. We do not practice questions enough to know what to do with these questions. (L39)*

Stoichiometry concepts largely involve problem solving. The method of teaching that the participants experienced did not demonstrate the importance of understanding concepts, their association, and application to solving stoichiometry problems. Tigere (2014) emphasises that a learning environment that engages learners in problem solving encourages the development of proficiency in stoichiometry. In addition, learners expressed their dislike for the insufficient time spent in the classroom in learning or solving related questions to the concept being discussed, for example L42 stated: "*I think it is difficult because we do not do enough practice questions*".

Furthermore, the learners felt that there were many learning objectives for a single period. This they opined, made stoichiometry lessons cumbersome and uninteresting. One of them stated: "*The class is always so boring. Mole ratio, chemical equation learning them together is so boring and does not make much sense to me*" (L44). Also, L9 said: "*Many of the topics are difficult because we learn many of the topics within a period and it is not enough to learn them very well. It always a quick explanation and that is all*".

Another learner summarised his experience this way:

> *First, stoichiometry topics are difficult because we learn so many topics in one class and I don't know how they are related. Second, it is because stoichiometry topic are boring and we are taught the definition in the class but we will be asked to solve questions in the exam. (L51)*

In the same vein, learners made remarks that suggested that many stoichiometry concepts were taught in a single lesson and learners could not make connections between them, making the concepts seemingly difficult. One learner remarked that:

> *These topics are difficult for me because we are taught all of them together in a day. Before I get to understand one, we have started the other topic and so I cannot put all together and know how to connect them. (L12)*

Equally, another learner expressed that:

> *I find these topics difficult because we learn almost all these topics at a time and they are just too much to understand at a time. It makes me confused and I cannot master each of them very well. (L10)*

These excerpts from learners describe the nature of the formal science classroom which is driven by a predetermined set of requirements that the teacher has to finish in a given time frame. Omwirhiren and Ibrahim (2016) acknowledge the large volume of content in the chemistry syllabus which results in teachers adopting the lecture method to cover the content within the stipulated period. This inadvertently results in inadequate conceptual understanding by learners (Omwirhiren & Ibrahim, 2016).

Also, learners' responses suggest that the more learners understand concepts, the probability of rote learning would be reduced, thereby improving their interest in learning. This notion was supported by the comments below:

> *These are difficult because I only cram them because I do not undersand (sic). (L29)*
>
> *Many of them are difficult because I only know them by cramming and cramming is also difficult. (L4)*

It could be deduced that learners resolved to rote learn because of the instructional practice which deterred deeper comprehension of stoichiometry concepts. Therefore, they found learning stoichiometry uninteresting, hence developing a negative attitude towards it.

5.3.2 Nature of the subject (stoichiometry)

The result revealed that learners considered stoichiometry concepts more abstract than other chemistry topics. They believed that this made stoichiometry difficult to learn or required a higher level of reasoning ability. For instance, L41 wrote:

> *These topics are difficult because they are not what you can experiment or see to understand how it is like other topics such as change of matter or organic chemistry where you can see what happens. (L41)*

Their opinion was that stoichiometry is difficult because it is not practical. This finding resonates with Achor et al. (2011) who reports that sciences are commonly considered to be abstract subjects, and learners associate this with difficulty.

The perception of science subjects as abstract could be linked to the level of engagement or interaction during learning (Achor et al., 2011). Learners should be actively engaged in the process of learning to facilitate a meaningful understanding of an abstract concept (Vygotsky, 1978). In my own opinion, learners' notion of stoichiometry as just theoretical has not been diffused by the instructional method used by the teacher in their classrooms. This is connected to theme 1 as discussed in Section 5.3.1 above. By implication, the degree of the appropriateness of instructional methods in the teaching of scientific concepts could influence learners' understanding of concepts perceived as abstract (Asheela et al., 2020).

What is also pervasive in their responses was the phrase, "*stoichiometry is confusing*". Learners remarked that most stoichiometry concepts had confusing meanings and as such inhibited proper grasp of concepts. For instance, L6 mentioned that "*empirical formula, molecular formula, molecular mass, moles and gases ... they are confusing, and I do not see any difference between them. They are difficult*". Their opinion was that stoichiometry concepts were not distinct, and the corollary was the perceived difficulty of stoichiometry. The results from the interview affirmed this view. Interviewed learners expressed that they could not tell concepts apart when they were asked or the formulas to use in solving stoichiometry. L11 said, "*I get confused with some questions sometimes like empirical and molecular formula"* (L11). Another interviewee, L28 put it this way, "*they are sometimes confusing... you will not know what they are asking for ... most times I get confused about moles and molecules or atoms or the equation to use to solve them*" (L28).

This is similar to Cardellini's (2012) finding that learners tend to have 'doublethink' when they do not have a proper understanding of the chemistry terms used. Learners' poor achievement in chemistry has been attributed to lack of adequate comprehension of the chemistry terms or questions amongst other variables (Cardellini, 2012). Having a poor foundation in chemistry could account for learners' inability to understand certain concepts in stoichiometry (Omiko, 2017). For instance, poor knowledge of gas laws, writing symbols of chemical formulas, and monoatomic and polyatomic ions will militate against the understanding of balancing chemical equations and the mole concept.

It was also clear from learners' responses that stoichiometry involved a lot of mathematical calculations which most learners were not skilful at solving. For example, some learners pointed out that:

> *This topic is difficult because it involves cramming a lot of definitions and formula that are even confusing. (L36)*

> *These topics are boring and are just pure mathematics, full of equations and many things. (L2)*

> *They are difficult because they are more like maths which is also hard. You have to be very good at maths before you will understand them. (L5)*

In support, during the interview many learners were swift to speak about their perceived difficulty of stoichiometry concepts because of the calculations involved. One of the interviewees evinced that, "*there are a lot of calculations involved. If you don't know how to calculate and convert very well or even when to convert, you cannot understand stoichiometry*" (L40).

It is evident from the statements above that learners' perceived difficulty of stoichiometry might have emanated from their inadequate mathematical skills. DeBerg (2012) avows that many learners detest science because of the mathematics that is involved. Learners with inadequate proficiency in mathematics may find it challenging to understand or solve stoichiometry problems (Preininger, 2017). This finding resonates with that of Omiko's (2017) and Preininger's (2017) findings that most learners who perceived science as difficult have difficulty in solving basic mathematical problems.

Furthermore, learners felt that the difficulty experienced with learning stoichiometry concepts were associated with the lack of connections between the concepts or their immediate environment. Many of them could not find the relevancy of stoichiometry content to other aspects of chemistry or in their future careers. One learner put it this way:

> *They are difficult to me because they do not make so much sense. Why can't we just learn things that we know we can make use of in the future at work? Not just calculating stuff that is not useful later. (L47)*

Likewise, L19 stated that:

> *These topics are difficult for me because I do not understand most of them and why we are doing it. It is not like other topics that we understand its usefulness in the whole of chemistry!*

This result resonates with other literature (Agunbiade et al., 2017; Hofstein & Mamlok-Naaman, 2011; Juan et al., 2018; Mavuru & Ramnarain, 2020) indicating that the identification of the link between science concepts and learners' immediate environment increases their interest in science. These studies have highlighted learners' appreciation of studying science topics that they find associated with their everyday life. Mavuru and Ramnarain (2020) emphasise that when scientific concepts are taught by providing contexually relevant examples, it promotes learners' appraication and understanding of the concepts due to relevance. Learners' responses in this study suggest that they do not see the usefulness and the potential use of stoichiometry concepts in their environment or their future. This again implies that the instructional technique was inadequate in presenting and linking the concepts to learners' surroundings.

5.3.3 Learners' attributes

From the findings, most of the learners had a pre-conceived notion that science was generally difficult. They felt that since stoichiometry required mathematical representations/calculations, it was difficult to learn and they did not need to try to learn it. They believed that one has to be exceptionally intelligent to be able to carry out stoichiometry tasks. Learners' pre-conceived difficulty of science/stoichiometry were reflected in statements such as:

> *…because it needs high level of smartness to be able to understand these topics. All topics are difficult and a lot of calculations and formula. (L30)*
>
> *I find all of them difficult because I know that science topics are difficult and it is only for the intelligent people. (L50)*
>
> *I do not know why but I know they are just difficult and I do not like them. (L49)*

Agunbiade (2015) notes that many learners are made to believe that science is difficult and only for the intelligent even before they start studying it. They carry on with this notion and make less efforts to understand or improve their performance in science due to this belief. Having a preconceived notion that science or stoichiometry is difficult might be a reason why most learners would not take up science careers as observed in the TOSRA and interview results. In the interview, one of the participants said, "*if I later find chemistry and physics easy I might decide on science courses later on. I don't want to register a course that I will struggle with*" (L2).

Similarly, participants expressed their dislike for stoichiometry concepts or lack of interest in science/stoichiometry. This was cited as the reason why they claimed stoichiometry concepts were difficult. They preferred memorising concepts for assessment rather than understanding them because of lack of interest. One learner stated that: "*They are all difficult and I hate them. I just do cram pour and forget for the exams, I hate the topics*" (L23). While another participant indicated, "*I don't like stoichiometry!!!*" (L17). Nhase (2019) clarifies that learners tend to resolve to rote learn when content appears difficult or abstract and therefore do not make any effort to understand the concept.

Nevertheless, some learners indicated that self-study was one of the reasons they found stoichiometry concepts easy. They had a personal interest in learning the concept, thus becoming resilient learners in the process. They stated that they made efforts to learn and understand the concepts individually or asked for help from their siblings or friends. Participants wrote:

> *They are easy because I try to study and I ask my sister to help me with the difficult part that I do not understand. (L16)*

> *These topics are easy for me because I started learning them before we were taught in the class so that it will be easy for me to understand. (L45)*

This suggests 'agency' – learners becoming active participants in their own learning and engaging in self-initiated learning experiences that are driven by their interest (Schunk 2012). According to Vygotsky (1978), agency mediates and is mediated in a socio-cultural context.

It was observed that some learners were aware of the usefulness or importance of stoichiometry in chemistry. This awareness influenced their resilience in learning stoichiometry and the conclusion that stoichiometry concepts were easy. For example, they stated:

> *They are easy because I study hard to understand them. I know they are important topics in chemistry. (L7)*

I think these topics are easy for me because I just try to learn them using many textbooks and other ways. This is because I need to understand it and use it in other chemistry topics. (L52)

These learners strived to take full ownership of their own learning, thus, demonstrating 'agency' (Vygotsky, 1978). The comments above suggest that learners with interest in science or positive perceptions of chemistry/stoichiometry are resilient stoichiometry learners. Resilient learners are influenced by their mindsets and environments and tend to persevere when faced with learning challenges, and subsequently perform better academically (Artuch-Garde et al., 2017; Makila et al., 2017).

5.3.4 Additional findings: Highlighted features for a positive experience with learning stoichiometry

Participants highlighted desirable features which they identified would create positive experiences when learning difficult concepts/topics. As Fulmer et al. (2019) noted, learners' attitudes towards science are associated with how their experiences of science instruction align with their instructional preference. Learners proffered that having detailed explanations from their teacher and giving relevant examples could alleviate the difficulty of chemistry topics. They stated that difficult concepts could be simplified by giving relevant examples from their immediate environment or by making connections between the two while in the classroom. The following accounts of learners are representative of this claim:

The teachers should take their time to explain the topics better and not rush us in the class. (L9)

Explaining very well and giving many examples that will make it easy to understand. (L43)

The literature underscores the importance of teachers' personality and support in the learning process. For instance, Agunbiade et al. (2017) argue that teachers' patience and clear explanation of concepts enhances learners' enjoyment of science lessons. Participants also mentioned that practical activities with a step-wise explanation from their teacher could help them with a better understanding of chemistry topics. From the results, it appeared that learners considered or preferred practical/engaging activities that would make difficult topics which they regard as abstract, real for them. Learners made notes such as:

Doing more practical and things that will make it look real and understandable. (L31)

> *Making the topics interesting and simple with some examples that I can see around me or play with. (L22)*

More so, learners desired to have sufficient time to learn chemistry concepts. Learners used phrases such as "*we should have more time*", "*take more time to explain*", "*having more time to learn it*" to express their wishes. These phrases suggest that learners believed that spending more time to learn difficult concepts could be of advantage in alleviating the problem. This finding was supported by the results from the semi-structured interviews after the POGIL intervention where learners expressed their desire to be given sufficient time to engage with POGIL activities. For instance, L3 said, "*we need more time to discuss and finish the work, sometimes we cannot finish up some of this classwork*". I argue that learners desire a chemistry classroom where the teachers will 'slow down' the lessons and allow learners to think/ask the why and how questions concerning chemistry concepts, or the possible relations between concepts. Learners' responses implied that in-depth understanding of the concepts was limited by insufficient learning time which is one of the drawbacks of a formal science classroom.

5.4 Chapter Summary

In this chapter, I presented, analysed, and discussed data generated from the SLQ. This was aimed at responding to research question 1: What enabled and/or constrained the learning of stoichiometry concepts by learners in the senior secondary school chemistry curriculum before the POGIL intervention? The results revealed that inappropriate instructional methods in teaching stoichiometry concepts, the nature of stoichiometry, and learners' attributes were enabling or constraining factors to learners' positive experiences with learning/understanding stoichiometry. The overall results described learners' feelings about their experiences in the existing stoichiometry classroom before the intervention. This provided a foundation on which to base the remaining phases of this study. Next, I focus on the progression of their proficiency in stoichiometry in relation to POGIL. In the following chapter, I present, analyse, and discuss the data for the research question 2 which is on learners' shift in proficiency in stoichiometry as they participated in POGIL intervention.

CHAPTER SIX: LEARNERS' EVOLVING PROFICIENCY IN STOICHIOMETRY

When children are given instruction that emphasizes thinking strategies, children are able to develop the strands of proficiency in a unified manner. (Kilpatrick et al., 2001, p. 7)

6.1 Introduction

Research question two: *How does learners' proficiency in stoichiometry change (if at all) over the period of participation in the POGIL intervention?*

In the previous chapter, findings from the SLQ were presented, analysed, and discussed. This provided the baseline information of learners' experiences with learning stoichiometry. In this chapter, I present, analyse, and discuss data generated from the SAT to answer research question two which focused on shift in learners' proficiency in stoichiometry. As previously described in Chapter Four, I administered the SAT pre-test and post-test to examine how learners' proficiency in stoichiometry changed while participating in POGIL.

The SAT was analysed based on 53 learners that completed both the pre-test and post-test questionnaires. Learners' overall scores represent their level of proficiency on the SAT instrument. They were profiled into three levels of proficiency based on the score division using the class interval formula. Scores from 0-18 were 'below proficiency', 19-39 were 'intermediate proficiency' while 40 and above were 'proficient' learners. Likewise, learners were categorised into the three levels of proficiencies based on their scores in each proficiency strand (CU, PF, and SC) of both the pre-test and post-test using the class interval formula. CU and PF: low (≤5), average (6-11), and high (12-18). For SC, learners were categorised into low (≤ 6), average (7-15), and high (16-24). The class intervals for CU and PF were different from that of SC because of the number of questions assessing each of these strands. CU and PF both had six items each on the SAT while SC was assessed with eight items (see Appendix I). Learners' profiling in each proficiency strands are shown on a bar chart below. The data are largely quantitative, however, in the discussion of the results, I used segments of learners' scripts, interviews, or journal entries for illustrations of arguments as well as providing supporting evidence. As alluded to in the methodology chapter, this was a mixed-methods research where both quantitative and qualitative data were obtained, integrated, and interpreted to understand the research questions (Schoonenboom & Johnson, 2017).

6.2 Findings from Stoichiometry Achievement Tool (SAT) Pre- and Post-Test

Learners' scores in the SAT (Appendix I) pre-test and post-test on items assessing their conceptual understanding (CU), procedural fluency (PF), and strategic competence (SC) are shown in Figures 5.3, 5.4, and 5.5 below. Tables 6.1 and 6.2 represent the paired sample *t*-test of the SAT pre-test and post-test mean scores.

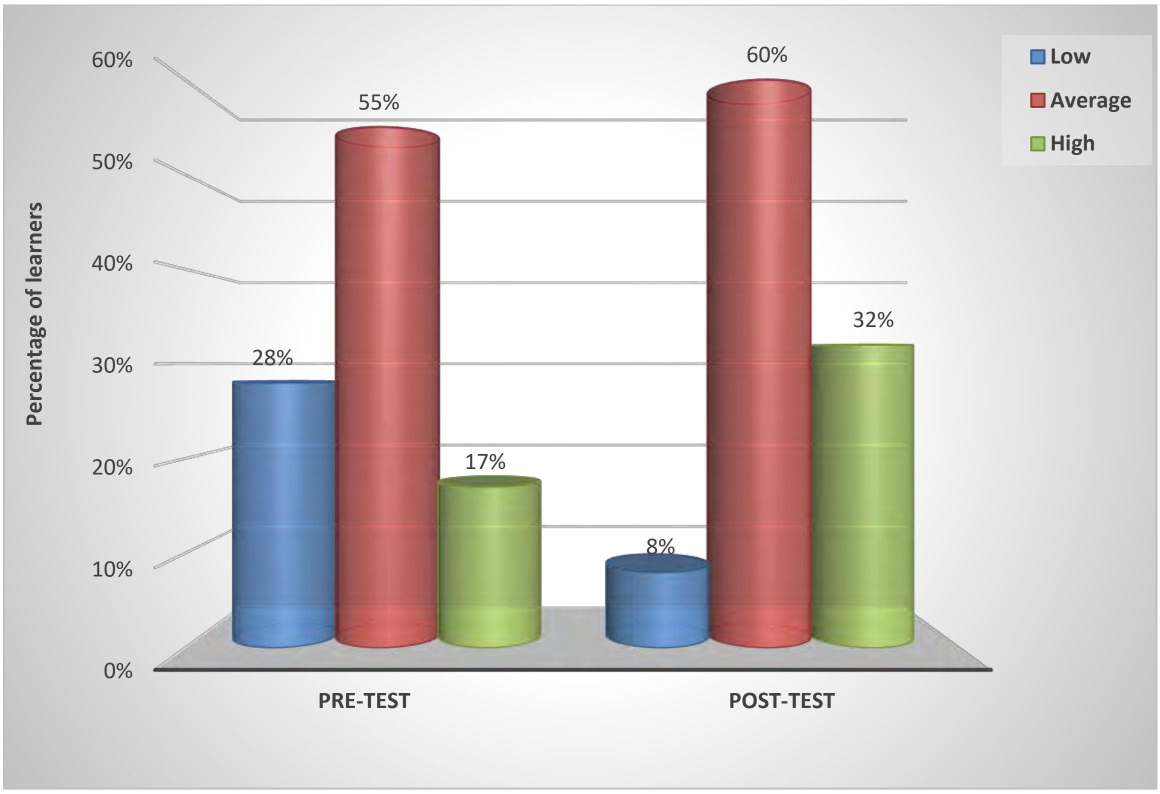


Figure 5.3: Learners' proficiency based on scores on items assessing CU

Figure 5.3 shows that 15% more learners had a higher score on items assessing conceptual understanding of stoichiometry in the post-test. Learners in the group of 'average' CU increased by five percentage points at the post-test compared with the pre-test. However, only 8% of the learners were in the low CU group at the post-test compared to 28% at the pre-test.

This suggests a major shift in the learners' conceptual understanding of stoichiometry after participating in the POGIL.

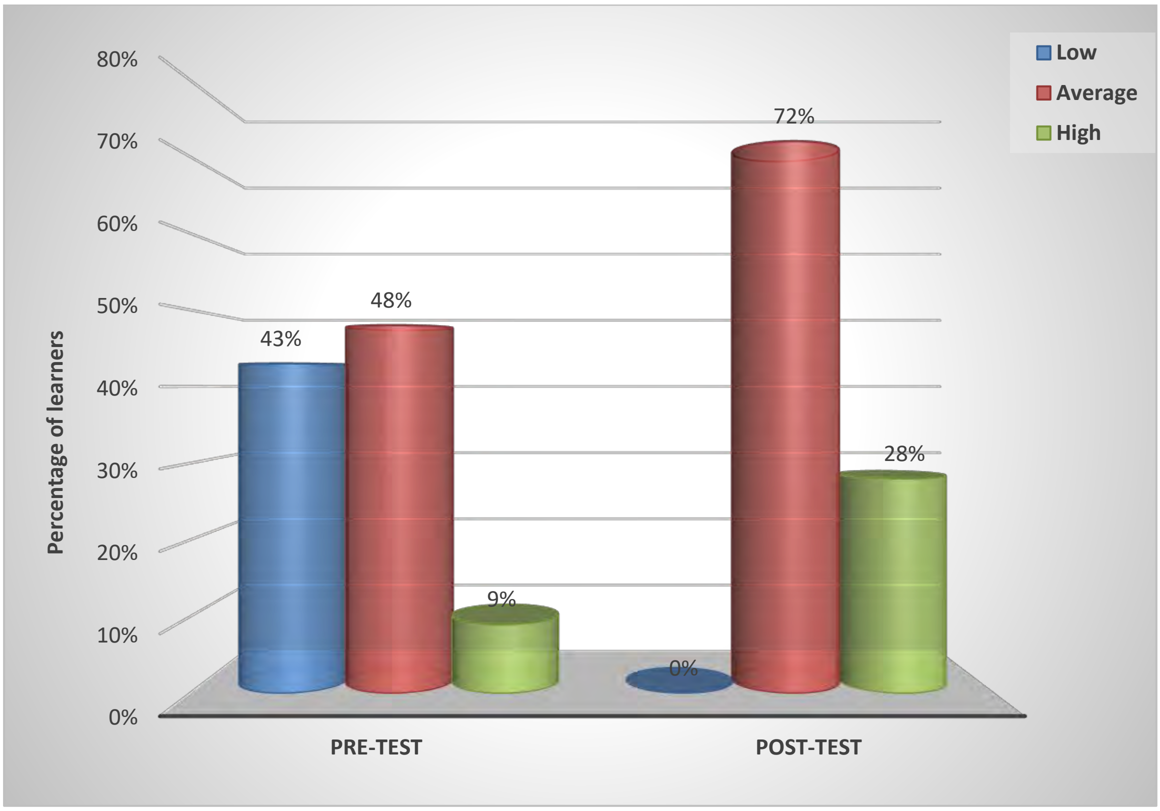


Figure 5.4: Learners' proficiency based on scores on items assessing PF

Figure 5.4 indicates that learners attaining a high procedural fluency level in stoichiometry increased by 19 percentage points in the post-test compared to the pre-test. Likewise, there was an increased percentage (24%) of learners who attained average PF at the post-test compared to the pre-test. Significantly, there were no learners (0%) with low PF at the post-test compared to 43% at the pre-test. This trend shows that there was a major shift towards improved procedural fluency in stoichiometry by learners participating in this study.

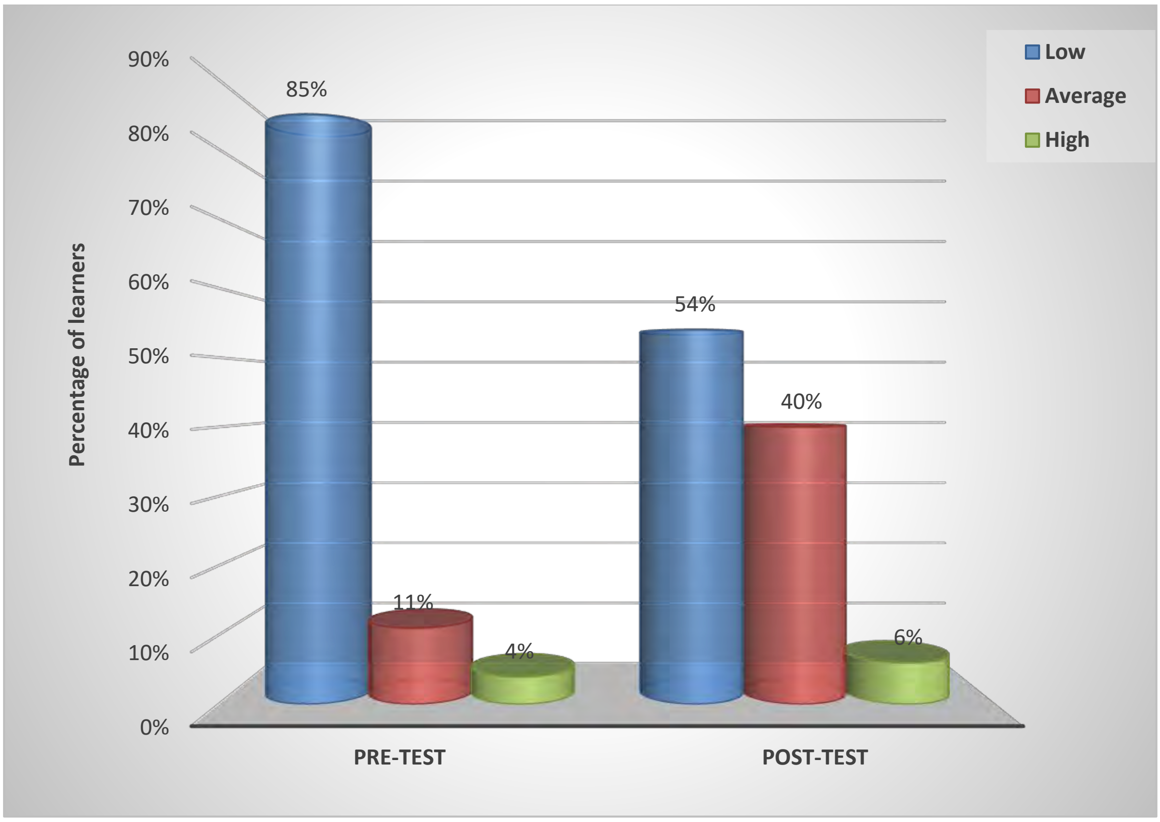


Figure 5.5: Learners' proficiency based on scores on items assessing SC

The percentage of learners that attained average and high SC levels in stoichiometry rose by 29 and two percent points respectively at the post-test. There were 31% fewer learners with low SC in stoichiometry concepts at the post-test compared with the pre-test as shown in Figure 5.5 above. The chart reveals a minimal shift in the learners' strategic competence in stoichiometry.

Table 6.1: Mean difference of each of the SAT Proficiency Strands (*n*=53)

<u>Paired samples test</u>

	Mean	Std. deviation	t	df	Sig. (2-tailed)
CU pre-test	6.8491	3.39907	5.059	52	.000
CU post-test	9.0566	3.19504			
PF pre-test	5.8868	3.05501	5.327	52	.000
PF post-test	8.7736	2.75012			
SC pre-test	6.3396	3.79749	1.724	52	.091
SC post-test	7.0755	3.63132			

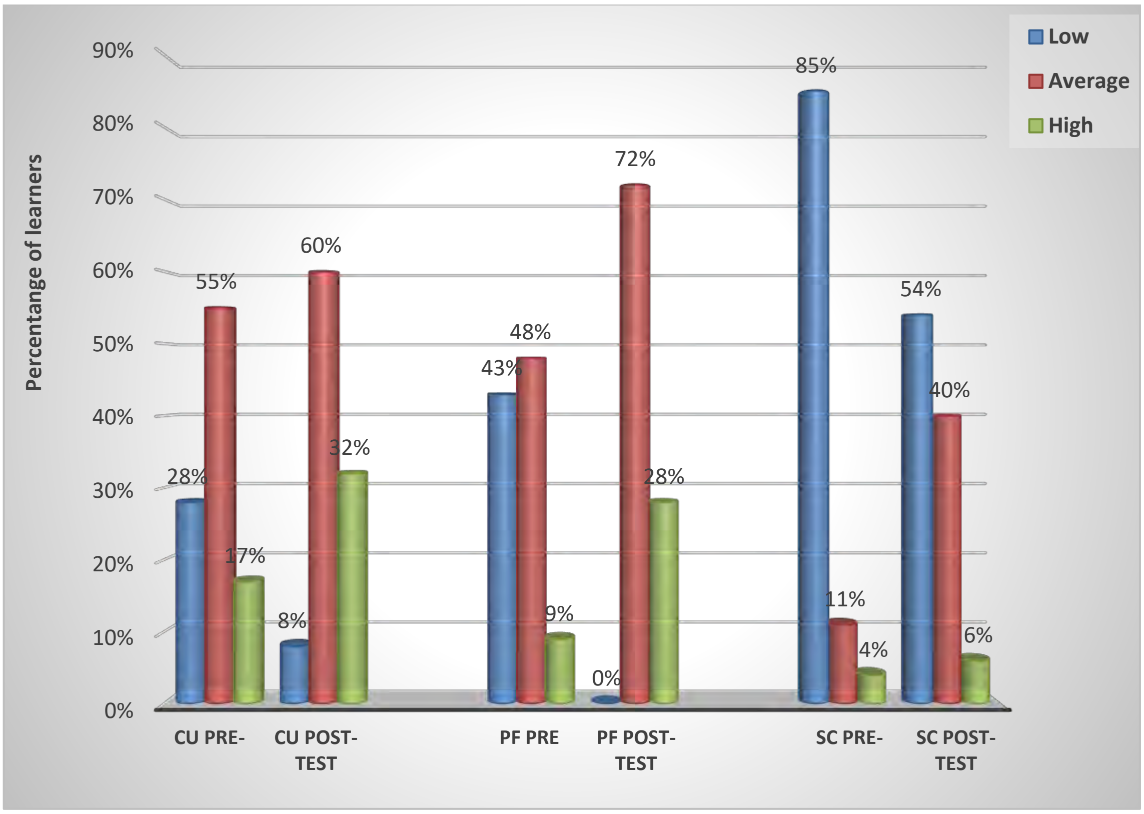


Figure 5.6: Comparison of pre- and post-test proficiency levels of the strands

Table 5.6 shows the paired samples *t*-test of SAT pre-test and post-test scores. The mean difference in the means of CU, PF, and SC are 2.21, 2.89, and 0.74 respectively as shown in Table 6.2 below.

Table 6.2: Mean differences of pre-and post-tests scores of the SAT proficiency strands

Proficiency strand	Std.deviation	Mean differences (Pre-and post-tests)
CU pre-test	3.39907	2.21
CU post-test	3.19504	
PF pre-test	3.05501	2.89
PF post-test	2.75012	
SC pre-test	3.79749	0.74
SC post-test	3.63132	

Moreover, there is significant statistical difference observed for the CU and PF (sig. 2-tailed $p = .000$) after 10 weeks. In contrast, the mean difference of SC is not statistically significant (sig. 2-tailed $p = .091$) at 10 weeks. Likewise, the bar graph in Figure 5.7 displays the difference in the mean scores of the pre-test and post-test of the SAT proficiency strands. Large differences between the pre-test and post-test results were observed at the CU and PF strands. However, after 10 weeks of POGIL work, only a slight difference is observed at the SC strand.

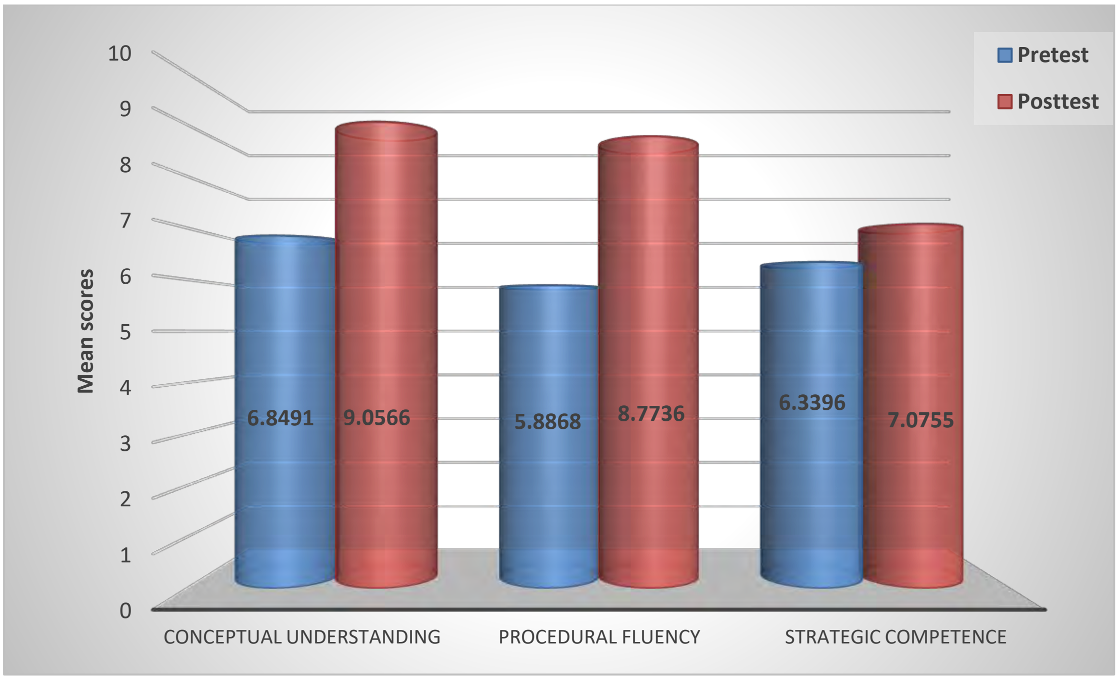


Figure 5.7: Means of learners' pre- and post-test scores in each proficiency strand

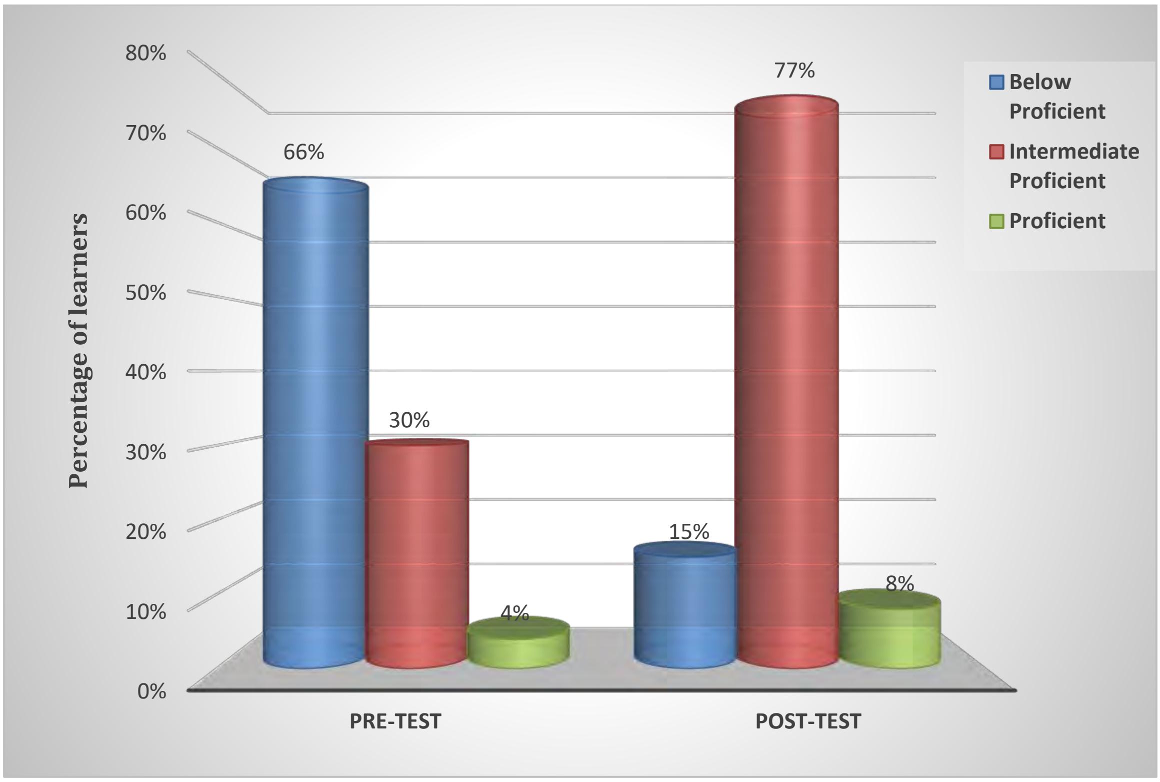


Figure 5.8: Distribution of learners' proficiency groups based on SAT pre- and post-test

Figure 5.8 displays learners' overall proficiency levels in stoichiometry based on their scores on the SAT pre- and post-test. At the pre-test, 35 out of 53 (66%) learners were below the proficiency level in stoichiometry. Also, the percentage of learners in the intermediate proficiency level was less than half (30%) of the learners surveyed while the percentage of proficient learners was comparatively low at 4%. After 10 weeks, the percentage of learners below proficiency in stoichiometry reduced markedly from 66% to 15%, a difference of 51 percentage points, while 41 out of 53 learners (77%) were now in the intermediate proficiency group. Also, the percentage of learners in the proficient group increased by four percentage points.

Table 6.3: Mean difference in overall SAT pre- and post-test scores (*n*=53)

	Mean	Mean diff.	Std. deviation	t	df	Sig. (2-tailed)
Proficiency pre-test	18.6226	6.51	7.96682	7.487	52	.000
Proficiency post-test	25.1321		6.66229			

The mean difference in the overall SAT pre-test and post-test scores is 6.51 as shown in Table 6.3. The overall proficiency of learners in the pre- and post-test is statistically significant (sig. 2-tailed $p = .000$) after10 weeks.

6.3 How Learners' Proficiency in Stoichiometry Shifted While Participating in POGIL

The overall SAT post-test result showed a positive shift in learners' proficiency in stoichiometry when compared with the pre-test. Based on the proficiency class levels, more than two-thirds (66%) of learners were below the proficiency level in stoichiometry, 30% were in the intermediate proficiency level while a lesser percentage (4%) were proficient in the pre-test (Figure 5.8). This implies that only two out of 53 learners surveyed could be referred to as proficient in stoichiometry at the beginning of the study.

This may be due to lack of responses to some questions, incorrect responses, or wrong procedures which resulted in wrong answers at the pre-test. For instance, questions number 3, 8, 11 and 13(b) on the SAT were not answered by most of the learners. These four questions are mainly on mass-mole relationships and reaction yields. The incorrect responses and blank spaces suggest that they lacked understanding of the stoichiometry concepts. Some learners struggled with accurate problem representation or solving problems that involved many steps. Most of them, however, extracted information correctly from the question and substituted correctly in the formula but executed it incorrectly, while those that used the correct procedures and executed the procedures correctly extracted the wrong information from the text given. This finding corroborates the WAEC (2017; 2018) report that revealed the major weakness of learners in solving stoichiometry problems was their inability to extract or translate word problems to mathematical statements. When correct procedures were utilised and correct information was extracted from the text, they got the answers correct. Learners' procedures and approaches to solving problems might be incorrect but they were efficient in their mathematical computation. This implies that learners' competency in mathematics does not necessarily translate to proficiency in stoichiometry. More so, a few learners that got the multiple-choice questions correct could not even justify their answers. Thus, the full mark for the question was forfeited.

On items assessing conceptual understanding (CU) of stoichiometry (Figure 5.3), 28% of learners had low scores at the beginning of the study compared to 8% at 10 weeks. Learners that had average and high scores increased by 5% and 15% respectively after participation in POGIL. The result shown in Figure 5.3 is evidence that there was a major positive shift in learners' conceptual understanding of stoichiometry after participating in POGIL. This is also supported by the statistically significant difference in the mean of the pre- and post-test of conceptual understanding reported in Table 6.2. The higher scores on CU in the post-test were probably because learners had the opportunity to interact more with stoichiometry concepts while they collaborated with peers in the POGIL classroom. Hence, there was better understanding of concepts, as opposed to just learning concepts by rote.

To further describe this finding, learners' improvement in conceptual understanding was demonstrated in their responses to items on the SAT assessing their conceptual understanding in the post-test compared with the pre-test. For example, in the pre-test, it was difficult for learners to understand the definition of 'mole'. They could not relate Avogadro's number to the mole of a substance. Learners showed poor understanding of stoichiometry concepts as they could not tell the connection between them, whereas in the post-test, learners could easily define and relate the mole of a substance to Avogadro's number of particles. According to Omiko (2017), learners with poor understanding of foundational chemistry principles or terms will struggle with other related chemistry concepts. Tigere (2014) avers that learners who are proficient in stoichiometry should be able to identify the connection between quantities or concepts as well as relate them appropriately in problem-solving.

One example of development of conceptual understanding was when learners were asked to define and describe their understanding of stoichiometry during the interviews. For example, L31 said;

> *Stoichiometry is calculating the amount of reactant and product in a reaction using a balanced equation. The ratio from the balanced equation is used to calculate the amount of the product and reactant. (L3, I)*

Describing her understanding of stoichiometry further, L31 offered a practical example in defining and explaining what stoichiometry means:

> *For example, if … ok. If I want to make cookies, the ingredients are the reactants, and the cookies is the product. The amount of each of the ingredient I used like the butter, flour, egg to make let's say 20 cookies is the equation. So, you need to know the amount of butter, flour to use and how many eggs will make 20 cookies. The mass of all the ingredients should be equal to the mass of the 20 cookies you have made*

because no mass should be lost. Then the amount of each of the ingredients is their ratio. (L31, I).

In this instance, L31 represented the concept of stoichiometry by relating it to the immediate environment. This example from L31 suggests that the learner gained better understanding of what stoichiometry entails because it was related to what she could connect with within her immediate environment. This buttresses the notion that giving appropriate examples from learners' immediate environments in teaching scientific concepts increases their understanding of the concept being taught.

A notable improvement in the post-test was in test items that covered limiting and excess reactants. Learners' answers in the pre-test to these questions indicated lack of understanding of these concepts which is important in stoichiometry. This prevented many of them from attempting or even answering items 10, 11, and 12 successfully and contributed towards their low scores in the pre-test. For example, L38 in the pre-test, described the difference between limiting reactant and excess reactant as follows: "*Limiting reactant is the reactant that act like inhibitors to a reaction by not making it to occur. Excess reactant are reactant that are more than the other reactant in the reaction*" (Figure 6.1).

This is shown in Figure 6.1 below.

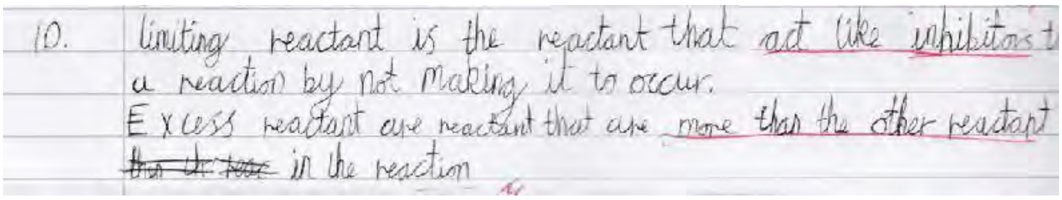

10. limiting reactant is the reactant that act like inhibitors t
a reaction by not making it to occur.
Excess reactant are reactant that are more than the other reactant
in the reaction

Figure 6.1: Learner's vignette on limiting reagent

L38's response, as shown above, indicates a partial knowledge of the concepts and the use of incorrect terms to describe the concepts. In the post-test, L38 improved in the conceptual understanding of limiting and excess reactant and explained that:

Limiting reactant is the reactant that is completely used up in a reaction and no other reaction occur after it has finished. The excess reactant is the reactant that remains when the limiting reactant has been completely used up. (Figure 6.2).

From the example above, it is clear that L38 now understood the meaning of the two concepts and could relate them to each other while differentiating them.

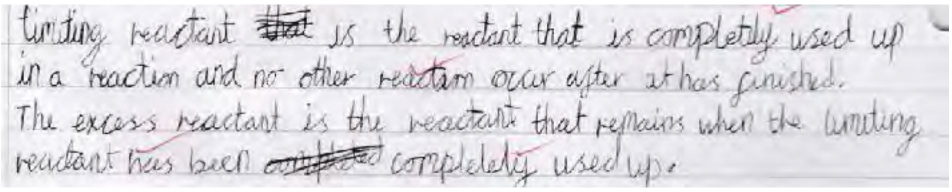

limiting reactant is the reactant that is completly used up in a reaction and no other reaction occur after it has finished. The excess reactant is the reactant that remains when the limiting reactant has been completely used up.

Figure 6.2: Learner's vignette on limiting reagent

Similarly, Hanson (2016) found that it is difficult for learners to understand or identify limiting or excess reactant in a chemical reaction. Learners' difficulties with understanding associations between stoichiometry concepts are described in other studies as well (Boujaoude & Barakat, 2003; Chandrasegaran et al., 2009; Furio et al., 2002; Marais & Combrinck, 2009; Tigere, 2014). These authors confirm that learners do not have an accurate understanding of the mole concepts, limiting reagents, mass-volume, or mass-mole relationships. Marais and Combrinck (2009) argue that the level of understanding of basic stoichiometry concepts come into play when considering limiting and excess reactants as learners are more confused when asked to identify both. Likewise, Chandrasegaran et al. (2009) point out that when learners are able to state the meaning of limiting or excess reactants, they demonstrate poor understanding of the concepts in their problem-solving.

The mean of the pre- and post-test of procedural fluency (PF) scores were statistically significant after 10 weeks as shown in Table 6.2 In the pre-test, 43% of the learners had low scores on items assessing their procedural fluency (PF). Learners were confused about how to best solve some of the stoichiometry problems because of the different formulae or steps involved. This was confirmed by one of the interviewees saying that, "*I get confused with a lot of way to answer some of the questions… I know what to do but I miss one step and then I will get everything wrong*" (L2). Comparably, Boujaoude and Barakat (2003) found that many learners use incorrect procedures in solving problems involving moles, volume, and molar quantities.

Interestingly, there were no (0%) learners in the low procedural fluency category after participating in POGIL. There was a notable increase in the proportion of learners who had high scores on procedural fluency when comparing prior and after participation in POGIL – 9% and 28% respectively. Also, the percentage of learners who had average scores increased from 48% to 72% at the end of the study. The trend in the data shows that there was a major positive shift in learners' procedural fluency at the end of the study. It could be assumed, therefore, that participation in POGIL improved learners' procedural fluency in stoichiometry.

Tables 6.1 and 6.2 reveal that there is no significant statistical difference between the means of the pre- and post-test of strategic competence (SC) scores. Nevertheless, as shown in Figure 5.5, most learners' strategic competency in stoichiometry before participation in POGIL was low. This is shown by their scores on items assessing their strategic competence. Learners' strategic competency was assessed using the analytical framework, representing problems using chemical equations, symbols, and explaining problem-solving steps correctly.

Knowing how to write and balance chemical equations appropriately is a prerequisite for solving stoichiometry problems. For instance, learners have the knowledge that writing the chemical equation is necessary to solve stoichiometry questions, but, many of them could not identify what information was essential to extract from the question nor the information that was provided by the chemical equation (i.e., the ratio of the amount of reactants or products). As a result, the ratio is not considered when necessary. Many learners who knew the importance of the ratio did not have any idea of its derivation or found it difficult to balance a chemical equation and use the coefficient ratio appropriately. Consistently, Lemma (2013) and Marais and Combrinck (2009) in their separate studies found that learners' inability to balance chemical equations is often a consequence of failure to understand basic terms in stoichiometry where they cannot identify the products and reactants of the reaction appropriately. Lemma (2013) further reports that learners lack the knowledge and implications of coefficient and subscript in chemical equations.

Interestingly, in the pre-test, one learner wrote the chemical equations without the chemical symbols, using the name of the compound shown in Figure 6.3 $Methane + O_2 = CO_2 + H_2O$. This learner's inability to write the chemical equation correctly resulted in the inability to solve the problem.

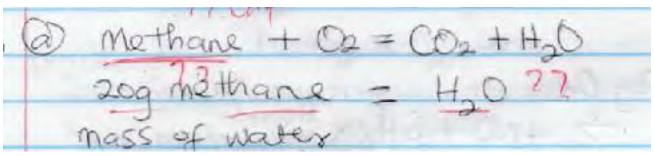


Figure 6.3: Learner's vignette on chemical equation

Concurrently, Lemma (2013) found that learners' inability to write chemical equations correctly or disregarding the coefficient in chemical equations results in wrong answers when solving stoichiometry problems. Likewise, Cardellini (2012) argues that the learning of symbols and chemical equations in chemistry are regarded as abstract concepts which can be confusing for learners. The learning of these concepts is likened to learning a foreign language.

In the post-test, the percentage of learners with high and average strategic competence increased by 2% and 29% respectively. Likewise, the percentage of learners who had low scores on items assessing strategic competence at the beginning of the study decreased from 85% to 54% at 10 weeks. This suggests that there was a change in learners' strategic competence in stoichiometry, albeit minimal, it still improved at the end of the study.

In comparing the three proficiency strands examined by the SAT, procedural fluency had the highest change, followed closely by conceptual understanding while strategic competence had the lowest shift after 10 weeks (Figures 5.6). This pattern showed variation in the changes of each of the proficiency strands examined in this study. Learners' procedural fluency and conceptual understanding improved significantly in the post-test while that of strategic competence in stoichiometry was not as distinct compared to conceptual understanding and procedural fluency.

One possible reason might be that the length of the intervention programme period may not have been adequate to effect a significant change in learners' strategic competencies compared with the two other strands. The relationship between conceptual understanding, procedural fluency, and strategic competence was supported by Kilpatrick et al. (2001) and Sabilah et al. (2018). These authors assert that learners' procedural fluency develops as their conceptual understanding deepens which eventually increases their strategic competence. It is assumed that of the three, strategic competence might be the strand that is developed later. In agreement, Suh and Seshaiyer (2014) point out that strategic competence requires providing adequate time and space for learners to develop the skill. Though the change might not have been great, learners demonstrated procedural fluency at the post-test. The result (Figure 5.5) shows that learners performed better on items assessing strategic competence at the post-test than the pre-test.

To corroborate the quantitative result, I present an example of how L3's procedural and strategic competence improved in the post-test compared to the pre-test. Item 3 on the SAT assessing learners' strategic competence required learners to find the number of atoms of hydrogen in 3 moles NH_3. In the pre-test, L3's strategy, as shown in Figure 6.4 below, was to count the number of atoms in NH_3 and multiply it by the number of moles of NH_3 and got 9 moles as his answer.

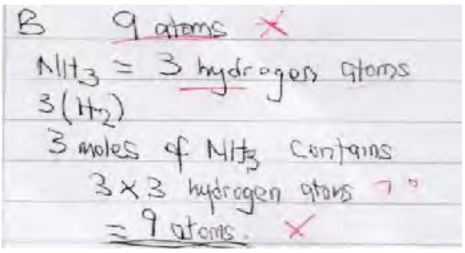


Figure 6.4: Learner's vignette on number of atoms

At the post-test, L3's strategy improved by equating 1 mole of NH_3 to Avogadro's number as shown in Figure 6.5. He was able to represent the given text mathematically and accurately and used his knowledge of logarithms to arrive at the correct answer. L3 demonstrated the ability to connect within the representation of stoichiometry concepts with accuracy, thus, showing an improved procedural fluency.

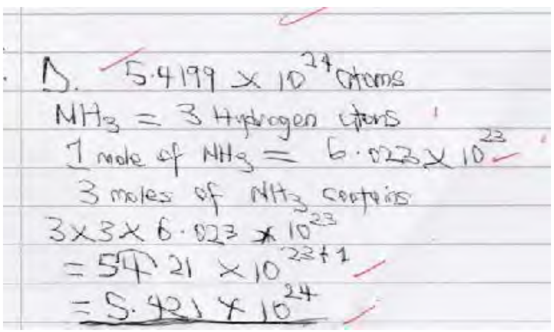


Figure 6.5: Learner's vignette on number of atoms

Learners' mathematical skill is one factor that has been significantly linked with the perceived difficulty of stoichiometry units. Learners also iterated this idea in their responses to SLQ items and during the interviews. However, while examining learners' scripts, learners that got the procedures correct also executed the mathematical computation correctly. Participants demonstrated their mathematical skills with simplifying exponents and proportions when solving problems. Learners' procedures and approaches to solving problems might have been incorrect but the mathematical computations were correctly executed. My interpretation of this is that learners were mathematically competent, but had challenges with information representation or procedural accuracy. This finding is contrary to previous studies (Ajao & Awogbemi, 2012; Preininger, 2017) where learners' mathematical skills were reported as a deterrent to their problem-solving skills in chemistry. These studies by Ajao and Awogbemi (2012) and Preininger (2017) found that learners who were proficient in solving mathematical problems transferred the skill to solving chemistry problems, thereby developing proficiency in it.

Each item on the SAT was selected to assess learners' proficiency in the proficiency strands surveyed. Learners' responses or approaches in answering each question provided information about their proficiency in another strand when the item was aimed to assess a particular strand. For instance, question 12 was designed to elicit learners' procedural fluency:

> *The balanced chemical equation below shows a reaction between ammonia and oxygen.*
>
> $4NH_{3\,(g)} + 5O_{2\,(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(l)}$
>
> *If 750 g of ammonia and 750 g of oxygen reacted, which reactant will be totally consumed and which will be in excess? Show how you arrived at your answer.*

Participants were required to identify the limiting and excess reagents in the question and show how they arrived at their answer. Despite their knowledge of converting the mass in grams to moles, many of them divided oxygen by 16g, the atomic mass instead of its molecular mass of 32. This procedure resulted in wrong answers. More than half of the learners failed to calculate the number of moles of ammonia and oxygen but multiplied the mass given by the coefficient ratio in an attempt to identify the limiting reagent. It was clear from many of the learners' responses that they had the conceptual understanding of limiting and excess reagent but lacked both the procedural fluency and strategic competence to find it in a given problem.

An example below is the response of L35 to question 12 on limiting and excess reactants in the pre-test.

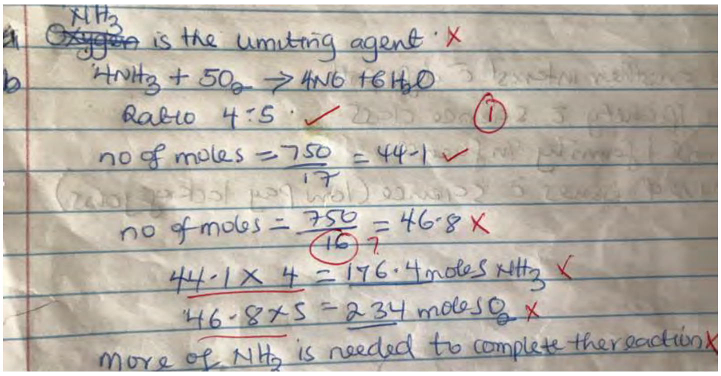


Figure 6.6: Learner's vignette on limiting and excess reactants

I argue that L35 had the knowledge of the procedure or rules on how the number of moles of ammonia and oxygen should be calculated but could not represent oxygen with the appropriate molar mass in the formula. This was not the only mistake made by the learner. Despite knowing the importance of the coefficient ratio, this was not applied to the problem correctly, showing poor strategic competence.

In the post-test, in response to the same question, L35 demonstrated three strands of proficiency, CU, PF, and SC as shown below. The learner explained why the oxygen was the limiting reagent in comparing the moles of oxygen available to react with that of ammonia. The coefficient ratio was applied appropriately which resulted in the correct answer to the question. L35's proficiency progression could be because of collaboration in solving numerous related questions in the classroom. This agrees with Boujaoude and Barakat's (2003) and Hanson's (2016) findings that learners with more conceptual understanding of stoichiometry concepts are more successful in problem-solving.

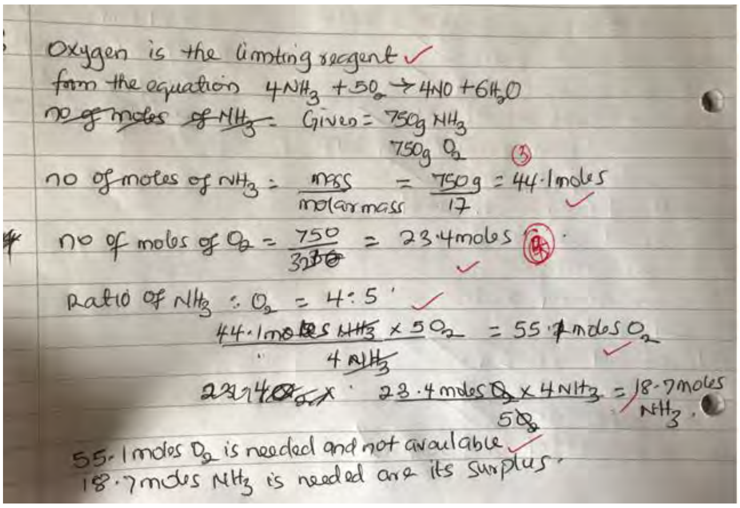


Figure 6.7: Learner's vignette limiting and excess reactants

Nonetheless, the pattern that emerged from the overall SAT post-test results revealed an improvement of learners' proficiency in stoichiometry. After 10 weeks of participation in POGIL activities, the percentage of learners that were below proficiency levels in stoichiometry reduced considerably to 15%. Learners that were averagely proficient in stoichiometry increased to 77%; this showed a 47% rise in the average proficient group after participating in POGIL. In addition, there were twice as many learners (8%) as the pre-test percentage of 4% who moved to the proficient group after 10 weeks.

According to Denuga (2019), Tigere (2014), and the design of the SAT questionnaire, a higher score in the SAT indicates a high level of proficiency in stoichiometry. Concurrently, Table 6.3 shows that the changes in learners' proficiency in stoichiometry were statistically significant after 10 weeks. The comparison of the pre- and post-test proficiency levels show that 85% (77% + 8%) of the learners surveyed became more proficient in stoichiometry after participation in POGIL compared to 34% (30% + 4%) in the proficient level before participation (Figure 5.6). As discussed in Section 3.3 of the theoretical framework, positive interactions between learners or learners and teachers in the classroom facilitate understanding and development of the self-regulated learner (Harrison & Muthivhi, 2013; Vygotsky, 1978). The process of self-regulation is often facilitated by engaging learners in collaborative problem-solving or goal-directed tasks (Harrison & Muthivhi, 2013; Pintrich, 2000; Vygotsky, 1978). The reason for the observed progression could be the learners' interactions and engagement in POGIL activities. This is detailed in Chapter Eight. Vygotsky's (1978) socio-cultural theory stresses the fundamental role of social interaction in that it involves collaborative dialogue and problem-solving activities seen as effective in developing skills and promoting cognitive development.

The result of this study showed that learners with a higher level of conceptual understanding used efficient methods or strategies to solve stoichiometry problems. Learners with improved conceptual understanding could give detailed steps or explain the solution efficiently without following the algorithmic method. Learners' procedural fluency but insufficient strategic competence may be due to insufficient practice or lack of reflective thinking. According to Toth and Kiss (2005), teachers should carefully plan instructional strategies to teach stoichiometry problems as this has a great impact on learners' understanding and problem-solving abilities in stoichiometry.

Overall, from the data presented above, I would argue that most of the learners showed improvement in stoichiometry proficiency across the three strands, albeit minimal in strategic competence. In the SAT post-test, learners were not solely guessing procedures or answers to the questions but were using the elements of conceptual understanding, procedural fluency, and strategic competence to find answers to the questions. By implication, there was an improvement in learners' proficiency in stoichiometry. This coheres with the findings of Hein (2012) who notes that learners' proficiency in organic chemistry improved with a significant p value after participating in POGIL. Hein's results showed that there were fewer learners with lower grades in the standardised test after participating in POGIL.

6.4 Chapter Summary

In this chapter, I presented, analysed, and discussed learners' proficiency in stoichiometry and how it shifted during the study. The finding that emerged is that most participants in this study had low proficiency in stoichiometry before the POGIL intervention. After participating in POGIL, however, many of the learners improved to being intermediate or highly proficient in stoichiometry. This chapter also presented the distribution of learners according to their scores in each of the proficiency strands. The results indicated that after the POGIL intervention, there were no learners with low procedural fluency, while the majority improved significantly in conceptual understanding of stoichiometry concepts in the post-test. In the next chapter, the data analysis and discussion of the findings on learners' attitudes towards science generated through TOSRA-2 are presented.

CHAPTER SEVEN: LEARNERS' EVOLVING ATTITUDE TOWARDS SCIENCE

> *Attitude is a relatively more dispositional construct that changes slowly and influences the broad range of perception, views, and values regarding science, as well as their interest in pursuing potential careers in science.* (Fulmer et al., 2019, p. 3)

7.1 Introduction

Research question three: *How do learners' attitudes towards science change (if at all) over the period of participation in the POGIL intervention?*

This chapter focuses on the shift (if any) of learners' attitudes towards science over the course of the study in relation to their participation in POGIL. Therefore, the Test of Science Related Attitude (TOSRA-2) pre-test and post-test results, and subsequent analysis are presented and discussed in this chapter. The TOSRA-2 instrument was utilised to generate data on learners' attitudes towards science, aimed at answering research question three. Data were generated based on learners' responses to each of the three sub-scales studied: perception of science, interest in science, and enjoyment of science.

The data were analysed based on 53 learners that completed both the TOSRA-2 pre- and post-test questionnaires. Firstly, learners' responses to all the five categories: 'Strongly Agree' (SA), 'Agree' (A), 'Not Sure' (NS), 'Disagree' (D) and 'Strongly Disagree' (SD) were represented on a bar chart. These were useful in showing the detailed responses of learners on each of the attitude sub-scales. Thereafter, to ascertain the overall indication about the agreement or disagreement with the items of the scales, the Likert scales were combined into three main categories; agree, not sure, and disagree. The positive (agreement), undecided (not sure), and negative (disagreement) categories of learners' responses were useful in showing the overall trends in the data (Cohen et al., 2018).

In this chapter, I firstly present the trends in learners' responses to TOSRA-2 subscales shown on bar charts that were derived from a frequency table. Next, the bar graph and paired samples tables which show differences between the pre-and post-test mean scores are presented. Following this, learners' profiling into attitude groups based on their scores from the TOSRA-2 pre- and post-test are compared and shown on a bar chart. Afterward, I discuss the results of the findings from the TOSRA. Although the data is purely quantitative, I draw some insights across other instruments which are both quantitative and qualitative (SLQ, SAT, learners' interviews, and journal entries) intending to clarify or provide supporting evidence relevant to the argument. This emphasises one of the advantages of mixed-methods research which is that data from either quantitative or qualitative instruments could support the other or provide clarifications (Cohen et al., 2018).

7.2 Data and Findings from TOSRA-2 Pre-test and Post-test Questionnaire

Learners' responses to the items on TOSRA- 2 (see Appendix F) pre- and post-test assessing their perception, interest, and enjoyment of science are shown in Figures 7.1, 7.2 and 7.3 below.

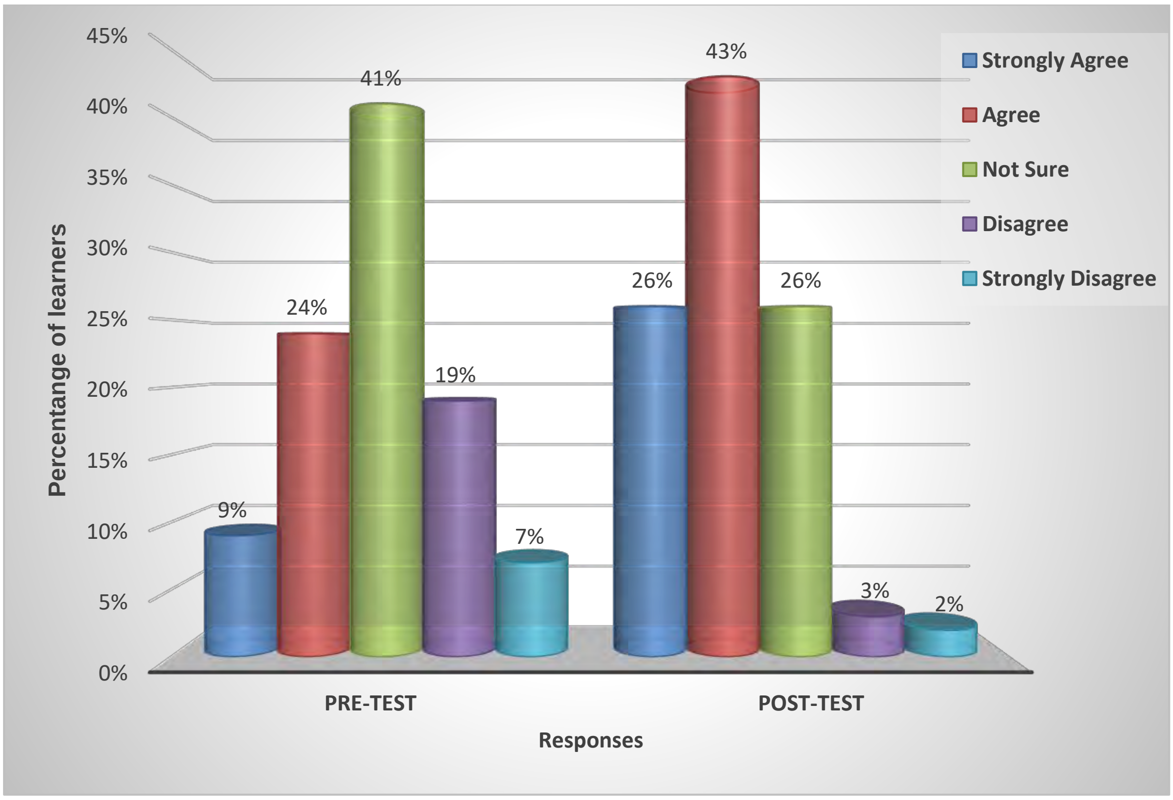


Figure 7.1: Learners' responses to items assessing the perception of science

Figure 7.1 shows that out of 53 learners surveyed, 33% had a positive perception of science at the pre-test. This increased to 69% at the post-test. Conversely, 26% had a negative perception of science in the pre-test which substantially decreased to 5% at the post-test. In the pre-test, 41% were undecided on their perception of science, but only 26% of learners remain undecided in the post-test. This data suggests that learners' perception of science may have shifted to the positive after participation in POGIL.

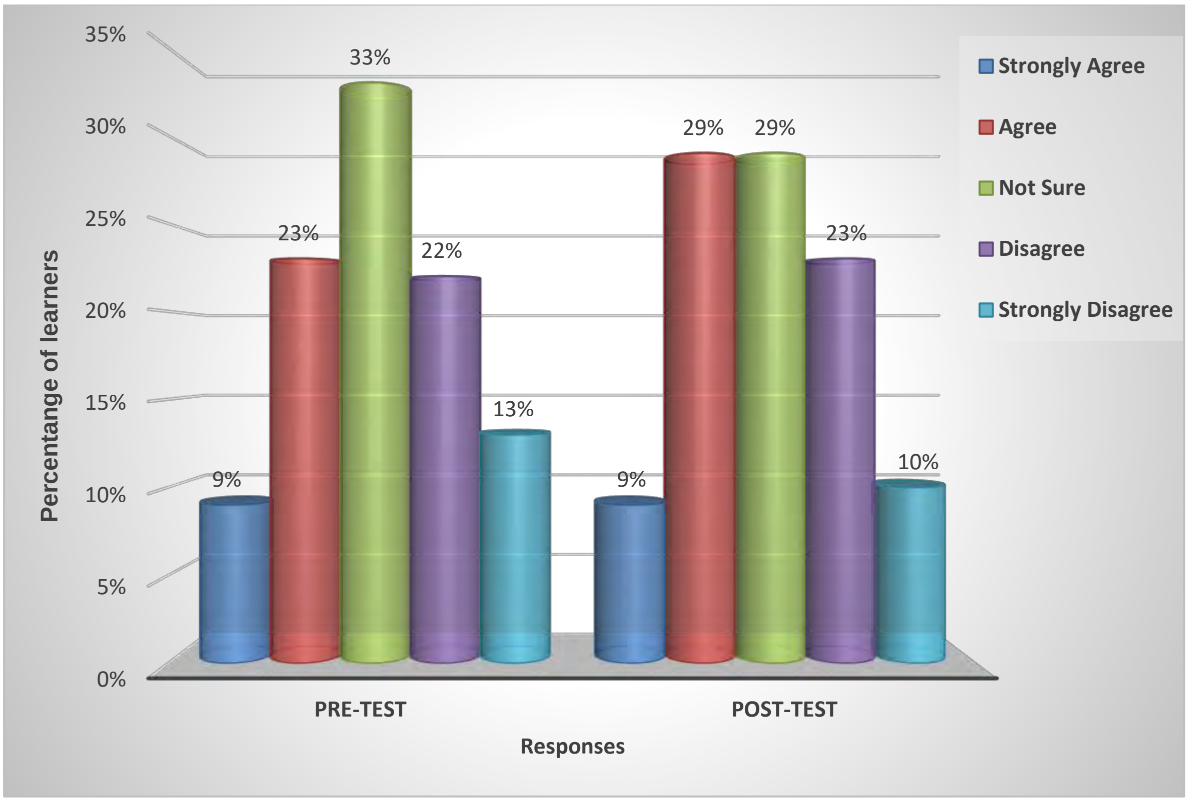


Figure 7.2: Learners' responses to items assessing interest in science

Figure 7.2 reveals that 39% had an interest in science or science-related careers prior to their participation in POGIL. The same number of learners (39%) demonstrated no interest in science at the pre-test while 31% were undecided. After 10 weeks of participation, there was no substantial difference in the learners' expression of interest in science or science-related career. Only 35% were interested in science, 29% were not sure, while 35% did not have an interest in science. The trend above thus suggests that learners' interest in science appears inconclusive when comparing prior and after participation in POGIL.

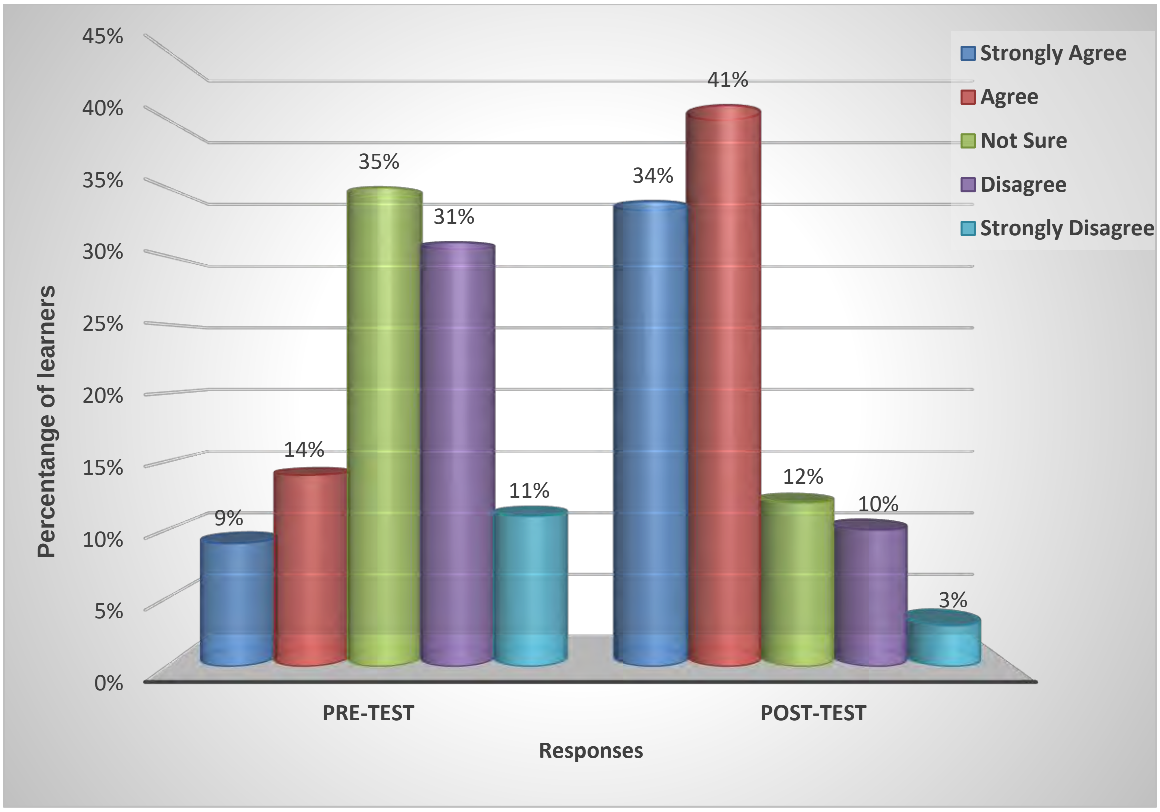


Figure 7.3: Learners' responses to items assessing enjoyment of science

From Figure 7.3, in response to the pre-test, 23% of learners enjoyed science lessons and activities, 35% were not sure and 42% did not enjoy science. This indicates that most of the learners 'do not enjoy' or 'are not sure if they enjoy' science lessons and activities before they participated in POGIL. However, after 10 weeks, up to three-quarters of the learners (75%) indicated that they do enjoy science lessons and activities. The number of learners who do not enjoy science decreased to 13% while only 12% of learners remained undecided. This indicates that learners' enjoyment of science lessons or activities shifted positively after participation in POGIL.

The comparison between learners' responses in the overall TOSRA-2 pre-test and post-test and attitude groups are shown as Figures 7.4 and 7.5, respectively.

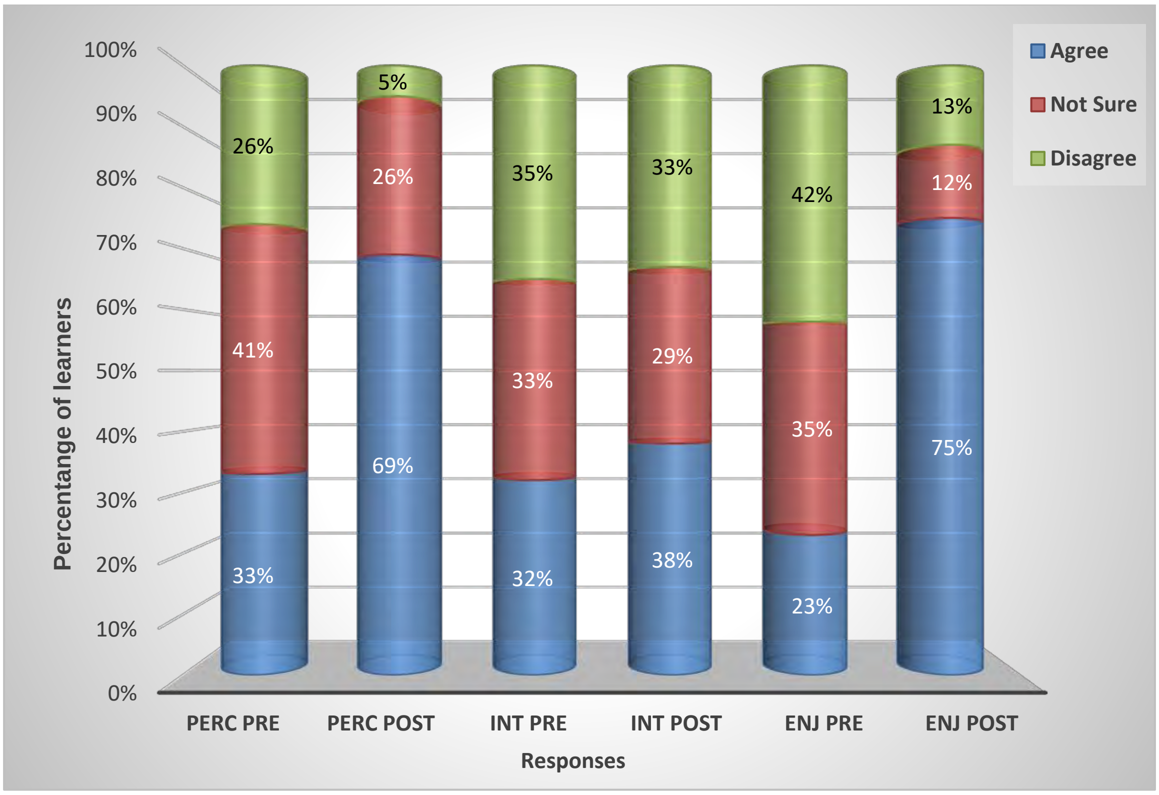


Figure 7.4: Comparison of responses from pre- and post-test

Figure 7.4 represents learners' responses for each of the three attitude sub-scales examined in the pre- and post-test of this study. It shows learners' overall indication of agreement and disagreement with each of the sub-scales.

Using the class interval formula (Range of scores/Number of groups), learners were categorised into three main attitude groups based on their mean scores in the TOSRA-2 pre- and post-test. The highest score achievable was 175 while the lowest was 35. The high attitude group included learners with scores from 129-175, the average groups had scores from 82-128, and the low attitude group from 35-81.

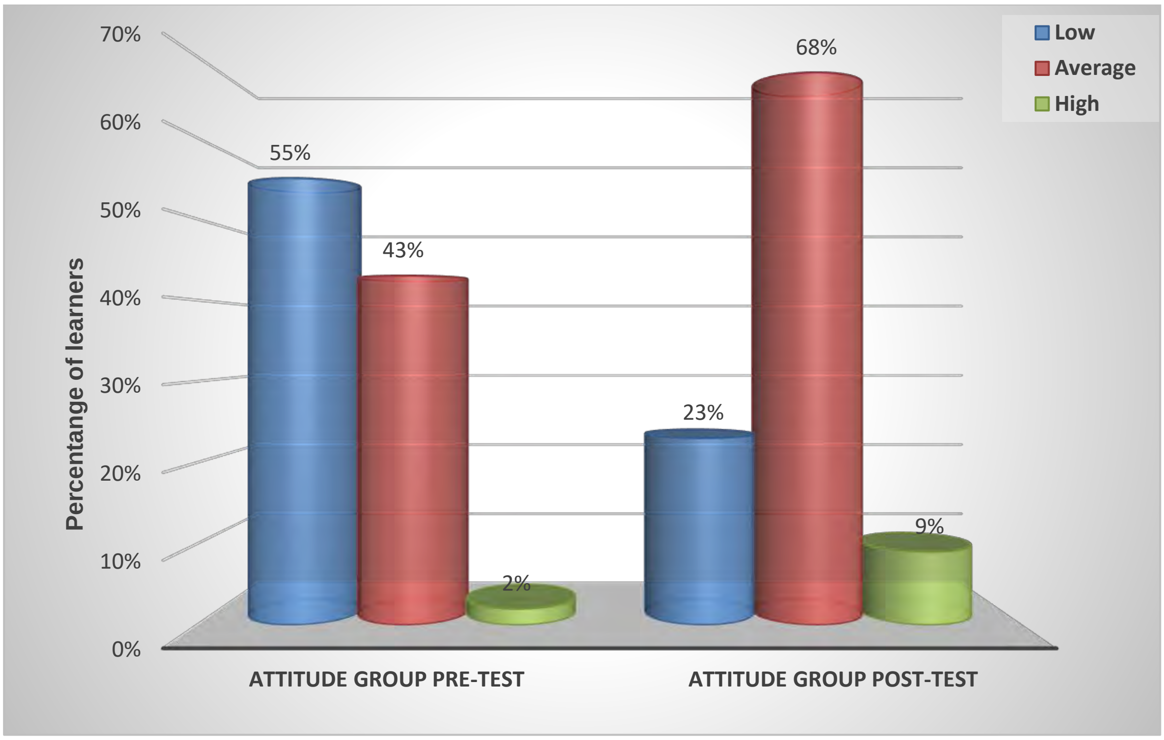


Figure 7.5: Comparison of learners' attitude groups in the TOSRA-2 pre- and post-test

Figure 7.5 shows the distribution of the attitudes of learners. Overall, both the average and high attitude groups increased, with the resultant decrease in the low attitude group in the post-test. There were 7% more learners in the high attitude group in the post-test compared with the pre-test. Likewise, there were 25% more learners in the average attitude group, while there were 32% fewer learners in the low attitude group at the post-test compared with the pre-test.

Table 7.1: Mean difference in attitude sub-scales (*n*=53)

<u>Paired samples test</u>

	Mean	Means diff.	Std. deviation	*t*	df	Sig. (2-tailed)
Perception pre-test	28.2264	8.51	13.38719	4.117	52	.000
Perception post-test	36.7358		12.00024			
Interest pre-test	23.0943	0.45	10.48491	.237	52	.814
Interest post-test	23.5472		10.24801			
Enjoyment pre-test	26.4528	15.89	12.28283	7.813	52	.000
Enjoyment post-test	42.3396		9.26628			

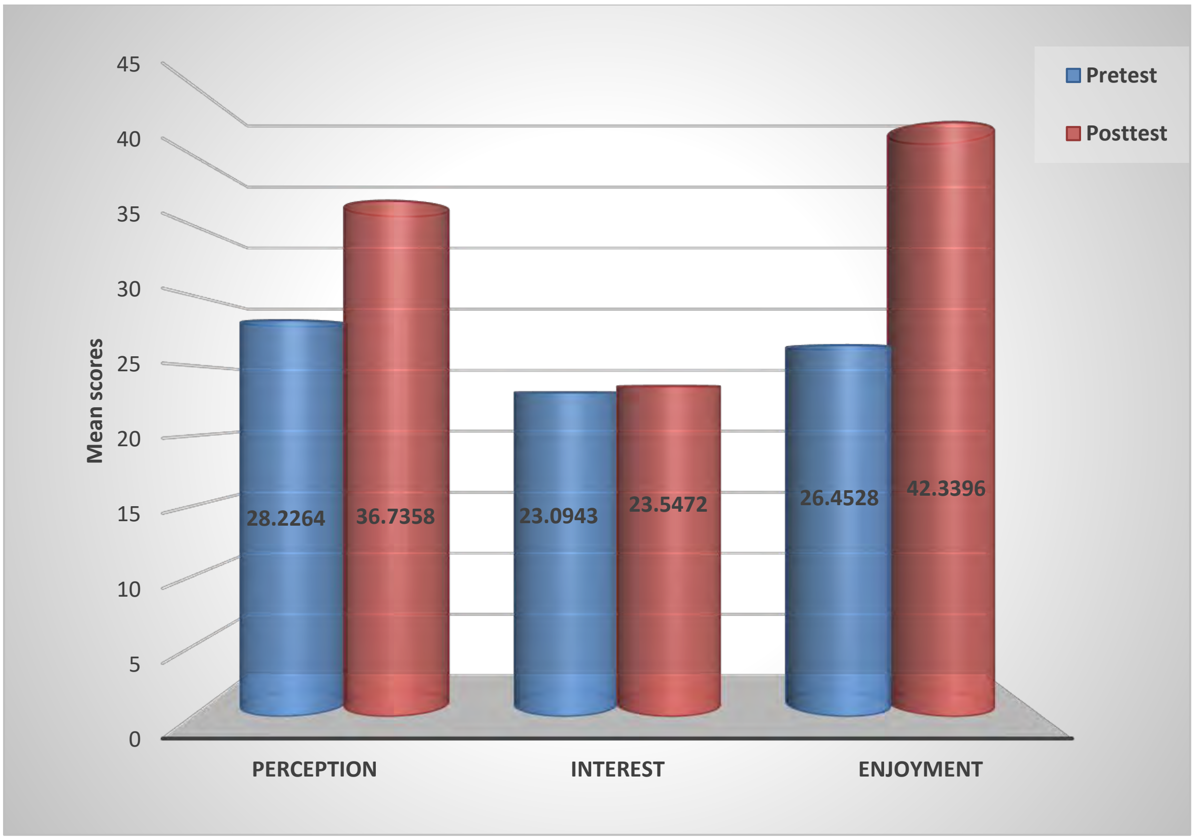


Figure 7.6: Means of pre- and post-test scores in the TOSRA-2 sub-scales

The paired samples *t*-test shown in Table 7.1 illustrates the statistically significant difference between the pre- and post-test scores of the attitude sub-scales. The difference between the means each of perception and enjoyment between the pre- and post-test are 8.51 and 15.89, respectively. This is statistically significant (sig. 2-tailed $p = .000$) after 10 weeks. In contrast, the difference between the means of the pre- and post-test for interest (0.45) is not statistically significant (sig. 2-tailed $p = .814$) after 10 weeks.

Equally, the bar graph in Figure 7.6 illustrates the trend of learners' attitudes between the 1st and 10th week of the study according to the three sub-scales examined in this study. The figures were given as the mean scores of the pre- and post-test of the attitude sub-scales. The bar graph shows a major difference in the enjoyment sub-scales with a noticeable increase of 15 points at the post-test. Similarly, the perception of science followed an upward trajectory from 28 points to 36 points. In contrast, learners' interest in science shows a slight difference after 10 weeks.

Table 7.2: Mean difference in overall TOSRA-2 pre- and post-test scores (*n*=53)

<u>Paired samples test</u>

	Mean	Mean diff.	Std. deviation	*t*	df	Sig. (2-tailed)
Attitude pre-test	78.6792	23.94	20.87027	7.151	52	.000
Attitude post-test	102.6226		1978755			

Table 7.2 reveals a statistically significant difference (sig. 2-tailed p = .000) between learners' overall attitude scores in the pre- and post-test with a difference in the means of 23.94.

7.3 Discussion of TOSRA-2 Result – Shift in Attitude Towards Science over Time for Learners Participating in POGIL

Learners had higher scores in the overall TOSRA-2 as well as the attitude sub-scales in the post-test when compared with the pre-test. As shown in Figure 7.5, more than half (55%) of learners did have a negative attitude towards science at the beginning of the study. Learners in the average and high attitude group (45%) had positive attitudes towards science prior to their participation in POGIL. In the post-test, the proportion of learners with a positive attitude towards science increased tremendously from 45% to 77% while those with negative attitudes reduced significantly from 55% to a marginal percentage of 23% (Figure 7.5). As affirmed by Fraser (1981), high scores in TOSRA indicate a high attitude towards science. This result shows a possible positive effect of participation in the POGIL intervention.

Furthermore, learners' scores in each of the attitude sub-scales in the post-test were more than that observed at the pre-test (Table 7.1). The interest in science sub-scale had the lowest percentage (38%) at the post-test compared to the perception and enjoyment of science with high positive responses of 69% and 75% respectively after 10 weeks (Figure 7.4). This shows the variability of learners' attitudes to science based on the constructs of attitude examined in this study.

In the perception sub-scale (Figure 7.1), 33% of learners agreed to the items assessing their positive perception of science in the pre-test compared to 69% at the post-test. The percentage of learners (41%) who were not sure of their perception of science at the onset of the study reduced to 26% after 10 weeks. Similarly, the proportion of those with a negative perception of science decreased considerably from 26% to 5% at the end of the study. It could be deduced from this result that most of the learners' perceptions of science were positively influenced after participating in POGIL activities.

Learners who showed interest in science at the onset of the study were considerably little (32%). Likewise, a comparable percentage of them were not sure (33%) or disagreed (35%) with interest in science at the beginning of the study (Figure 7.2). This pattern shows that the majority of participants in this study did not have or were not sure of their interest in science before they participated in this study. After 10 weeks, there was no substantial change in the participants' interest in science compared to the previous pattern before participation in the POGIL intervention programme. This is shown in Table 7.1 where the difference between the means of the interest pre- and post-test were not statistically significantly different after 10 weeks with the 2-tailed $p = 0.814$. In addition, the pattern that emerged from the bar graph (Figure 7.2) indicated a minimal difference between the interest pre- and post-test after 10 weeks.

The findings of previous studies on the effect of POGIL on learners' interest in science careers differed from mine, and this was observed with interest. A possible explanation could be that the POGIL intervention may not have significantly changed learners' perspectives about careers in science. For instance, during the interviews, learners enunciated the importance of science and scientists and how they had enjoyed learning chemistry through POGIL, but they were quick to dismiss the thought of having a career in science because of other issues with science professions. Participants said:

> *It is always difficult to get job with science except you do courses like medicine, pharmacy like that … my brother who did engineering is working as a banker. So… I don't know. (L2, I)*

> *Scientist don't have money, they are not rich. I wasn't thinking of anything science line because I always think people in science don't pass well in their exams, they struggle … most people in science also don't get a good job afterward. (L31, I).*

The excerpts above showed that learners enjoyed science but did not see it as a career option. Interestingly, L31 expressed her love and enjoyment of science but she believed that science professionals did not have enough job opportunities or were always unemployed, hence, her lack of interest in a science career. She indicated that she would love to be in a field where she could get a job without difficulty and be professionally fulfilled. By implication, if learners enjoy and have a positive perception of science but are not assured of a future career/personal fulfilment, they may not have many aspirations in that field. In the same line, the report of the Institution of Engineering and Technology IET (2008) affirms that learners perceived science courses as less lucrative. In addition, Juan et al. (2018) assert that learners' interest in science is influenced by their awareness of probable career fulfilment or the availability of the scientist role models around them. This finding contrast to Fulmer et al.'s (2019) view as alluded to in the epigraph, that as attitudes evolve they influence learners' interest in pursuing science careers.

Most learners did not enjoy (42%) or were not sure (35%) of enjoying science activities or lessons while only 23% elicited personal pleasure in science lessons or activities before they participated in POGIL. This was indicated by their responses to the items in the enjoyment sub-scale (Figure 7.3). On the contrary, after 10 weeks of participation in POGIL activities, 75% of learners found science lessons and activities enjoyable. The percentage of learners that did not enjoy science and were not sure decreased by 29% and 23% respectively. Similarly, the most obvious trend in Figure 7.4 and 7.6 was that learners' enjoyment of science lessons/activities increased considerably over the 10 weeks participation in POGIL. It could be assumed from these results that POGIL activities influenced learners' pleasure in science positively.

Overall, the results described above indicate that there was a positive shift in the majority of learners' attitudes towards science by the end of the study. As described by the participants, a better understanding of concepts either through cooperative learning or active engagement with POGIL learning materials had a positive impact on their enjoyment of the stoichiometry lesson and endeared them to science. Learners preferred studying topics that they could associate and link with their environment. They disliked notetaking, memorising, or rote-learning and not being actively involved in their learning. Marais and Combrinck (2009) assert that learners' enjoyment of chemistry becomes more certain when there is a better understanding of concepts and this could subsequently ignite the desire for continuous learning in science. In the same vein, Agunbiade et al. (2017) found that the nature of science teaching that learners experience is an important determining factor in the formation of their attitudes towards science. This most likely points to the reason why the percentage in agreement with the enjoyment of science increased substantially at the post-test.

7.4 Chapter Summary

In this chapter, I presented and discussed the data for three. The data on learners' overall attitudes towards science and the three sub-scales were presented and discussed. To capture a robust inference of the TOSRA-2 result, I used selected transcripts from the interview and journal entries as supportive evidence for the evolution of learners' attitudes where necessary. It is clear from the previous and current chapters that the quantitative data yielded results suggestive of an improvement in stoichiometry proficiency and attitudes towards science over time, respectively. With this in mind, we need to look at the qualitative data collected through the semi-structured interviews and learners' journal entries to get a greater understanding of factors that influenced stoichiometry proficiency and attitudes towards science over time. In the next chapter, I present, analyse, and discuss data generated through the semi-structured interviews and learners' journal entries.

CHAPTER EIGHT: CONTRIBUTING FACTORS TO LEARNERS' PROFICIENCY IN STOICHIOMETRY AND ATTITUDES TOWARDS SCIENCE

> *All forms of instruction can best be examined from the perspectives of how teachers, students, and content interact in context to produce teaching and learning*. (Kilpatrick et al., 2001, p. 8)

8.1 Introduction

Research question four: *What experience do learners value (if any) during their POGIL lessons?*

This study investigated the influence of the POGIL instructional strategy on learners' proficiency in stoichiometry and attitudes towards science. The previous chapters (Chapters Six & Seven) presented the findings and discussions on learners' proficiency in stoichiometry and attitudes towards science as a result of their participation in POGIL. It is, therefore, of importance to examine the experiences of POGIL that learners and features that might have enabled the shifts in proficiency in stoichiometry and attitudes towards science in the POGIL classroom as discussed in the previous chapters. Building on the quantitative data discussed in the previous chapters, this chapter presents the detailed qualitative analysis of the learners' interview transcripts and journal entries in a composite attempt at answering the fourth research question.

As described in the methodology chapter (see Section 4.4), seven learners who were available for the WhatsApp interviews, showing different trends in proficiency and attitude shifts amongst other factors were interviewed, while ensuring a mix from both participating schools. Each interview was audio-taped and then transcribed which gave me a corpus from which to work. The transcriptions of the recorded interviews were then reviewed to extract the prevalent ideas from the participants. Likewise, all learners' journal entries were collated. These entries were analysed together with the interview transcripts to find patterns, discover relationships in the data, and form broad categories informed by the analytical framework in Table 3.1 (see Section 3.4).

I proceeded to analyse the patterns of learners' responses to the key questions on: stoichiometry proficiency, attitudes towards science, and their POGIL experiences. While employing the features of the socio-cultural framework: *social interactions, cultural tools, self-regulation, ZPD* – as discussed in Section 3.3 – and their relationship with the POGIL principle, I examined how this enabled or constrained learners' development of proficiency in stoichiometry and attitudes towards science. I acknowledge that the interpretations might not count in totality as evidence but rather they provide the illustrations for arguments being made in this chapter.

The discussion of the results aims at amalgamating the findings from the qualitative tools, allowing for comparison of data across learners and other research instruments based on the research question. Nine preliminary themes emerged from the analysis and data groups generated as shown in Table 8.1 As it could seem cumbersome to present and discuss the interviews in entirety, I needed to select segments of data that illuminated various ideas that contributed to the discussion of the research questions. Nevertheless, fragments of data were not flouted but integrated and further used to enrich and improve the discussion as it arose.

8.2 Data and Findings from the Learners' Semi-Structured Interview Transcripts and Journal Entries

Table 8.1: Generating preliminary themes and codes

Assigned No.	Description of the highlighted text	Preliminary themes	Codes
16 **6** **8** **12** **22** **21**	Preference for teamwork, collaborative learning, mutual support within team, enjoyment of teamwork, leadership skills, positive perception of peers	Collaborative learning	COL
9 **13** **29**	sharing of knowledge/ideas, teamwork facilitates understanding, learn new ways of doing things	Peer tutoring	PTT
3 **10** **15** **5** **18**	Understanding eliminates rote learning, analytical thinking, understanding facilitates confidence, knowledge retention, knowledge transferability/application,	Learners' comprehension/mastery	LCM

2 **46** **32**	explanation facilitates understanding, understanding enhance positive attitude, understanding of concepts		
4 **19** **30** **7** **36** **28**	Engaging learning materials, engaging activities promotes regular study, making effort to learn, Problem solving activities, Interactive games and activities, engaging class activity	Engaging learning materials	ELM
20 **37** **38**	Hands-on experience, practical work is interesting, practical work enhance understanding	Hands-on experience	HOE
47 **34** **39** **26**	Positive perception of science, mathematical calculation involved, no/interest in science/career, perception of chemistry	Perception of science	PSC
11 **24** **25** **23** **17** **14**	Insufficient learning time, distraction, noisy environment, preference for independent learning, domineering peers, enjoyment of lessons	Nature of learning environment	NLE
1 **35** **41** **48** **27**	Facilitators' support, explanation from peers, family influence, linking science to everyday life, facilitators' explanation	Learning support	LSP
31 **45** **33** **40** **42** **43** **44**	Perceived difficulty of chemistry, Required mathematical skills, confusing concepts, poor achievement in science, scientists are not rich, low pay for scientist, lack of jobs	Perceived difficulty/ issues with science	PDS

The nine preliminary themes were reviewed and checked for similarities and contrasts. Subsequently, four main themes emerged as representing the enabling or constraining factors influencing learners' development of proficiency in stoichiometry and attitudes towards science as they participated in POGIL. These four themes were:

- Facilitator/learning environment features;
- Instructional characteristics;
- Learners' perception of science; and

- Learners' comprehension/mastery of concepts.

The qualitative data from the interview transcripts and learners' journal entries are presented and discussed to support and provide reasons for the answers to research questions 1, 2, and 3. The four themes are described using supporting themes and literature as shown as Table 8.2. Direct quotes from the interview transcripts (I) or journals (J) were used for interpretation and explanation regarding the research question – e.g. L53, I (learner 53, interview).

Table 8.2: Main themes and supporting theory/literature

Themes	Theory/literature
Theme 1: Facilitator/Learning environment features	
Collaborative learning (COL) Peer Tutoring (PTT) Teacher support (TSP) Nature of learning environment (NLE)	Vygotsky, 1978; Hanson, 2006; Longareth, Godinho, Parr, & Wilson, 2009; Schunk, 2012; Opara, 2014; Tigere, 2014; Shabani, 2016; Rodriquez et al., 2018, Koopman et al., 2019, Nhase, 2019.
Theme 2: Instructional characteristics	
Engaging learning materials (ELM) Hands-on experience (HOE)	Marais & Combrinck, 2009, Babalola 2017; Salonen et al., 2017.
Theme 3: Learners' perception of science	
Perception of science (PSC) Perceived difficulty of science (PDS)	Uchegbu et al., 2016; Agunbiade et al., 2017, Mujtaba et al., 2018, Ganeb & Montebo, 2018; Roberts et al., 2018.
Theme 4: Learners' comprehension/ mastery of concepts	
Learners' comprehension /mastery (LCM)	Vygotsky, 1978; Tripney et al., 2010; Bybee & McCrae, 2011; Agunbiade, 2015; De Gale & Boiselle, 2015; Preininger, 2017.

8.3 Factors Influencing Learners Proficiency in Stoichiometry and Attitude Towards Science in the POGIL Classroom

Data from the journal entries were collated and analysed with the interview transcripts as described in Section 8.2. Following the review of preliminary themes, four main themes emerged: facilitator/learning environment characteristics, instructional characteristics, learners' perception of science, and learners' comprehension/mastery of concepts. These themes are discussed below, for adequate exploration of the mechanisms that contributed to learners' development of proficiency in stoichiometry and attitudes towards science within the POGIL classroom as mentioned in Table 8.1.

8.3.1 Facilitators' learning environment features

Learners learn better when they perceive the learning environment positively. They perceived the POGIL classroom as lively, interesting, and fun-filled. In essence, they especially looked forward to learning activities. Participants in this study enjoyed the learner-to-learner interaction as well as the interaction with their teachers. They described the classroom as lively compared to the previous learning environment, including the instructional method. The teachers facilitated effective gathering and presentation of the information while learners cooperatively discussed with each other as a team. Learners explained that this process induced unique experiences such as increased enjoyment and understanding of stoichiometry. They described their teachers (facilitators in this study) as being supportive and patient enough to explain in detail any question or concept they struggled with. One of the participants explained their teacher's support in this manner:

> *She takes her time to explain more than before; when she just ask the whole class if we understand but nobody will say they don't. I will say she is more interested that we understand now. (L15, I)*

It was evident that learners wanted the attention and support of their teacher so much that they interpreted not getting attention as not getting adequate support for learning. This emphasises the significant role that well-equipped teachers play in the teaching and learning of stoichiometry. The facilitators are an integral part of the POGIL classroom though it may seem to an outside observer that learners are doing most of the work. Hanson (2006), while arguing that POGIL does not imply that learners are completely independent, stresses the importance of facilitators providing thoughtful and structured tasks. Maintaining structure and expectations in the classroom will enable productive learning and prevent disorderliness in the classroom. The facilitators create the content, learning objectives, and carefully develop the POGIL activities to meet the learning objectives as well as guiding and supporting learners in understanding and not deviating from tasks given as detailed in Section 4.6.4 of the methodology chapter.

The activity-oriented nature of POGIL requires learners to investigate and make discoveries on their own with the support of the teacher acting as a facilitator. The facilitators provided the opportunity and support for meaningful learning to occur in the classroom while discouraging the idea of rote learning. Raved and Assaraf (2011) report that learners' attitudes towards science were positively influenced by their teachers' attributes. A similar finding was reported by Kobiatko (2017) on the influence of teachers' perceptions on learners' perceptions of biology. Learners' perceptions of biology were significantly impacted by the perceptions of their teachers' personality or teaching qualities. In corroboration, Koopman et al. (2019) found that teachers' characteristics influence their instructional quality and consequently have a positive effect on learners' proficiency.

Also, participants expressed how POGIL provided a dynamic environment where they could freely discuss with each other and their teachers which increased their understanding and enjoyment of stoichiometry lessons. This, they attested, gave them the opportunities to be expressive in their learning, and encouraged self-confidence. Similarly, Koul and Fisher (2003) in their study found that learners develop more confidence and positive attitudes when they perceive that the learning environment gives opportunities for organised class activities and more teacher support. The structure and nature of the learning environment has the potential of determining the number of learning outcomes (Koul & Fisher, 2003). When asked about what they liked about the POGIL classroom, learners made the following statements:

> *Everyone must participate and we must respect everybody's idea. No one is rushing and we are all taking time to learn from one another. I think it is more fun. (L40, I).*

> *Because the way we work together makes the class very interesting and not boring. Another thing I can say is that it makes it easier to understand things. We are not in haste but like learning and playing. (L19, I).*

Although the classes were a bit noisier than usual, learners seemed to have enjoyed the lessons as they were able to express themselves freely in the construction of knowledge. According to Nhase (2019), in inquiry-based learning, learners co-construct knowledge and develop their own investigation rather than being passively fed as with the traditional classroom. This process allows learners to internalise the scientific process rather than merely learning by rote (Ramnarain, 2021). When learners can internalise concepts, the likelihood of applying them to similar contexts increases. POGIL provides the opportunity for learners to discuss their confusing ideas on complex concepts in chemistry and exploration of their mental abilities (Barthlow, 2011).

Qualitative data from learners' journal entries together with the interview transcripts indicated the influence of the support learners received from one another on their understanding of stoichiometry. They were enthusiastic to share their experiences of the cooperative learning teams in the POGIL classroom and how they benefited from the sharing of knowledge, ideas, and strategies among themselves:

> *When we work together even if you are wrong, someone will correct you and you will know why you got it wrong. We share our ideas and different method to do some questions. And at the end you will learn even a better way of solving the question than what you know before. (L15, I)*

> *We have been doing a lot of work in group, we discuss our ideas together, we try to listen to other people's thought too and learn from that to complete our worksheet. I think I enjoy it … if anyone knows the answer, he will explain to everybody. (L40, I)*

> *I enjoyed how we all discussed our work together. (L52, J)*

Sharing strategies and ideas among learners as a team in each group facilitated a deeper understanding of concepts and improved their self-confidence in stoichiometry. As espoused by Vygotsky (1978), their comments suggested that the MKO in their learning teams provided support and was willing to share their strategies for everyone in the team to have unified knowledge of the concept being learned. In the POGIL classroom, learners with different achievement levels were placed in the same team to support each other.

Participants highlighted how collaborative learning intensified their motivation for learning, curiosity, and problem-solving strategies in stoichiometry. This implies that they were able to modify their internal representations in response to negotiation with peers as they engaged in activities in the POGIL classroom. As cooperative learning is at the forefront of the POGIL framework, it is assumed that each learning team will have learners with varied problem-solving skills or intelligences thus, tasks that are challenging or that might be overwhelming for an individual are tackled collaboratively. Within the learning team, learners come to a resolution on any disagreement regarding their procedures or tasks and take ownership of their failure or success. This finding correlates with other studies reported in the literature (Longareth et al., 2009; Nhase, 2019; Opara, 2014; Sen et al., 2016) that a collaborative learning environment facilitates the development of problem-solving skills where learners can freely express their understanding of the problem and share their strategies with peers.

Correspondingly, peer learning support also known as peer-led tutoring has been identified as an effective teaching strategy at any level of education (Longareth et al., 2009; Rodriguez et al., 2018). According to Longareth et al. (2009), when learners give or receive learning support from their peers, it increases their understanding, motivation, sense of responsibility as well as social interaction. The socio-cultural theory enlightens that through social interaction, learners support each other to co-construct knowledge in a constructivist learning environment (Vygotsky, 1978).

Collaborating with other learners while engaging in structured POGIL tasks provided a climate of openness, respect for other team members, and the establishment of trust among learners which enabled the development of teamwork skills. Dialogue among learners can only be successful when there is tolerance and respect for differences in opinions. Learners' engagement in POGIL activities allowed for shared responsibility and respectful relationships where they accepted and valued others' opinions. For instance, learners pursued work for communal good rather than individual purposes based on competition with their peers. Some of them emphasised how they saw other learners in a new positive way that was different from their previous assumptions about them. For example: "*We learn from each other and somehow we have become friends, we cooperate a lot*" (L40, I).

According to Tigere (2014), an environment that encourages problem solving enables the learner to explore new strategies and build relationships. Giving learners the avenue to work cooperatively made them accountable to one another during the learning process. There is greater recognition of the effectiveness of collaborative learning in the literature. For instance, Rodriguez et al. (2018) affirm that incorporating small group cooperative activities in the classroom increases learners' engagement and creates positive experiences during and after the course. In such large science classrooms as those in Nigeria, it might be valuable for high achieving learners or the MKO to complement the teachers' explanations to support the low or different learning capabilities of learners.

Dialogue between learners promotes knowledge reconstruction and expansion (Shabani, 2016). This was observed with learners participating in POGIL as many of them stated how they had improved as they interacted with their peers. Placing learners in a team was effective at improving their problem-solving skills and competency in stoichiometry. Vygotsky highlights the importance of cultural tools as a mediating tool in the socio-cultural learning environment. The data emerging from this study showed that learning of stoichiometry concepts were mediated through 'cultural tools' such as POGIL learning materials, problem solving strategies, and language. Each learning team adapted the appropriate cultural tools necessary to complete their tasks successfully.

Learners described how developing problem-solving strategies within their learning teams had been of great value in developing proficiency in stoichiometry. L45 said: *"We create our method that we use in solving some questions in stoichiometry which made it easier to remember and I found it very easy*" (L45, I). Another learner said: "*Everyone supports each other. People that are very good and knows the best method to solve the questions teach people that do not understand"* (L19, I).

Learners could move to another level of competence in problem solving when they received support as they learnt cooperatively with their peers. Vygotsky (1978) identifies the ZPD as a symbolic space where learning takes place. The social interaction or collaboration between learners and their engagement with POGIL learning materials enabled the emergence of a ZPD (Schunk, 2012). For instance, one of them said:

> *When we work together even if you are wrong someone will correct you and you will know why you got it wrong. We share our ideas and different method to do some questions. And at the end you will learn even better way of solving the question than what you know before. (L15, I*)

Likewise L19 remarked:

> *People that are very good and knows the best method to solve the question teach people that do not understand it. (L19, I*)

From the statememts presented above, I would argue that the MKO in the learning teams had the opportunbity to build confidence in being able to use, apply, and communicate what they already knew. Learners took advantage of the collaborative nature of the POGIL activity to accomplish what they may not have been able to do on their own. These interactions enabled ZPD to emerge for the learners.

Furthermore, the characteristics of a socio-cultural learning environment where learners acquire language or strategies for solving problems and pass them on to others within the team were demonstrated in the POGIL classroom. One of the learners reiterated that the sort of explanation from their peers was different from that of the teacher:

> *But, you know in the group, we explain to each other gently and break things down the way we understood it ourselves so it is that way that we explain to others not like the teacher will explain it. (L19, I)*

L19 was probed further to understand how their peers' explanations differ from that of their teacher and she said:

> *... just a simple way that others will understand. (L19, I)*

The preference for peers' dialogue by learners suggests that language might also have played a role in the learners' understanding. Vygotsky's perspective is that learners jointly construct knowledge, thereby developing understanding through dialogue. The learner's explanation suggests that learners share knowledge using their own designed science language to explain to their peers. An important aspect that would be worth knowing is the kind of conversation that ensued among learners in the team.

At the earliest sessions of POGIL, though learners found it enjoyable, they expressed frustration with the change from the passive to active learning in their journal entries. For example, one learner remarked, "*the class is fun and lively but is difficult because we have to think more and come up with the ideas ourselves*" (L3, J). Some learners felt that others with typical extrovert personalities would dominate the interaction within their team at the initial introduction to POGIL, in essence inducing passivity in those with introverted personalities, thereby creating a cadre in the team which could deprive them of learning in the classroom. Besides, participants lamented on the time taken to discuss and give explanations to peers during POGIL activities, therefore, they perceived that not much would be covered by the end of the lesson. For instance, in the journal entries, one learner wrote:

> *Everyone in my group wanted to have a say and it was not just organised. We tried to do some work which we could barely finish because of lots of argument. I prefer to do the starter and extension activity myself. (L43, J)*

A few of them expressed their dislike when they had differing opinions in solving problems and they had to listen to the ideas of everyone before they could progress within the limited time. Some of their negative comments of their experience with POGIL at the initial stage included:

There were lots of distractions as people were just talking and making so much noise. There were so much work and questions to do, they get harder and they were just so much. (L26, J)

The noise and distraction disturbs us a lot. The class is very interesting if other groups can keep their voices down when discussing. Sometimes, when I am trying to think, because some of the questions need you to think deeply, I get distracted by their talking. (L45, I)

Sometimes it doesn't look like normal class but at the end you will learn something. (L19, I)

However, as time progressed, these notions were later diffused as they began to understand the centrality of equal exposure and the opportunity to learn which is characteristic of the POGIL approach. Also, fewer, or no negative comments were observed in their entries. Consistently, Hanson (2006) warns that the change from a passive role to being the 'active agent' in the classroom with the teacher as a guide is not always welcome by learners, which suggests starting and continuing with POGIL as a gradual process when teaching a subject. More so, Longareth et al. (2009) suggest that teachers should be prepared to manage and assist learning groups at any point in time to lessen the time spent on the discussion between themselves. Quigley et al. (2011) explain that in an inquiry-based classroom, teachers have the responsibility of guiding the classroom interactions, and ensuring learners listen to one another as they might argue during an inquiry-based learning approach.

8.3.2 Instructional characteristics

Learning through the POGIL learning cycle changed the overview of seemingly dull stoichiometry concepts to exciting ones associated with visual and practical learning experiences. Participants acknowledged the opportunities they had to be involved in the practical activities to investigate the scientific processes which made learning stoichiometry more appealing to them. For instance, L44 expressed her excitement in participating in experimental activities:

For example, I do not really understand the limiting reagent and calculating it… when we started it in class, we did one simple practical with bread slices and all that… how to identify the limiting reagent became so clear to me. If I have to explain limiting reagent, I can easily remember the bread and lettuce practical. (L44, I)

Engaging learners in practical activities, although very important, does not necessarily mean they are learning (Agunbiade, 2015), but through the POGIL worksheets, learners were able to connect ‘theories’ to ‘practice’ regarding stoichiometry concepts as they engaged in practical activities. They explicated that hands-on activities, with guidelines from their worksheets, and connected with the concepts being studied thereby bringing clarity to the usefulness of their investigations. Thus, the hands-on activities were carried out with understanding which was different from their previous experiences of practical work in chemistry, reinforcing the theory practically. For example, L3 wrote in the journal:

> *We had some practical experiment using the questions in our worksheet. We were to answer the question in the worksheet using the result of our practical work. The worksheet was very useful to understand what we are learning and explain each bit step by step than just cramming stuff. (L3, J)*

When learners carry out practical activities with understanding, they are more likely to internalise the concepts being investigated which deepens their understanding of them.

The higher scores in CU were perhaps because learners could relate the practical work to their pre-existing knowledge of concepts which made the perceived abstractness of concepts concrete and increased knowledge retention. As alluded to by Babalola (2017), engaging learners in practical activities bridges the gap between theory and practice as learners will be able to make inferences from their observations or results. Engagement in practical activities to explain stoichiometry concepts assisted deeper comprehension of concepts, minimised rote learning as well as enabled the development of a positive attitude towards learning stoichiometry. This could be one of the reasons why the percentage of those who responded positively to the enjoyment of science lessons increased substantially with the TOSRA-2 post-test.

Learners often mentioned enjoyment of POGIL activities as influencing their understanding and attitude towards learning stoichiometry. They shared how they had been able to participate actively in the learning process rather than just being passive, with excitement. They showed a lack of interest in the conventional teaching method where they were not allowed to contribute verbally during the teacher’s period. Learners made use of the opportunity to ask questions at any time during learning when they were confused. They were keen to share their experiences of engagement in various learning activities as compared to passively receiving knowledge. Through these engagements, they showed pride in their commitment and investment towards their learning:

We are more free in the class, we do a lot of things, we are allowed to talk and ask questions, not boring. (L45, I)

We do not just sit and scared or even shy of asking questions but … we talk, ask questions and enjoy learning at the same time … I don't feel bored. (L40, I)

The class became very interesting, our worksheet activity on its own keeps us busy and concentrating in the class. (L31, I)

The socio-cultural learning theory emphasises the need for an interactive, learner-centred environment which provides the opportunity for learners' active participation and makes them responsible and independent (Shabani, 2016; Vygotsky, 1978). Socio-cultural theory states that meaningful learning occurs in social interactions as learners work collaboratively. Thus, knowledge is shared rather than an individual experience.

Learners found the POGIL learning materials relevant and more engaging which is beneficial for the active learning process. Comments from participants in their journal entries and during the interviews reflected certain relish at the variety and challenging learning materials. For instance, L14 explained why he enjoyed the stoichiometry lessons by referring to the content of learning materials: "*I learn a lot more difficult things from the worksheet and it was really fun because it challenges us the more and makes me to want to learn more. The class is lit*" (L14, J). Participants also explained that the content and examples used in the learning materials to learn stoichiometry increased comprehension of concepts because they could draw an association between the examples of the activities and the concept being learnt.

The provision of the learning materials makes learning stoichiometry more concrete because it helps to create a 'real picture' for the learning processes. Before the POGIL intervention, the result from the SLQ suggested that learners perceived stoichiometry as an abstract concept. This could be because of the former instructional method of teaching the concept. As explained in Chapter Five, the conventional 'chalk and talk' method was used in teaching the concept which learners found boring. Engaging learners in the inquiry method helped them connect the dots and bring the abstractive nature of chemistry to an understandable format (Bada, 2015; Barthlow & Watson, 2014; Nhase, 2019). This confirmed the findings of Marais and Combrink (2009) that claim that the structured worksheet considerably improves learning and the level of understanding of students.

A participant pointed to some cases where POGIL activities or materials provided opportunities to practise what they learnt and further strengthened their fluency in stoichiometry. This opportunity built learners' confidence in applying what they knew to solving stoichiometry problems, as pointed out by one of them:

> *I think I am more confident in chemistry now… I practice more of the questions and I can tackle many questions because I have seen something related before. Those scary topics like all these moles are easier. (L40, I)*

As stated by Hanson (2006), POGIL cycles guide learners to construct, deepen, and refine their understanding of concepts under investigation. Most of the participants indicated an increased level in their ability to perform tasks in stoichiometry or chemistry generally. Degale and Boiselle (2015) similarly report improved academic confidence among learners involved in POGIL. However, this result contrasts with Shatila's (2007) findings that there was no improvement in learners' confidence levels at solving problems in organic chemistry after participating in POGIL.

In addition, they explained that engaging with the POGIL learning materials promoted thinking rather than their previous learning that promoted memorising:

> *I enjoyed practising with the questions in the worksheet. Particularly the starter activities, do it yourself and extension activities. It makes me to understand step by step than just cramming it. (L26, J)*

> *The worksheet was useful to understand what we are learning and explain step by step than just copying notes and cramming it. (L44, I)*

Similarly, Sen et al. (2016) found that learners that participate in chemistry POGIL sessions have positive outcomes such as cooperative learning, increased knowledge retention which eliminates rote learning, increased curiosity with learning, and interest in chemistry. In addition, Walker and Warfa (2017) found that participating in POGIL increases the retention capacity of learners as well as the course pass rate. Harmoniously, Nhase (2019) and Ramnarain (2021) remark that, learning science through the inquiry method meaningfully engages learners in learning and eliminates rote learning. In the same vein, Ayoberd and Yaayin's (2018) study reported that learners' attitudes towards chemistry were positive when they were taught 'the mole concept' using the problem-solving learning approach.

The use of learning materials with practical activities and other engaging learning activities provided opportunities for changing the classroom to an active learning environment where learners could construct knowledge and aid its retention. This result resonates with other literature (Ayoberd & Yaayin, 2018; De Gale & Boiselle, 2015; Nafees et al., 2012; Nhase, 2019) whose findings maintain that the inquiry-based instructional method in science classrooms enables the retention and recall abilities of learners which translate to increased performance in science. Similarly, Vanags et al. (2013) found that students participating in the POGIL session had improved retention of information and materials studied compared to their counterparts in the control group.

Omwirhiren and Ibrahim (2016) emphasise that science teachers should be able to develop a variety of instructional methods while they implement the most effective and applicable one in teaching particular concepts. When learners are engaged with interactive and guided inquiry, it has a positive effect on their proficiency (Cocca & Cocca, 2019; Hein, 2012). The socio-cultural framework is based on the notion that learning occurs when learners are actively involved in the process, where they can test their ideas and strategies with others within a social and collaborative environment (Vygotsky, 1978).

The notion of the socio-cultural theory adopted for this study came into existence for the development of proficiency and attitudes towards science that occurred in this study. According to Vygotsky (1978, p. 86), "what a child is able to do in collaboration today, he will be able to do independently tomorrow". Vygotsky identifies the ZPD as a symbolic space where learning takes place. The finding from this study was that social interaction or collaboration between learners and their engagement with POGIL learning materials enabled ZPD to emerge. The opportunities for participants to progress in stoichiometry proficiency and attitudes toward science occurred when the ZPD came into existence in each of the learning teams.

The careful selection of activities in different sections of their POGIL materials was to assist the development of proficiency in stoichiometry where learners could move from an independent level of competence to the potential level they could attain with the support of others. Learners revealed during the interview sessions how they had moved between what they could do alone and what they could achieve with the assistance from peers through collaboration.

Some of the participants accentuated that the POGIL materials did not only help with the retention of information but also provided the materials to help other people learn, which in the process reinforced their own understanding. For example, L31 during the interview explained that: "*I think the more I teach her or even when I try to teach my friends, the more I understand something that I overlooked before*". L31 became more confident and was able to explain how to balance the chemical equation to a younger member of her family using her class worksheet. This experience increased her understanding of the concept. This suggests that learners developed a deeper understanding of concepts themselves in the process of explaining or breaking down concepts for the other learners to understand.

Learners perceived that the instructional materials provided were oriented towards helping them learn better. They highlighted how the learning materials encouraged critical thinking not only to find solutions to a given problem but also being able to justify the answers. One of them explained that:

> *When I participate in the group activities, it helps my understanding of the lesson, because we just don't write down the answers we must be able to explain how we got our answers. So when we discuss in the group, we think deeply and it has helped me to understand. (L19, I)*

Furthermore, the POGIL approach encouraged learners in developing other skills beyond academic content. Participants in this study demonstrated developing both the cognitive and affective process skills: information processing, critical thinking, problem-solving, oral/written communication, teamwork, management, and self-assessment in the course of the study and at the end of the study (journal entries, interviews, and SAT post-test). The POGIL instructional method was designed to help learners become more creative and aid the development of seven process skills as shown in Figure 2.1 (Section 2.6) (Hanson, 2006). Inquiry-based learning stimulates intelligence and creativeness in the mind of learners (ibid.).

Learners accentuated that the structured inquiry learning materials and activities in which they engaged in the POGIL classroom, fostered the development of higher-order thinking, presentation, analysis, leadership, and other process skills. For instance, in the POGIL classroom, learners were compelled to communicate their ideas and strategies with team members or the whole class which increased their communication skills. Learners were sometimes required to justify their conclusions with other learning teams, which further expanded their understanding of the concepts involved. The following represents some of the learners' comments from journals and interviews showing the development of POGIL process skills.

> Teamwork skills*: It is easier and simpler because we explain to ourselves. We worked together to complete the worksheet and teach everyone our own ideas so that everyone will understand. (L8, J).*
>
> Teamwork skills: *We understood each other and helped ourselves to understand the group work. We learn from each other and we are all happy. (L25, J)*
>
> Communication and teamwork skills: *I represent my group to solve the questions written on the board and I got it. I think my confidence in chemistry has improved. I finished the extension activities on my own within 10 minutes. (L47, J)*
>
> Management skills: *So I have to coordinate whatever we are doing in the team and make sure we finish our work and everybody must participate. (L45, I)*
>
> Management skills: *We organise ourselves to plan how we want to do our work. (L31, I)*
>
> Problem-solving skills*: The class was very helpful because I didn't know how to solve many questions on quantitative analysis. I realised that it is very important and other topics we have learnt now makes it easier to calculate molarity and solve other questions after the titration. (L43, J)*
>
> Critical thinking skills: *We were given questions and the extended activity makes us to think more carefully about our answers and to be able to defend our answers. (L14, J)*
>
> Critical thinking skills: *We used the starter activity to understand what limiting reagent and excess reactants are. The making of the sandwich and the ingredient quantities is like finding the amount of excess reactants and limiting reactant in a reaction. (L52, J)*
>
> Information processing and critical thinking skills: *I love the games we played with the flashcards, identifying the unknown and given substance and picking the correct mole ratio. It helps with understanding the steps in solving stoichiometry problems. (L8, J)*
>
> Information processing and critical thinking skills*: We did a practical experiment with baking soda and vinegar. It was interesting as we keep increasing the amount of baking soda until our bag is filled with gas. The bag got bigger and busted. We use the practical for calculation of the sodium acetate and water. We got the ratio from the balanced equation of the reaction. (L43, J)*

The comments above suggest that the design of POGIL activities in this study did not only facilitate content learning in stoichiometry but also the development of process skills. It could be deduced that learners developed these skills in the course of negotiating meanings and analysing or solving content-specific problems in the stoichiometry classroom. The result suggests that providing the opportunities to improve in process skills did not hinder content learning and coverage as illustrated by previous studies (Barthlow, 2011; De Gale & Boiselle, 2015; Moog et al., 2006). Learners' content mastery could be proven by the improved proficiency in stoichiometry demonstrated in the SAT post-test.

According to Pedretti (2010), engaging learners in inquiry learning promotes critical thinking skills which enables deeper conceptual understanding. Learners who participate in inquiry-based science learning also have a better attitude towards science (Pedretti, 2010). In support, Sen et al. (2016) report that the active engagement of learners in the learning process promotes critical thinking. This finding is consistent with those of earlier studies (Barthlow & Watson, 2014; Sen et al., 2016; Walker & Warfa, 2017) that found that learners in POGIL classrooms develop and improve in process skills along with content mastery.

Furthermore, Salonen et al. (2017) argue that engaging learners in activities that will help them develop skills that would be useful in the workplace is of great value. The skills mentioned above are among the core lifelong skills that learners are expected to develop and transfer into the working environment (Salonen et al., 2017). Several studies (Masnick et al., 2010; Osborne & Dillion, 2008; Salonen et al., 2017) state that the outcome of secondary education includes the subject knowledge outcomes but not the development of skills that are transferrable to learners' prospective professions. For instance, Salonen et al. (2017) aver that science educational practice is not well attuned to the development of social work skills. The 21st century employer expects not only the knowledge base but also a number of social and employability skills such as those mentioned above (Salonen et al., 2017), meaning that it is important to foster the development of these lifelong skills earlier in learners in order to meet the demands of the job market in the future.

8.3.3 Learners' perceptions of stoichiometry/science

Many studies (Agunbiade et al., 2017; Papanastasiou & Zembylas, 2004; Roberts et al., 2018) have shown that learners' perceptions of science are a key determinant of their engagement in science. More so, their understanding of concepts in stoichiometry/science influences the way they perceive stoichiometry/science. Some participants in this study appeared to form an opinion about stoichiometry/science based on what they were told, their experience observing someone with a science-oriented profession around them, or their previous experiences with learning sciences, particularly when they encounter difficulty in the comprehension of some concepts. Besides, learners in the same learning environment could interpret their learning experiences differently, which ultimately influences the way they perceive stoichiometry/science individually. Learners who participated in this study shifted in their perception of science and stoichiometry, possibly due to their positive experiences with POGIL.

Learners seemed to have a pre-conceived notion that stoichiometry is difficult because it involves a lot of mathematical calculations. This impression might have emanated from their family members' or friends' previous experiences with learning stoichiometry (or learning mathematics). Some others believed they could not be successful at understanding stoichiometry because they lacked adequate mathematical skills required in stoichiometry. Interestingly, learners recognised the association between stoichiometry and mathematics. One of them succinctly said: "*stoichiometry is basically maths*" (L45, I).

Previous studies (De Berg, 2012; Hanson, 2016; Omwirhiren & Ibrahim, 2016; Preininger, 2017) likewise report the connection between mathematics and stoichiometry or sciences. These studies enlighten that learners who are deficient in basic mathematical skills could find many chemistry topics challenging, subsequently developing a negative attitude about the topic or chemistry entirely. The formal school environment with its voluminous syllabus and rigorous testing was stifling to the learners which contributed to their negative perception about stoichiometry or science. One learner stated: "*Science exams are not easy, we've got a lot of textbooks to read and many topics. It's just too much for me*" (L2, I). While learners realised that science goes hand in hand with mathematics, some of them thought that they did not have sufficient mathematical skills to be successful in science courses. This contributes to the decision against pursuing science careers and could be one reason why the result on learners' interest in science in this study appears unconvincing.

The notion that learners' competency in mathematics could be a predictive factor in choosing a science career resonates with Preininger's (2017) submission. Preininger (2017) avers that improving learners' mathematical skills has wide-ranging implications for increasing the number of learners choosing science professions globally. Once a learner considers science as a difficult subject to comprehend, the probability of choosing further study or career options related to science decreases (Omwirhiren & Ibrahim, 2016). These perceptions might arguably explain the marginal shift in learners' strategic competence in stoichiometry as well as their interest in science or science-related career despite their participation in POGIL (see Sections 5.2 & 6.2 respectively).

Despite learners' dread of mathematical engagement, some of them tried to learn and be successful in stoichiometry as they interacted continuously with their team members in problem-solving tasks. L44 pointed this out clearly during the interviews:

> *Chemistry or let me say stoichiometry is very difficult like people say. Many of stoichiometry questions need maths, I know I struggle with maths but I realised because we work it together in our group over time they became somehow easy or let say I know what to do, I would even say I got better in maths.* (L44, I)

This statement revealed that this learner had a preconceived notion that stoichiometry was difficult which was subsequently modified by interaction with the instructional activities of POGIL. This also implies that learners' perception of stoichiometry is linked to the nature of the instructional method in teaching stoichiometry. For instance, participants explained that the instructional characteristics of POGIL enabled deep comprehension of stoichiometry concepts, thus eliminating rote learning to pass their tests. L40, while describing his experience with learning stoichiometry through POGIL said:

> *I think I will say I don't just cram some of the stuff for test and exams again, I have more understanding and try to remember how we solved a question that was similar in the group. My last chemistry test was very good. I will say… I think I am more confident in chemistry now, I practice more of the questions and I can tackle many questions because I have seen something related before. Those scary topic like all these moles are easier for me now. (L40, I)*

Learners in this study were allowed to generate information themselves during the POGIL activities where learning was mediated by peers or facilitators using the appropriate mediating tools. Learners with a better understanding of the task given, often assumed the role of the MKO in the learning teams in order to help their members understand and complete the task at hand. This support from peers helped learners internalise knowledge thereby developing better awareness and improving their expertise in problem-solving skills. One of the participants noted in the journal entries at the beginning of the study, "*We figured out all the answers but I forgot how we did some of the questions when I was presenting our result*" (L1, J). However, towards the end of the study, the same learner wrote in her journal that, "*I finished the extension* *activities on my own without my group. I am excited. I think I am more confident doing all the activities on my ow*n" (L1, J).

Furthermore, this learner could be referred to as resilient, having made an effort which secured success in learning a concept that was initially perceived as difficult (Artuch-Garde et al., 2017; Makila et al., 2017). Artuch-Garde et al. (2017) argue that resilience can be regarded as one of the positive outcomes of self-regulation which can be influenced by learners' environments. It is a developmental process. Learners in this study developed confidence with support from others guided by self-regulation, often leading to better learning outcomes. Self-regulation improves scientific reasoning in learners and consequently leads to improved academic achievement (Artuch-Garde et al., 2017; Vincent-Ruz & Schunn, 2017). As emphasised by the socio-cultural theory, learners develop self-regulation when they collaboratively engage in problem-solving tasks with peers or the MKO (Makila et al., 2017).

From the results, learners recognise the importance of studying stoichiometry or science but lack interest in choosing science careers. Participants who chose not to enrol in science studies perceived science careers as having no opportunities for future affluence. They believed that scientists did not have career fulfilment with respect to good pay or jobs. They based their views on the observed experiences of family members or others in society. In this study, learners were keen to share how the POGIL activities had positively influenced their perception and enjoyment of Chemistry (stoichiometry) but, only two out of the seven interviewed participants had aspirations for a science career. It thus seems that one of the determining factors in whether learners choose science or science-related careers is its perceived link to one's fulfilment or desired quality of life. This further expounds on findings from previous research (Bennett et al., 2013; Grabau & Ma, 2017; Mujtaba et al., 2018; Osborne et al., 2003; Raved & Assaraf, 2011) that identifies factors such as teachers' influence, enjoyment of school science, science curriculum, and gender as influencing learners' decisions to take up science careers.

One interviewee stated that she might drop science and register for other courses in the final exams because she believed other careers offer more financial fulfilment. For instance, L31, a high attaining learner (both in attitude and stoichiometry proficiency scores) pointed out how she enjoyed and excelled in learning science but did not intend to pursue a science or science-related career. This learner was convinced by the experience of family members that scientists did not get good jobs and therefore did not have their desired status in life. Learners' perception of the relevance of science to their success in life has lingering implications for their career choices. This confirms and further elucidates findings from the previous studies (Agbaje & Alake, 2014; Babalola, 2017; Economic and social research council (ESRC), 2013; Mujtaba et al., 2018; Omwirhiren, 2015; WAEC 2016) that many high school learners are beginning to favour business-related subjects over sciences resulting in an incessant decrease in the number of learners taking science. ESRC (2013) in the ASPIRES, report that below 20% of learners had aspirations for a career in science while more that 60% of the learners surveyed agreed to pursuing a career in business.

Consistent with the assertion above, only 35% of learners agreed to having an interest in science or a science-related career in the TOSRA post-test (see Section 7.3). Most learners who had higher scores in stoichiometry proficiency indicated a lack of interest in science or science-related careers in their responses in the TOSRA tool. This may be corroborated by the lack of statistically significant correlation between learners' proficiency in the post-test and interest in science in the post-test. Table 8.3 below shows the Pearson correlation coefficient (*r*) between learners' proficiency in the post-test and interest in science in the post-test as -0.084 (*Sig. level* = 0.552).

Table 8.3: Correlation plot of learners' proficiency and interest in science post-tests.

Correlations

		Profi_Post	Interest_Post
Profi_Post	Pearson Correlation	1	-.084
	Sig. (2-tailed)		.552
	N	53	53
Interest_Post	Pearson Correlation	-.084	1
	Sig. (2-tailed)	.552	
	N	53	53

*Profi_Post = Proficiency post-test *Interest_Post = Interest post-test.

For example, L40 had an improvement in stoichiometry scores from 'below proficiency' (9) in the SAT pre-test to 'intermediate proficiency' (36) in the SAT post-test. In contrast, there was no substantial difference between the learner's attitude scores in the TOSRA pre- and post-test. L40's attitude score was 47 and 81 which was a low attitude in both the pre and post-test, respectively. The examination of learners' scores in each of the attitude sub-scales revealed that the lowest scores were from the perception of science and interest in science at the TOSRA post-test. See Figure 8.1 below (L40 highlighted). Learners' pseudonyms were merged with their assigned numerical identifiers as discussed in Section 4.5.5, therefore, L40 was assigned number 40 in the quantitative. When asked about career choices during the semi-structured interview, L40 stated that:

> *I don't think I would like to be a scientist. Many people who are in the sciences do not find good job after their study and science courses are difficult compared to the pay when you even get a job… Though I can say some science subjects are interesting especially chemistry and even biology. (L40, I)*

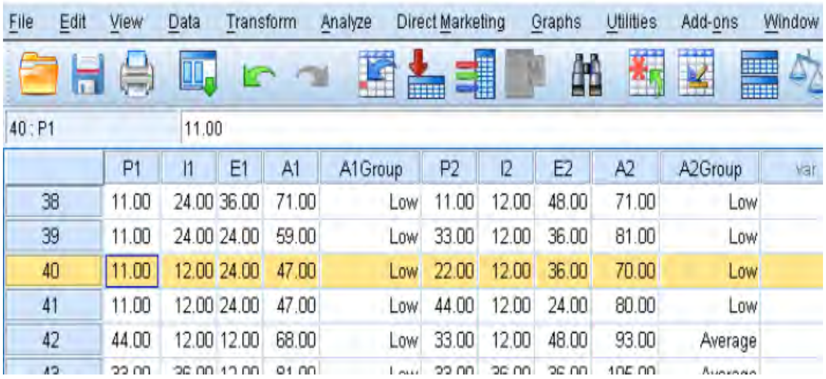


Figure 8.1: Learners' TOSRA scores vignette

*P1 = perception pre-test	I1 = interest pre-test	E1 = enjoyment pre-test
*P2 = perception post-test	I2 = interest post-test	E2 = enjoyment post-test
*A1Group = pre-test attitude group		A2Group = post-test attitude group

This finding supports the claim of Ganeb and Montebo (2018). In their study on learners' perception of science, the authors elucidate that when learners have a negative perception of science, they are not motivated to continuously engage while aiming for success. This subsequently hinders learners from developing an interest in science. It thus appears that in many cases, one of the driving factors of learners' career choice is the perceived relationship between science and their plans for the future. Learners' perceptions of science and choice of science careers may be influenced by relevance to the desired future, rather than its academic usefulness.

Salonen et al. (2017) assert that learners could develop a negative perception of science or science careers if they are unaware of science career options. It may also result from inadequate awareness of professionals working actively in the science field. To mitigate this lack of awareness, mentoring has been identified as a positive influence on learners' interest in science (Noam & Shah, 2013; Salonen et al., 2017). Osborne and Dillion (2008) in their study argue that knowledge of the diversity of science careers and self-development should be included to the content in the science curriculum. Having greater awareness and personal connection with science professions or professionals could help improve learners' perceptions and interest in science careers.

8.3.4 Learners' comprehension/mastery of concepts

The preference for an in-depth comprehension of stoichiometry or scientific concepts was obvious from learners' responses in the interview and comments in their journal entries. Learners recognised that learning stoichiometry was important as it was an important aspect of chemistry. Hence, they pointed out how a greater level of understanding was critical to their achievement and attitudes towards chemistry. As shown by comments below, a greater level of understanding of concepts in stoichiometry usually eliminates rote learning, increases academic confidence, and improves achievement in chemistry.

> *I don't just cram some of the stuff for test and exams again, I have more understanding and try to remember how we solved a question ..., my last chemistry test was very good ... I think I am more confident in chemistry now. (L40, I)*

> *I have started to understand that stoichiometry is not that difficult as we think, when we were taught topics like mass and percentage formula in SS1 I do not understand so many things. I just cram a lot of things just to pass my test and exams. (L44, I)*

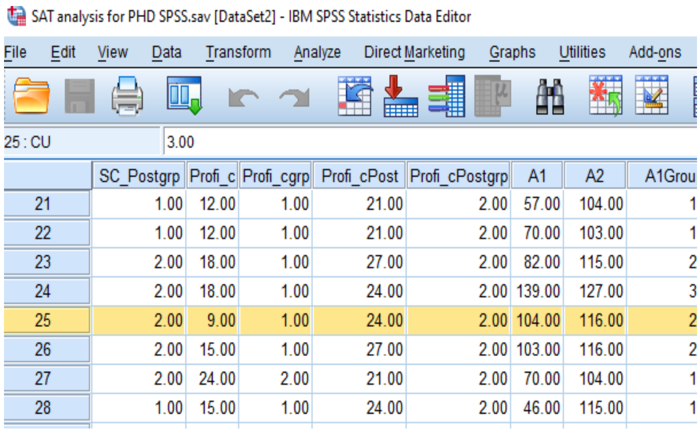
> *I represented my group and solved the question written on the board, and I got it. I think my confidence in chemistry has improved. I finished the extension activities on my own within 5 minutes. (L47, J)*

> *I would say chemistry is interesting, some topics are boring and difficult but I think ... when you understand you will be able to explain it without cramming and you will like it more. (L15, I)*

As mentioned in Section 8.3.3, learners' lack of interest in science careers could be because science is perceived as difficult. In essence, if they struggle with science now, they presume it will be difficult to succeed with a career in science. Preininger (2017) asserts that many learners rule out science careers from high school due to this perception. In view of that, L2 during the interview declared: "*I don't want a course I will struggle with*", in response to why he was not interested in science careers.

Though learners did not mention explicitly that understanding concepts influenced their proficiency or attitudes towards science, it could be inferred from their comments that a greater level of comprehension of stoichiometry concepts was connected to learners' proficiency in stoichiometry and attitudes towards science. For instance, L25's journal entries included statement such as: "*I think my confidence in chemistry has improved. I finished the extension activities on my own within 5 minutes*" (L25, J).

L25's statement was confirmed with the scores in the SAT pre- and post-tests. The proficiency score improved from the initial 9 point to 24 point in the post-test. This is shown in Figure 8.2 below (highlighted).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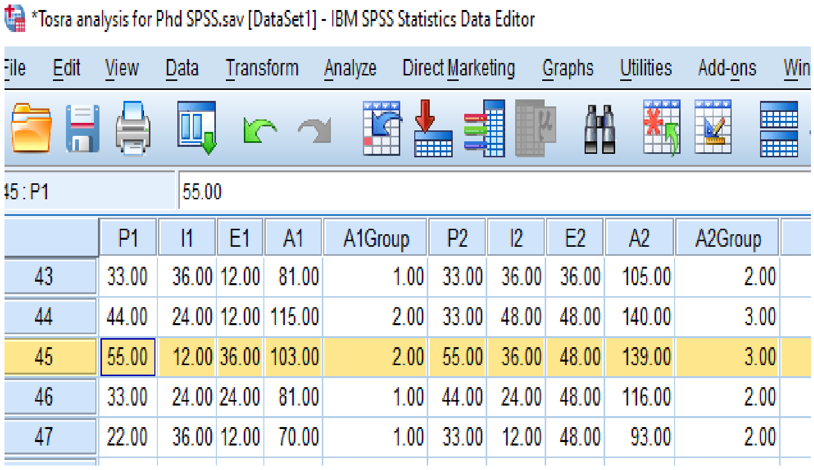
	SC_Postgrp	Profi_c	Profi_cgrp	Profi_cPost	Profi_cPostgrp	A1	A2	A1Grou
21	1.00	12.00	1.00	21.00	2.00	57.00	104.00	1
22	1.00	12.00	1.00	21.00	2.00	70.00	103.00	1
23	2.00	18.00	1.00	27.00	2.00	82.00	115.00	2
24	2.00	18.00	1.00	24.00	2.00	139.00	127.00	3
25	2.00	9.00	1.00	24.00	2.00	104.00	116.00	2
26	2.00	15.00	1.00	27.00	2.00	103.00	116.00	2
27	2.00	24.00	2.00	21.00	2.00	70.00	104.00	1
28	1.00	15.00	1.00	24.00	2.00	46.00	115.00	1

Figure 8.2: Learners' SAT scores vignette

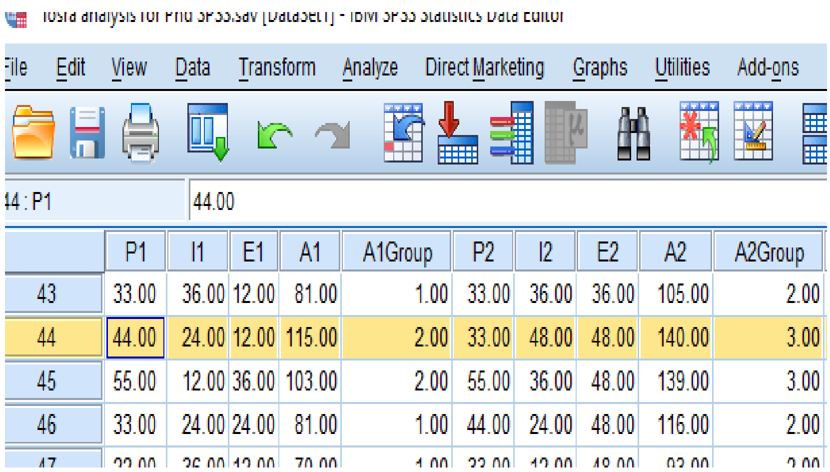
The results of the SLQ in Chapter Five suggests that learners' displeasure with learning stoichiometry stemmed from the inability to fully comprehend it. From another viewpoint, learners' responses also showed that they were more endeared towards learning stoichiometry or chemistry because they had a better understanding as they learnt in the POGIL classroom. They ascribed the enjoyment of stoichiometry units or chemistry to improved comprehension of the concept being taught. Thus, it could be inferred that a greater depth of understanding scientific concepts is associated with enjoyment of science, and consequently better attitudes towards science. For example, L45 commented that, "*It can be interesting too if it is the aspect that I understand very well. I enjoy it and doesn't look so hard for me*" (L45, I). The quantitative data on L45’s enjoyment score in the pre- and post-test TOSRA-2 supported the statement. Figure 8.3 below shows that L45’s score (highlighted) in enjoyment of science in the pre-test was 36 points while in the post-test, it increased to 48 points.



	P1	I1	E1	A1	A1Group	P2	I2	E2	A2	A2Group
43	33.00	36.00	12.00	81.00	1.00	33.00	36.00	36.00	105.00	2.00
44	44.00	24.00	12.00	115.00	2.00	33.00	48.00	48.00	140.00	3.00
45	55.00	12.00	36.00	103.00	2.00	55.00	36.00	48.00	139.00	3.00
46	33.00	24.00	24.00	81.00	1.00	44.00	24.00	48.00	116.00	2.00
47	22.00	36.00	12.00	70.00	1.00	33.00	12.00	48.00	93.00	2.00

Figure 8.3: Learners’ enjoyment score vignette

Likewise, L44’s score on the enjoyment sub-scale improved to 48 points in the post-test compared to the 12 points in the pre-test (Figure 8.4). L44 also declared during the interview that: “*It’s quite interesting especially when you understand and can reason why somethings happens and how it happens. It’s something that I enjoy*” (L44, I).



	P1	I1	E1	A1	A1Group	P2	I2	E2	A2	A2Group
43	33.00	36.00	12.00	81.00	1.00	33.00	36.00	36.00	105.00	2.00
44	44.00	24.00	12.00	115.00	2.00	33.00	48.00	48.00	140.00	3.00
45	55.00	12.00	36.00	103.00	2.00	55.00	36.00	48.00	139.00	3.00
46	33.00	24.00	24.00	81.00	1.00	44.00	24.00	48.00	116.00	2.00

Figure 8.4: Learners’ enjoyment score vignette

The result above resonates with other literature (Agunbiade, 2015; Barthlow & Watson, 2014; Brown, 2010; Sen et al., 2016) suggesting that learners who have a greater level of understanding of scientific concepts develop a positive attitude towards learning it.

Furthermore, participants expressed the challenges experienced with the comprehension of concepts that were later resolved by their collaborative work and extensive activities in the POGIL classroom. They subsequently shared their excitement when they grasped the concepts they struggled with. One of the interviewees put it this way:

> *I always look forward to chemistry class. We work together on the questions in the worksheet but we have our own separately. Truly, I always think all these stoichiometry and all that … were so difficult. I think they are. But we help ourselves and those that knows it teach the other ones we understand a lot of things. It just makes chemistry class fun and lively. It's not boring I enjoy it. (L44, I)*

As alluded to in Section 8.3.3, most learners expressed how learning cooperatively with their team while engaging with a variety of learning activities had influenced their understanding of stoichiometry.

Concerning learners' attitudes towards science, the present study's findings were consistent with earlier reports that indicate the influential role of the teacher or teaching quality, learning experiences, and achievement in science on learners' proficiency and attitudes towards science. This study did not set out to explore the correlation between learners' stoichiometry proficiency and attitudes towards science. It was however, found that there was no statistically significant correlation between learners' proficiency in stoichiometry and attitudes towards science both in the pre- and post-tests. The pre- and post-test correlation coefficient was $r = 0.173$ and 0.015 respectively (significant levels 0.215 and 0.917). This is as shown in Table 8.4 and 8.5 below. This suggests that it may not be possible to simply predict learners' proficiency from their attitude scores. However, as discussed above, learners' comments during the interviews and journal entries suggest that greater levels of understanding concepts ultimately influence learners' proficiency and attitudes toward sciences.

Table 8.4: Correlation of learners' proficiency and attitudes towards science pre-test

Correlations

		Profi_Pre	Attitude_pre
Profi_Pre	Pearson Correlation	1	.173
	Sig. (2-tailed)		.215
	N	53	53
Attitude_pre	Pearson Correlation	.173	1
	Sig. (2-tailed)	.215	
	N	53	53

Table 8.5: Correlation of learners' proficiency and attitudes towards science post-test.

Correlations

		Profi_Post	Attitude_post
Profi_Post	Pearson Correlation	1	.015
	Sig. (2-tailed)		.917
	N	53	53
Attitude_post	Pearson Correlation	.015	1
	Sig. (2-tailed)	.917	
	N	53	53

Looking at the variables of the learning environment, teacher characteristics, instructional characteristics, perception of science, and learners' comprehension or mastery of concepts as discussed above, they interrelate and connect with learners' proficiency or attitude towards science.

As shown in Figure 8.5 below, the facilitator (teachers) influences the learning environment or vice versa, and affects the instructional strategies employed which ultimately impact learners' understanding of concepts. The choice of instructional method and the role of facilitators in the classroom emphasise the need for an environment that enables communication and collaboration. This could stimulate the positive perception of stoichiometry and its adequate comprehension. In concordance with the results reported in the literature, these findings seem to indicate that the variables of learning environment, teachers' personality, and instructional characteristics embedded in POGIL principle, all have an impact on learners' comprehension and mastery of stoichiometry concepts as shown in Figure 8.5 below. These are consistent with the socio-cultural learning theory. Concurrently, Kilpatrick et al. (2001) as alluded to in the epigraph suggest that the manner in which the teacher, students, and content interact in an environment determines the type of learning that is created.

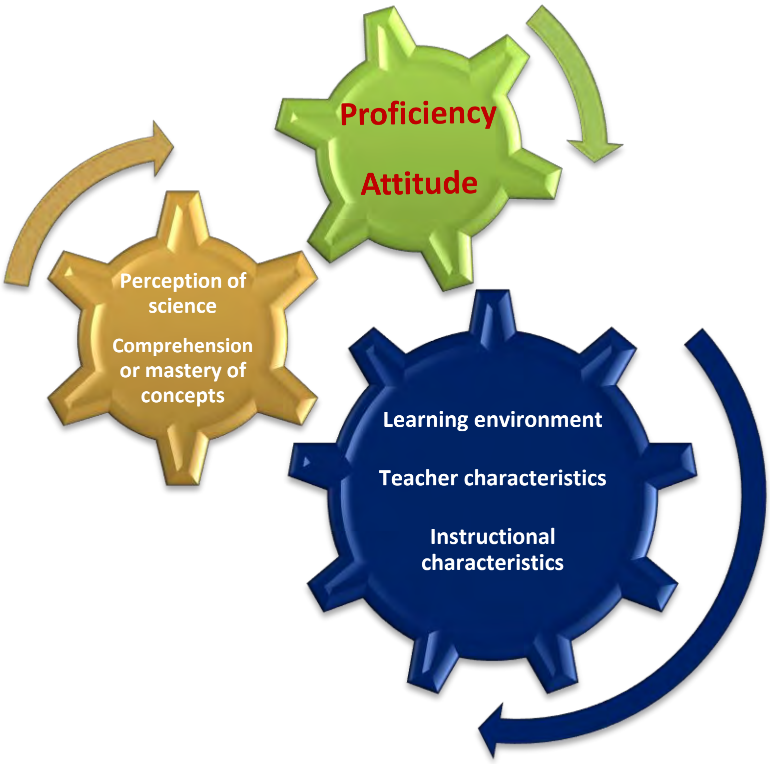


Figure 8.5: Relationship between the driving factors of proficiency and attitude in this study

Overall, from this study, learners preferred a stimulating science classroom with features emphasised by the POGIL tenets. These features mirror a socio-cultural learning environment that is collaborative and engaging for learners. A practical synchronisation of these characteristics in the science classroom encouraged learners' proficiency in stoichiometry and improved their attitudes towards science. As described by the socio-cultural framework, a socio-cultural learning environment enables knowledge construction and retention, via collaboration and conversation between learner-learner and learner-teachers (facilitators in this study). I argue that the POGIL approach provided the ideal environment for these key processes to occur. The design of the POGIL activities encouraged learners' activeness and interaction where they were able to explore, construct, and share knowledge with others while being practically involved in their learning.

8.4 Chapter Summary

This chapter began with the presentation and analysis of data from the two research tools: semi-structured interviews and learners' journal entries in response to research question four. Based on this analysis four main themes emerged within the POGIL classroom arguably influencing learners' proficiency in stoichiometry and attitudes towards science. These were: facilitators and environment features, instructional characteristics, perceptions of stoichiometry or science, and learners' comprehension or mastery of concepts. In the next chapter, the summary and conclusion drawn from the results of this study, limitations of the study, the recommendations, and my reflections as the researcher are presented.

CHAPTER NINE: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

> *Transforming science learning through student-centred instruction that engages students in a variety of scientific practices is central to national science-teaching reform efforts* (Granger et al., 2012, p. 105).

9.1 Introduction

In the previous chapters, I explored and discussed the results obtained from the SLQ, SAT, TOSRA-2, semi-structured interviews, and learners' journal entries. In this chapter, I present a summary of the findings, conclusion, contributions, and limitations of the study. It also includes my recommendations, suggestions for further study, and my reflections about the study.

The main goal of this study was to explore learners' evolving proficiency in stoichiometry and attitudes towards science as a result of their participation in the Process Oriented Guided Inquiry Learning (POGIL) instructional strategy. Therefore, I employed the socio-cultural framework as proposed by Vygotsky (1978). This was necessary for the discovery of the integral role of social interactions, mediation, self-regulation, and ZPD on learners' proficiency in stoichiometry and attitudes towards science. To achieve this goal, the following research questions were explored using a mixed-methods approach:

1. What enabled and/or constrained learning of stoichiometry concepts by learners in the senior secondary school prior to the POGIL intervention?
2. How does learners' proficiency in stoichiometry change (if at all) over the period of participation in the POGIL intervention?
3. How do learners' attitudes towards science change (if at all) over the period of participation in the POGIL intervention?
4. What experience do learners value (if any) during their POGIL lessons?

Both quantitative and qualitative data were generated and analysed to answer these research questions. I now present the summary of my findings in relation to these research questions.

9.2 Summary of Findings

For research question one, both quantitative and qualitative data were generated from the SLQ at the pre-intervention phase with the aim of establishing learners' perceptions of stoichiometry and factors affecting the learning of stoichiometry before the intervention. This provided a baseline for monitoring learners' experiences with stoichiometry and a structure for the intervention phase, whose focus was on improving their experiences. The TOSRA-2 and SAT pre-tests generated quantitative data to answer research questions two and three, respectively. Semi-structured interviews and learners' journal entries provided data to respond to research question four as well as supporting the findings that emerged from other research tools.

9.2.1 Research question 1: What enabled and/or constrained learning of stoichiometry concepts by learners in the senior secondary school prior to the POGIL intervention?

The results presented in Chapter Five revealed learners' perceptions of stoichiometry concepts and their experiences while learning it, before participation in POGIL. Section 5.2 indicated that 'moles and solutions' was perceived to be the stoichiometry topic which the greatest percentage of learners (87%) found difficult. This was followed closely by 'reaction yield' (85%) while other units such as 'moles & compounds', 'mole & gases', 'limiting reagent' and 'mole ratio' were considered as being difficult to some extent by the learners. The stoichiometry units that most of the participants identified as easy were 'percentage composition', 'atomic masses', and 'empirical formula'.

Stoichiometry units that involve balancing chemical equations and molecular mass were considered both easy and difficult by a similar proportion of learners. The results shown in Figure 5.2 on the proportion of stoichiometry units that learners found easy or difficult indicated that most of the learners considered stoichiometry as a difficult chemistry topic before the POGIL intervention.

This study sought to establish the factors that might be influencing learners' perceptions of how easy or difficult a stoichiometry unit is. In this regard, there was considerable dissatisfaction with the nature of stoichiometry and teaching strategies used in stoichiometry classes before the commencement of this study. The findings revealed that the traditional teaching method was the most common strategy used in the teaching and learning of stoichiometry and this contributed to its perceived difficulty.

Learners frequently mentioned the nature of the instructional strategies in teaching stoichiometry as boring and not offering the opportunity to interact with others or their teachers, when prompted for the reasons why they found stoichiometry concepts difficult. They did not enjoy, nor were they interested in stoichiometry lessons that revolved around taking notes or listening to lectures on a boring topic. They expressed disappointment at the lack of problem-solving activities relevant to stoichiometry in the classroom and teachers' insensitivity to their learning needs. They believed that these hindered their understanding of stoichiometry. This finding corroborates that of Ajayi and Ogbeba (2017), Cardellini (2012), Omiko (2016), Opara (2014) and Uchegbu et al. (2017) who found that the lecture method of teaching was ineffective in engaging learners in science classrooms. This literature reports that the lecture method might hinder deeper understanding of scientific concepts.

More so, many learners indicated that they did not understand the relationship or distinction between some stoichiometry concepts. As this study revealed, this might be due to overloaded stoichiometry lessons with multiple learning outcomes. This often prevents the teacher from providing clarity or a detailed explanation to foster deep learning of a concept.

Learners also claimed that there were few or no relevant examples used in the teaching of stoichiometry that could facilitate full comprehension. In consequence, they perceived stoichiometry as an abstract concept because they could not relate their experience in the stoichiometry class with familiar events around them that could explain the theory. For the learners, stoichiometry remained abstract because there was a paucity of real-life examples in their environment to facilitate deep learning. These findings support the views of Agunbiade et al. (2017) and Asheela et al. (2020) that when scientific concepts are connected to learners' immediate environment, it makes them comprehensible and increases learners' interest in learning.

Most learners pointed out the abundant mathematical calculations involved in stoichiometry and the insufficient practice of solving stoichiometry questions in the classroom. As alluded to in the literature (see Section 2.2), learners who are not proficient in mathematics might likely find stoichiometry a difficult concept. Based on the results of the SAT pre-test, learners' anxiety over the mathematical skills required in stoichiometry might have prevented learners from carrying out the procedures correctly. In corroboration, DeBerg (2012) reports that many learners detest and perform poorly in science because of the apprehension of the mathematics involved.

Learners' interest in chemistry or science generally plays a role in determining how easy or difficult a learner perceives stoichiometry topics. Results from the open-ended section of the SLQ indicated that some learners that were not personally interested in chemistry or science were complacent about making an effort to learn stoichiometry and in the process, resulted in memorisation of concepts just so they could pass examinations. Even before they started studying, some learners seemed to have the preconception that stoichiometry was difficult, either from the experiences of family members or from other people around them. They subsequently made no effort to learn it, finding it more difficult over time.

Some learners nevertheless exhibited resilience when learning stoichiometry, despite its perceived difficulty. Reasons for this resilience may include their interest in science, with their awareness of the significance of stoichiometry to their success in chemistry or science. Some others received support from peers or family members in learning which alleviated the difficulty and increased their interest in studying stoichiometry. Learners that persevere when faced with challenges in their learning become self-regulated learners and subsequently perform better (Artuch-Garde et al., 2017; Makila et al., 2017).

Additional findings from the SLQ tool suggest that learners expected that stoichiometry lessons should be exciting, hands-on, and engaging to improve their comprehension. Surprisingly, the use of the inquiry-based learning method was not mentioned by the learners as a strategy to improve their stoichiometry learning experience. Instead, participants desired to have sufficient learning time in the science classroom which would enable the teachers to explain concepts patiently for deep understanding. This can be a major drawback of the formal science classroom where teachers rush through the crammed curriculum within a constrained time. The literature (Agunbiade et al., 2017; Bybee & McCrae, 2011; Juan et al., 2018; Wong, 2016) emphasise that learners develop a negative attitude towards a subject when they do not enjoy learning it and that they expect science learning to be fun, active, and exciting.

In addition, learners especially looked forward to having more experimental activities where they would be actively involved in scientific investigations as an approach towards improving the stoichiometry learning experience. They claimed that talking without associating practical work in formal stoichiometry classes had made it uninteresting and difficult. This result corroborates studies in the literature (Ajayi & Ogbeba, 2017; Asheela et al., 2020; Babalola, 2017; Cardellini, 2012; Omwirhiren, 2015) that shows the relationship between the use of appropriate instructional methods and the promotion of meaningful learning experiences. The hands-on activity is identified as one of the most effective strategies that enhance learners' understanding of scientific concepts (Asheela et al., 2020; Opara, 2014). Also, this result demonstrates that learners prefer learning where illustrations are made from their immediate environment and are used to facilitate adequate comprehension. This could reduce the perceptions that stoichiometry is an abstract topic and does not have any existence in the physical world.

9.2.2 Research question 2: How does learners' proficiency in stoichiometry change over the period of participation in the POGIL intervention?

After 10 weeks of participation in the POGIL strategy the results from the SAT post-test indicated that there was an improvement in learners' proficiency in stoichiometry (see Section 6.2). For instance, the analysis of learners' scripts in the SAT revealed that learners' proficiencies ranged from 'below proficient' to 'intermediate proficient' and 'proficient' as shown in Figure 5.8 (see Section 6.2). One advantage of this study is that it examined specific strands of proficiency as defined by Kilpatrick et al. (2001). This study examined learners' conceptual understanding, procedural fluency, and strategic competence as assessed by the SAT tool. Variable shifts in learners' proficiency were observed in the proficiency strands shown in Figures 5.3, 5.4, and 5.5.

Learners' conceptual understanding and procedural fluency in stoichiometry shifted significantly after 10 weeks. Minimal improvement in learners' strategic competence was observed. There were fewer learners with low strategic competence at the end of the study as shown in Figure 5.5 but this was not statistically significant (p = .091) (see Table 6.1). The probable reason could be that learners were just adjusting to the POGIL approach, and if they had prolonged exposure, their strategic competence might be improved considerably. The overall positive shift in learners' proficiency in stoichiometry could be attributed to their participation in the POGIL activities. This was supported by the submission of the participants in the interviews.

When learners' pre-and post-tests scripts were analysed, they showed that their proficiency in stoichiometry had shifted considerably in all aspects. In the pre-test, for instance, most learners fell into the category of 'below proficient'. As alluded to previously, this may have been due to the lack of responses to some questions, incorrect responses, or wrong procedures which resulted in wrong answers at the pre-test. Learners' procedures and approaches to solving problems might have been incorrect, but they completed the mathematical calculation correctly.

This suggests that learners' proficiency in mathematics does not necessarily translate to proficiency in stoichiometry. This result differs from the findings of other studies (De Berg, 2012; Fach et al., 2007; Hanson, 2016; Kaundjwa, 2015; Preininger, 2017) that assert that learners who can correctly solve mathematical problems translate this skill into solving chemistry problems and develop proficiency in it.

Also, the analysis of pre-test scripts showed that more leaners struggled with the knowledge and connection of key concepts. The result showed that several learners were 'average' in conceptual understanding of stoichiometry concepts. In contrast, there was a significant improvement with the responses in the post-test scripts. There were fewer blank spaces left as learners attempted all questions. Learners' conceptual understanding of stoichiometry concepts improved as they could tell apart stoichiometry concepts, as well as explain the connection between definitions and stoichiometry concepts at the SAT post-test or during the interviews. Most learners progressed from misrepresentation of problems with formulae or equations to accurate representation, formulation of chemical equations, and identification of steps to solve stoichiometry tasks.

Looking at the SAT post-test scripts, it was obvious that learners had improved in extracting the necessary text or problem from the text given and could represent it numerically or symbolically. For instance, in the post-test, learners could identify that gases at the same temperature and pressure occupy the same volume at STP. They used the relevant data from the given text to analyse and answer the question. Many of them did not answer this question in the pre-test while those that did were mostly speculating.

Learners also improved in the execution of stoichiometry problems correctly. The strategy and order of steps seemed almost the same while these strategies varied with a few others. However, there were some minor inaccuracies observed in carrying out the tasks. For instance, some of the learners made errors with representation even when they could recognise the necessary information given in the task. One possible reason for this shortfall could be that learners jumbled formulae and symbols as they expressed during the interviews. From the SAT post-test, it was seen that many learners could solve some problems using fewer steps to arrive at the correct answer. This showed development in procedural fluency. As described by Kilpatrick et al. (2001), procedural fluency involves the ability to use the most efficient method to solve problems accurately in less time. Overall, the shifts observed in the SAT pre- and post-tests were that learners were more conceptually, procedurally, and strategically proficient in stoichiometry at the end of the study than they were at the beginning.

9.2.3 Research question 3: How do learners' attitudes towards science change over the period of participation in the POGIL intervention?

The TOSRA tool provided insight into how learners' attitudes towards science changed over the period of their participation in the POGIL strategy. Exploring each subscale of attitudes in the TOSRA-2, showed that only two subscales significantly changed over time when considering the mean scores of pre-and post-tests. The paired sample t-tests were significant at $p = 0.000$ for the perception, and enjoyment subscales of attitude indicating a significant improvement of the learners' attitudes in these subscales from the pre-tests to the post-test. However, interest in science pre-and post-test scores did not improve considerably with significant value $p = 0.814$. The result indicates a greater proportion of learners disagreed or were not sure of their interest in science before and after the POGIL intervention. This was confirmed by the qualitative findings. Although there was no statistically significant difference over time, the average scores for the post-test were higher than the pre-test. The findings that learners' interest in science and science-related careers did not have significant shifts at the end of the study as measured by TOSRA pre-and post-test contrast with previous studies on the impact of POGIL on learners' interest in science.

Some of the factors that could have influenced learners' enjoyment of science could have also impacted their perception of science. It is expected that if the enjoyment of science increases, so will perception of and interest in science. Despite learners' enjoyment of science, the findings revealed that most learners did not consider pursuing it as a career. In this case, how learners felt about science professions or science professionals in society impacted their interest in science or science-related careers. The lack of a clear path for career fulfilment is a problem highlighted by the participants. They believed that science could not offer them a fulfilling life, hence, their preference for other business courses. This agrees with the findings of ESRC (2013) that most learners like and enjoy science but are not interested in science career. Other studies (Agbaje & Alake, 2014; Mujtaba, et al., 2018; Olorundare, 2014; Omwirhiren, 2015; WAEC 2016) also found that many high school learners are beginning to favour business-related subjects over sciences resulting in the incessant decrease in the number of learners taking science. More so, Masnick, et al.'s (2010) study report that learners with no interest in science careers have the perception that science careers have no opportunity for future self-development and positions.

In the literature (Bae & DeBusk-Lane, 2019; Brown, et al., 2016; Ganeb & Montebo, 2018; Juan, et al., 2018; Salonen, et al., 2017) the relationship between learners' career choice/interest and the attributed future relevance or success has been reported. The findings of this current study seem to cohere with these earlier studies. These studies claim that when learners are continuously exposed to positive science learning experiences over a long period, it will positively impact their interest in science. The implementation of POGIL lasted for ten weeks in the current study, but it is clear from the results that their interest in science or science careers is not influenced by the school science learning experience.

The shifts observed in the TOSRA-2 post-test indicated an increase in learners' positive attitude towards science. The mean of the overall attitude showed that the post-test scores were higher than the pre-test score, hence an improved attitude towards science at the end of the study (sig. 2-tailed $p = 0.000$). The qualitative interpretations of learners' interview and journal entries suggest that perhaps the POGIL activities were responsible for the shift in their attitudes towards science. Results from these tools indicated that learners enjoyed science lessons and were more enthusiastic about science after engaging in POGIL activities than they were at the beginning of the study. Participants generally appreciated the collaborative learning, mutual support within the team, and the engaging or hands-on activities in the stoichiometry classrooms. This trend confirms the findings in the literature that learners' experiences in learning science could influence their attitude toward science.

9.2.4 Research question 4: What experience do learners value during their POGIL lessons?

The results from the qualitative data as presented and discussed in Chapter Eight revealed that learners' proficiency in stoichiometry and attitudes towards science were influenced by the POGIL instructional strategy. The factors identified as possessing significant impact included facilitators/environment features, instructional characteristics, learners' perceptions of science, and their comprehension or mastery of concepts. These features are intertwined and altogether are connected to learners' comprehension or mastery of stoichiometry. While the results from this study confirm the reports of earlier studies regarding the variables that influence learners' attitudes towards science, it expands further by highlighting the association between teachers'/learning environment features, instructional characteristics, and learners' mastery of scientific concepts. It revealed the influential role of understanding stoichiometry concepts on stoichiometry proficiency, their perceptions of science, and ultimately on learners' attitude towards science. In contrast, learners' perceptions of science careers or interest in science careers were not influenced by any of the variables mentioned.

Learners' responses about their experience of the POGIL instructional strategy were positive with a few negative comments. In the POGIL classroom, learners maintained free communication and openness with each other and their teachers, where they would otherwise have been less inclined to give an expressive opinion about their learning. The POGIL classroom encouraged learners to communicate and interact with their peers or teachers to build ideas and improve understanding of concepts. This corroborates findings from other studies (Agunbiade et al., 2017; Omwirhiren & Ibrahim, 2016; Sen et al., 2016) that report the association between the science learning environment and the science attitudinal outcomes of learners.

Learners' attitudes were impacted by their teachers' continued patience and support of their learning. Similarly, Kobiatko (2017) and Koopman et al. (2019) in their separate studies, found that highly supportive teachers have a positive impact on learners developing positive attitudes towards science. These studies and other literature (Raved & Assaraf, 2011; Rodiriquez et al., 2018) commonly report that teachers' relationship with the learners and their support in the classroom are associated with learners' attitudes towards science. The science learning environment should be organised in a way to develop learners' potential for creative thinking, reflectivity, and active participation.

Learners preferred hands-on and problem-solving activities. Learners recalled positive experiences of specific hands-on activities when asked to reflect on their experiences with the intervention programme. The features of the POGIL classroom such as cooperative learning in small groups, hands-on activities in learning stoichiometry concepts, and structured activities included in the learning materials, were mentioned as positive experiences that influenced their proficiency in stoichiometry and attitudes towards science.

The cooperative learning and discussion within the teams were significant in helping learners to have a greater level of understanding of stoichiometry concepts and increased their confidence in solving stoichiometry questions. This defused the notion that stoichiometry is a difficult concept. In addition, complementing pre- or after-class homework with in-class activities and discussions, built learners' confidence and improved their proficiency in stoichiometry. This finding is consistent with the assertions of Rodriguez et al. (2018) and Sen et al. (2016) who affirm that when learners are actively involved in the learning process it increases their confidence in the concepts under study. Learning collaboratively with peers provides learners with the opportunity to negotiate a 'meaning' and construct conceptual understanding thereby increasing self-reliance (Rodriguez et al., 2018; Sen et al., 2016).

The content and structure of the learning materials provided opportunities for learners to develop mastery of the stoichiometric concept learned. Learners felt the challenging learning materials integrated into their lessons increased their curiosity, connected the concepts to their' immediate environment which assisted with making abstract stoichiometry concepts concrete. The carefully designed POGIL activities stimulated learners to gradually develop in the seven process skills highlighted in POGIL: information processing, communication, teamwork, critical thinking, management, problem-solving, and self-assessment. The development of these process skills arguably supports their increased proficiency in stoichiometry and attitudes towards science.

Implementing science learning methods that include discussions, teamwork and practical activities, facilitate better understanding of concepts (Agunbiade, et al., 2017; De Gale & Boiselle, 2015; Omwirhiren & Ibrahim, 2016; Walker & Warfa, 2017). POGIL learning cycles combine these strategies (Hanson, 2006). Hanson (2006) describes POGIL as a holistic teaching strategy that moves away from rote learning, provides an authentic experience of a positive learning environment for learners. The findings of this study resonate with Hanson's account. Therefore, adopting a guided-inquiry and cooperative learning strategies engage learners productively in science learning environments, subsequently driving a shift in their proficiency and attitude towards science. The diverse instructional activities of POGIL worked in synergy with the learning environment including the facilitators' role to shape learners' perception of stoichiometry or chemistry as a whole. Each of these factors contributes significantly to learners' experience in learning science and in my opinion, none should be considered in isolation.

This study reaffirms the findings of related studies (Degale & Boiselle, 2015; Kaundjwa, 2015; Hein, 2012; Sen, et al., 2016) that observed improved learners' attitude towards chemistry or sciences using POGIL instructional methods. They suggest that the collaborative and inquiry-based instructional method enhances science learning outcomes of learners. In support, this study indicates that the POGIL instructional method is viable and has the potential to enhance secondary school learners' proficiency in stoichiometry and attitudes towards science. Although implementing the POGIL approach requires valuable instructional time, it does have a positive impact on learners' mastery of the contents taught in the chemistry classroom. However, the result thus contrasts that of Chase et al. (2013) that reported no impact of POGIL on students' attitudes towards chemistry or confidence in it compared to the control group.

9.3 New Knowledge in This Study

This study found that learners' mathematical computation skills do not necessarily translate to stoichiometry proficiency as found by previous studies. Learners might make use of their mathematical skills to compute and execute mathematical equations correctly but not necessarily solve stoichiometry problems correctly, particularly when they have not progressed in conceptual understanding, procedural fluency, and strategic competence. In addition, this study found that strategic competence is more challenging to develop and takes time compared to other strands of stoichiometry examined. More so, previous findings that stoichiometry is perceived as a difficult chemistry concept to learn was confirmed in this study.

The findings of this study are significant in that they demonstrate that enjoyment of science or enhancement of the science learning environment does not automatically improve interest in science careers. While this study showed improvement in learners' enjoyment of learning science in schools, they did not consider pursuing it as a career because of the lack of awareness in career opportunities in science in Nigeria or the perception of science-oriented careers as less fulfilling over time. Many previous studies highlighted gender, family influence, teacher personality, learning environment, and attitudes towards science as determinant factors. However, this study revealed that learners' perceptions of the science profession in terms of personal pleasure and fulfilment play a significant role in nurturing their interest in science careers even when other factors have been improved. This is new knowledge, given that the current study shows that the intervention programmes did not improve learners' interest in science careers, however, it surfaced or unearthed some insights into what could work. We must improve the public image of science and the science profession to entice the younger generation. This is quite vital so that as a country, Nigeria does not become constrained due to a limited supply of science professionals. In my own view, the relevance and status of scientists might have changed with the need for science during the Covid-19 pandemic.

Also, the findings of this study suggested that science learners are interested in strategies that would assist with learning and create a positive experience. Learners followed through to the end of the study as there was no drop out among participants despite the demanding task of completing questionnaires and quizzes. This suggested that they were willing to engage with a new teaching pedagogy if it is aimed at improving their ability to understand perceived difficulties in stoichiometry.

In addition, new knowledge was also established in the area of methodology. Kilpatrick et al's (2001) framework was adopted as a means of assessing proficiency in science education. This was an extension of the proficiency framework from its original use in mathematics. In this study, I also explored the option of examining specific strands to define learners' proficiencies and generating data that allowed comparisons between three strands of proficiency as described by Kilpatrick et al. (2001). This approach showed a richer description of learners' proficiency in the presentation and analysis of the data and how each of these strands evolved individually and jointly for the participants. This provided a way of tracking learners' areas of strength and weakness as it regards each proficiency strand while concurrently observing the shift in the composite proficiency as a whole. This could be a useful contribution to the field of science in Nigeria and an accessible way for teachers to track and analyse learners' proficiency in science.

Lastly, it was clear was that there is a dearth of research on learners' proficiency in stoichiometry and the effect of POGIL on proficiency and attitudes towards science in Nigeria. This study has contributed to science education research with regard to the socio-cultural framework incorporated into the POGIL approach as an active, creative, and collaborative learning methodology that proves beneficial in teaching science concepts that are perceived difficult to learn or teach. For instance, Mavhunga and Rollnick (2013) allude to the levels of teachers' capability and emphasise the quality of teaching a specific topic in science. As such, this opens up spaces regarding approaches using planned activities that will meaningfully engage learners in Nigerian science classrooms and develop a shift in proficiency and attitudes towards science.

9.4 Implications and Recommendations

The study set out to explore how learners' proficiency in stoichiometry and attitudes towards science shifted in relation to their participation in the POGIL intervention. The results revealed that the POGIL intervention impacted learners' proficiency in stoichiometry and attitudes towards science in a positive way. The implication of the findings of this study and the insight for secondary school science curricula and education policy are thus discussed. This knowledge could inform future efforts on the structure of intervention programmes aimed at improving learners' proficiencies or attitudes towards science.

As alluded to by Hanson (2006), it is vital to offer learners exciting content and processes so that they can actively participate in a more relevant and interesting curriculum. Science teachers are encouraged to adopt creative and engaging instructional practices that can revamp or change the preconceived negative notions about stoichiometry that learners bring into the classroom. Science teachers should endeavour to enrich their science lessons, especially stoichiometry, with engaging inquiry-based activities, accommodating innovations, and giving feedback to learners in order to offer stimulating learning experiences.

The current structure of the Nigerian science classrooms and instruction might need reconsideration to allow for active, exciting, and cooperative learning to emerge. Curriculum and education policy developers might need to consider how these could be applied and implemented in science classrooms. Implementing POGIL in the science classrooms does not require special equipment or materials, thus, the strategy could be adaptable to a wider range of senior secondary school science classrooms. Also, I recommend that schools provide the necessary instructional resources for effective application and implementation of creative learning to assist learners in learning perceived difficult topics such as stoichiometry.

The learning support, especially the influence of the teacher, is significant in providing a positive experience to stoichiometry learning and developing perceptions of science in general. Most learners desire a teacher that is supportive, patient in teaching, and interested in their learning success. This is perhaps one of the valuable insights from this study for teachers who seek to maximise the quality of the learners' experience of learning.

From the findings of this study, the perceived future relevance of a subject in terms of pleasure or appreciation is decisive. It would be of greater value as earlier studies have suggested, to consider the delivery of science curriculum with strategies and approaches that could aid the development of lifelong skills, consistent with the demands of the future work life. I, therefore, recommend that curriculum planners and education stakeholders deliberate on the review of secondary schools' science curricula design to include content that reflects the relevance of science education to the job market, technological advancement, and the nation's aspiration for economic growth. This should be an effective curriculum, attractive both in content and approach, providing learners with information and advice about career options in science as well as having support or close interactions with science mentors. I also implore the Nigerian government to look into ways of ameliorating career viability for science professions or professionals. This might go a long way in reforming the current image of scientists portrayed enhancing younger generations' interest in science.

Much emphasis has been placed on teachers' use of effective teaching strategies for improved science learning outcomes. Therefore, initiatives to improve their teaching strategies through professional development programmes are essential. This study suggests the need for developing a community of practice where teachers can reflect on their teaching practices and improve on them as required. Science teachers could be sponsored regularly to attend workshops or seminars on the effective use of POGIL or other active instructional pedagogy in the realisation of enhanced learning outcomes.

9.5 Researcher's Reflections

As I embarked on this academic journey, I kept on writing my personal and academic reflective journal used to explore the process of my learning and becoming. Therefore, my reflection as a researcher of this study does not only include the log of activities carried out during the research or the outline of what went well or poorly, but also the continuous critical thought on the work carried out as a process of learning and becoming. I also discuss my journey as a learner and researcher, detailing my experiences with the research activities, identifying the achievements, and the challenges.

At the commencement of this research, the implementation of the intervention programmes was daunting; I was nervous about negotiating with teachers or school authorities for access to the desired sample population necessary for the implementation of POGIL in their classrooms. The POGIL intervention has challenges or requirements in its design and implementation. One of the main challenges was how to fit an inquiry approach within a prescribed stoichiometry curriculum or create a good guiding inquiry for the unit. These questions also emerged during my earlier discussion with the teachers and could be a challenge for any teacher intending to explore it.

Other requirements with POGIL intervention include time, discipline, focus, planning, researching, and creativity. A lot of time was required in the planning of the workshop, design of worksheets in alignment with the lesson plans, and its implementation process. After each of the POGIL workshops, my work continued as I had to format the worksheets and print them out to distribute to the teachers. There were also financial implications as the worksheets consumed a lot of papers. Questions such as: how do we arrange learners in teams within the setting of the classroom, how do learners adjust to generating information through discussion, and how do we finish teaching the syllabus with all these activities were probed by the teachers.

At the initial stage, teachers found POGIL challenging to implement though they were enthusiastic about a different teaching approach. First, they found creating a culture of collaboration and teamwork, while they assumed a facilitative role in the classroom, strange. After the first POGIL class, one of the facilitators lamented that the class was disorderly and found it difficult to balance providing support and the need for learners' independence. Controlling learners' discussions seemed difficult as learners were enthusiastically emotional in defending their strategies or opinions. While observing the introduction of POGIL in the two schools, I realised how challenging it was for the learners as they were more familiar with the teacher-centred learning approach. Time management for discussions and activities seemed difficult as learners took considerable time discussing and arguing before reaching consensus on strategies to complete tasks.

Nonetheless, I was astonished by the rapport building from the onset, and the continuous support and eagerness of the chemistry teachers towards the success of the research as well as the intervention programme. Not only was this helpful, but an encouragement to me as an individual. Their willingness was particularly remarkable as this was an extremely busy and stressful phase in the senior secondary year level. During the Covid-19 pandemic, there were worries around having not yet conducted the interviews and the feasibility of having one even after school resumed. These teachers demonstrated their commitment to the successful completion of the research by assisting with the necessary arrangements for the virtual interviews.

Reflecting on the rigorous and yet relaxed POGIL workshops in which much collaboration and intellectual practice occurred, I enjoyed the CoP. I cherished moments of interactions with the teachers especially in our POGIL workshop sessions where we co-developed the instructional materials which is completely different from the usual practice among teachers. I could say that they turned from teachers to students because they desired to acquire the necessary skills to excel in their profession and I would say that this was the most overwhelming part of the research process. The fact that we were all science teachers with a mutual interest in improving science pedagogy had a real impact on the success of the study. Teachers that were non-participants in this study willingly joined in and attested to the value derived from planning and sharing of teaching strategies with other teachers. It was not only important that I was conducting research, but also that we were building a CoP with teachers from four different schools.

The workshops proved to have positive impacts on the teachers' professional development. On completion of the intervention, I perceived that these teachers desired the continuation of these practices for the rest of the school year. Some were in conversation with other chemistry teachers in their schools to join the CoP or form this in their respective schools. This suggests the acknowledgement of their professional progression because of the CoP. The active learning experiences in the POGIL workshops provided opportunities to adapt the practices to their classrooms. I noted that the POGIL workshops were effective as teachers could meet to explore a common problem in chemistry teaching and find solutions based on collective experiences and knowledge.

Another reflection was around my inclination to accept the bluntness of colleagues, critical friends, and participants. This provided me with learning opportunities to think deeply about my reactions to criticism and self-development as a scholar. While working together, we had different philosophies that stemmed from our degree of experience with the subject; through this, I learned the aspect of believing in the people we work with. I got to understand issues from other people's perspectives as my excitement about POGIL was somewhat insensitive, particularly to the concerns of the teachers, which could have damaged the development of relationships if not considered.

The better understanding of the concerns or needs of the participants and teachers in this study was another important learning point. Participants were interested in research that was mostly concerned about their academic success and how they were faring with learning. While carrying out this research, I became friendlier with many of the learners as I occasionally visited their schools during their free hours in order to interact with and earn their trust. I understood they needed a listening ear as they were always eager to share their learning experiences not only in chemistry but also with other subjects. Likewise, I realised that teachers do not just want a researcher asking them to implement a strategy in the classroom but also want to be relevant, respected, and involved in developing the strategy. During the workshops, we learned and unlearned together intending to become better science teachers, not only focusing on the research outcomes but also building relationships while supporting one another.

Furthermore, I have learned the importance of responding appropriately to circumstances as I had to make adjustments to plans for the activities involving the teachers at the beginning and during the study. Besides having progressed in my own academic identity and writing style, I have become more organised and question processes so that they form an understandable practical whole. Therefore, I can succinctly say that I experienced personal development as a result of engaging socially while carrying out this research.

If I were to conduct this research again, I would seek an environment where a video recording of the POGIL activities would be permitted and encourage the POGIL facilitators to reflect daily on the POGIL process and activities. This could generate more insight into the POGIL process. I did not ask the teachers to make notes of their reflections on the POGIL activities so as not to add to the workload with their engagement with POGIL, although they did so casually during our workshops. I would also seek research funds to extend the study to other geographical locations within the state which would enable comparison.

Overall, this research process has given me time to interact with much literature with the aim of getting a sense of them; this stimulated my thought pattern and resulted in the discovery of academic or professional information. I have learned the difference between a literature review and a report. I believe I have developed a systematic way of writing essays which is interesting and different for me. With this research experience, I see myself becoming a conscientious, avid researcher motivated by the words of Vygotsky who argues that learning occurs from one's experiences or ideas as we interact with our environments. I believe the process of my interaction with my environment (academic literature, work colleagues, and other researchers) progressed from generating or asking questions, to analysing of ideas, to the discovery of answers which constitute learning. I learned that teamwork is key to success in research and learning.

9.6 Limitations of the Study

Due to the nature of the study, the financial as well as time constraints, this study's sample and findings were derived from learners in the two participant schools in the Ilorin metropolis. Therefore, I cannot generalise its findings to all other senior secondary schools in the metropolis. Nevertheless, the sample has consistent characteristics typical of senior secondary schools in the metropolis in terms of age, gender, ethnic compositions, and economic/social status. It would be desirable to further examine these on a larger sample with a control group in order to compare the cause-effect of the intervention. Future studies could widen the population sample to include more schools within the state and a control group.

One other limitation of this study was the lack of opportunity to conduct a focus group interview with each of the learning teams due to the Covid-19 pandemic. This would have provided an opportunity to explore the group synergy during the POGIL sessions in their classrooms. In addition, I was unable to have video coverage of the POGIL lessons which would have shed more light on what transpired or the interactions within each learning team. Nonetheless, the relationship and trust that had been built with the learners might overcome this limitation in the sense that learners were at ease during the interviews and were seemingly free to express themselves in their journals. During the individual interviews, learners were able to describe both the undesirable and positive experiences in their learning teams.

Another limitation of this study that hindsight revealed is the fact that SAT data were mainly quantitative. Perhaps a balanced approach would have been better to further explore learners' responses in the SAT with individual interviews to possibly complement the quantitative result, even though in discussing the quantitative data, I included some of the learners' scripts to augment its description. Some of the responses to the SAT questionnaire needed further explanation from learners as it was difficult to determine this from the scripts. Notwithstanding these limitations, the implication of the study is significant for introducing an engaging inquiry-based instructional strategy into Nigerian science classrooms in developing stoichiometry proficiency and attitudes towards science among learners.

9.7 Recommended Areas of Further Studies

The following suggestions are included to encourage and enhance future research in the areas of learners' proficiency, attitudes towards science, and POGIL strategy, in particular. A longitudinal study on the influence of POGIL on learners' proficiency and attitudes towards science as they progress to the final year of the senior secondary school is recommended. This is to investigate the long-term effect of POGIL as against the short-term effect claimed in this study. It could be insightful to explore how these learners' proficiency in stoichiometry and attitudes towards science have progressed subsequently, especially as they transition and progress to the final year of the senior secondary school.

As mentioned above, developing a science professional learning community on POGIL could be explored and the impact it might have on teachers' practices and teaching quality. Also, I would like to carry out further work on the influence of the POGIL instructional method in other chemistry topics or science subjects at the secondary school level to compare findings. I also wish to explore analysis of learners' proficiency followed-up with interviews where learners would be able to explain their understanding and strategies in solving a problem. Future research could investigate further the influence of another active instructional strategy on learners' proficiency, explore the role of learners' socio-economic, socio-cultural backgrounds or gender on attitudes towards science.

9.8 Conclusion

This study employed an intervention programme to explore evolving proficiency in stoichiometry and attitudes towards science with SSS 2 learners in two selected schools in Ilorin metropolis, Kwara state, Nigeria. In order to accomplish this, four research questions were posed and both quantitative and qualitative data were generated in an attempt to answer them.

This study revealed that learners' proficiency in stoichiometry and attitudes towards science shifted significantly after a period. The result also suggested that the contributing factors to these shifts are features identified within the POGIL approach, namely, facilitators and learning environment features, instructional characteristics, perceptions of science, and comprehension or mastery of concepts. These features are also associated with the principles of *social interaction, self-regulation, tools, and ZPD* all embedded in Vygotsky's (1978) socio-cultural learning theory.

Thus, this study demonstrated that a carefully designed POGIL approach has the potential to foster learners' development of proficiency and attitudes towards science. As such, the study contributes to the body of research regarding specific characteristics of the learner-centred approach which allows learners to take responsibility for their own learning which is fundamental to their evolving proficiency and attitudes towards science.

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APPENDICES

Appendix A: Ethical Clearance

RHODES UNIVERSITY
Where leaders learn

Human Ethics subcommittee
Rhodes University Ethical Standards Committee
PO Box 94, Grahamstown, 6140, South Africa
t: +27 (0) 46 603 8055
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e: ethics-committee@ru.ac.za

www.ru.ac.za/research/research/ethics
NHREC Registration no. REC-241114-045

20 January 2020

Mrs Arinola Agunbiade

Review Reference: 2019-0593-2141

Email: g15a6914@campus.ru.ac.za

Dear Mrs. Arinola Agunbiade

Re: Exploring Learners' Proficiency in Stoichiometry and Attitudes towards science through the Process Oriented Guided Inquiry Learning intervention

Principal Investigator: Prof. Kenneth Mlungisi Ngcoza

Collaborators: Mrs. Arinola Esther Agunbiade

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Ethical Standards Committee (RUESC) – Human Ethics (HE) sub-committee.

Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying when the annual report is due.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on the completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloging number allocated.

Sincerely

Prof Joanna Dames

Chair: Human Ethics sub-committee, RUESC- HE

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Appendix B: Permission Letter to the School Principal

P. O Box 14
Ilorin, Nigeria.

Dear Sir/Madam,

Request for Permission to conduct a research study on learners' proficiency in stoichiometry and attitudes towards learning science

I am Agunbiade Esther, a doctoral student of Rhodes University, South Africa.

I am writing to ask for your permission to conduct an educational research with the senior secondary school two (SSS2) science learners in your school from the first to the third term of the 2019/2020 academic year. My research topic is: exploring learners' evolving proficiency in stoichiometry and attitudes towards learning science and it is expected that this information will give valuable information to Science teachers through the Process Oriented Guided inquiry Learning.

My study will explore learners' difficulties in stoichiometry and their attitudes towards learning science and it is expected that this information will give valuable information to Science teachers. Should you give me permission, I will work with the chemistry teachers who will develop appropriate Process Oriented Guided Inquiry Learning (POGIL) materials for the SSS2 chemistry curriculum. POGIL is an instructional strategy where learners work in small groups on activities specially designed to follow a learning cycle. As a qualified Science High School teacher, I will take care not to disrupt teaching and learning in the classrooms of the research.

The research will also involve administering questionnaires, video recording of some POGIL lessons, taking photographs of some POGIL activities (only if consent if given by the school and learners) and conducting interviews with learners on their proficiency and attitudes towards science. These will be administered at a time and place agreed upon by yourself and your management team.

During the research outlined above, I will abide by the ethical principles pertaining to educational research by respecting all participants' rights to withdraw at any time in the study, their privacy and confidentiality. The outcome of this study will be published in a thesis, which will be available to yourself and teacher participants on request. Later articles on the research will be available for decision-makers and curriculum developers in order to improve the learning of stoichiometry in the senior secondary school. In all these documents I will ensure the anonymity of all participants.

This research has been approved by both the Rhodes University Ethical Standards Committee and the Education Department Higher Degrees Committee (Reference number – 2019-0593-2141). During the research, any concerns may be directed to Mr. Siyanda Manqele, Ethics Coordinator, Research Office, Rhodes University +27 (0) 46 603 7727, s.manqele@ru.ac.za.

You can contact me at queenesther4throne@yahoo.com or 08061519126 or my supervisor at K.Ngcoza@ru.ac.za if you have any questions.

I would be grateful to receive a positive response.

Yours sincerely,

Esther Agunbiade.
Rhodes University.

Appendix C: Letter of Consent to SSS2 Science Learners

Dear participants

Participation in research on proficiency in stoichiometry and attitudes towards learning science.

My name is Agunbiade Esther. I am a doctoral student at Rhodes University in South Africa. I am kindly asking you to participate in a study aimed at exploring learners' proficiency in stoichiometry and attitudes towards learning science.

The study will be in three phases. The first phase will require you to complete a questionnaire on attitudes towards science, what you think about stoichiometry topics and a short quiz on stoichiometry concepts. The second phase is the intervention which will involve you working in a group to learn and complete activities during chemistry lessons. The lessons will be video recorded but only if you consent to the recording. In the third phase, you will complete another questionnaire on attitudes towards science and a short quiz on stoichiometry. You might also be interviewed as a group to know about your experience in the chemistry class.

Your participation in this study will be highly appreciated but it is completely voluntary. This means that you can withdraw anytime if you wish to do so and it will not have any implications for your learning. Your identity, participation, and contributions in this study will be treated as confidential and will not be disclosed to anyone without your consent.

If you have any further questions or concerns, please contact me at queenesther4throne@yahoo.com or 08061519126 or my supervisor at K.Ngcoza@ru.ac.za.

Yours sincerely,

Agunbiade Esther

Declaration by participant

Project Title: Exploring learners' proficiency in stoichiometry and attitudes towards learning science
Researcher's name: Agunbiade Esther
Name of participant: ………………………………………………………………………………

1. Has the researcher explained what she will be doing and wants you to do?

YES	NO

2. Has the researcher explained why she wants you to take part?

YES	NO

3. Do you understand what the research wants to do?

YES	NO

4. Do you know if anything good or bad can happen to you during the research?

YES	NO

5. Do you know that your name and what you say will be kept a secret from other people?

YES	NO

6. Did you ask the researcher any questions about the research?

YES	NO

7. Has the researcher answered all your questions?

YES	NO

8. Do you understand that you can refuse to participate if you do not want to take part and that nothing will happen to you if you refuse?

YES	NO

9. Do you understand that you may pull out of the study at any time if you no longer want to continue?

YES	NO

10. Do you know who to talk to if you are worried or have any other questions to ask?

YES	NO

11. Has anyone forced or put pressure on you to take part in this research?

YES	NO

12. Are you willing to take part in the research?

YES	NO

_________________________ ____________________

Signature of learner Date

Appendix D: Parent / Guardian's Informed Consent

Dear Parent/Guardian,

Consent to your child participating in research on proficiency in stoichiometry and attitudes towards learning science.

My name is Agunbiade Esther. I am a doctoral student at Rhodes University in South Africa. I am kindly asking you to consent to your child to participate in my study. It is aimed at exploring learners' proficiency in stoichiometry and attitudes towards learning science.

The study will be in three phases. The first phase will require the participants to complete a questionnaire on attitudes towards science, why they find stoichiometry difficult or not and a short quiz on stoichiometry concepts. The second phase is the intervention which will involve the participants working with other leaners in their classrooms to learn and complete activities during chemistry lessons. The lessons will also be video-recorded if the learner consent to it. In the third phase of the study, the participants will complete another questionnaire on attitudes towards science and a short quiz on stoichiometry. Participants will also be interviewed as a group to know about their experiences in the chemistry class.

Your child's participation in this study will be highly appreciated and it is completely voluntary. He or she can withdraw anytime they wish to and it will not have any implications for their learning. Your child's identity, participation, and contributions in this study will be treated as confidential and will not be disclosed to anyone without your and their consent.

This research has been approved by both the Rhodes University Ethical Standards Committee and the Education Department Higher Degrees Committee. During the research, any concerns may be directed to Mr. Siyanda Manqele, Ethics Coordinator, Research Office, Rhodes University +27 (0) 46 603 7727, s.manqele@ru.ac.za.

If you have any further questions or concerns, please contact me at queenesther4throne@yahoo.com or 08061519126 or my supervisor at K.Ngcoza@ru.ac.za.

Yours sincerely,

Agunbiade Esther

Informed Consent Declaration

Parent or Guardian

Project Title: Exploring learners' proficiency in stoichiometry and attitudes towards learning science through the Process Oriented Guided Inquiry Learning Approach

Esther Agunbiade from the Department of Education, Rhodes University has requested my permission to allow my child/ward ……………………………to participate in the above-mentioned research project.

The nature and the purpose of the research project, and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to explore learners' proficiency in stoichiometry and attitudes towards learning science through the Process Oriented Guided Inquiry Learning Approach
2. The Rhodes University has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate. [Certificate number]
3. By participating in this research project my child/ward will be contributing towards growing the field of active learning and the field of science education in Nigeria
4. My child/ward will participate in the project by completing questionnaires, participating in focus-group interview, keeping a weekly chemistry journal and video recorded lessons
5. My child's participation is entirely voluntary and if my child/ward is older than seven (7) years, s/he must also agree to participate.
6. Should I or my child/ward at any stage wish to withdraw my child from participating further, we may do so without any negative consequences.
7. My child may be asked to withdraw from the research before it has finished if the researcher or any other appropriate person feels it is in my child's best interests, or if my child does not follow instructions.
8. Neither my child nor I will be compensated for participating in the research.
9. There may be risks associated with my child's participation in the project. I am aware that
    a. the following risks are associated with participation:
        i. Learner might feel that their learning experience or abilities is under scrutiny
        ii. There is the possibility of intimidation from peers as they learn in teams and during the interview
    b. the following steps have been taken to prevent the risks: I will ensure:
        i. I obtain consent of learners before any action that involves them is taken
        ii. That learners fully understand the research before they give their consents
        iii. Learners are interviewed in a focus group and in an open room where their safeguarding staff is also present

iv. That leaners discuss with their teachers or safeguarding staff if they find participating in the research stressful or have any concern
v. That learners' identity and information shared with me during the study remain confidential during and after the study

There is a 50% chance of the risk materialising

10. The researcher intends publishing the research results in the form of thesis. However, confidentiality and anonymity of records will be maintained and that my or my child's/ward's name and identity will not be revealed to anyone who has not been involved in the conduct of the research.
11. I will not receive feedback in the form of letters regarding the results obtained during the study.
12. Any further questions that I might have concerning the research or my participation will be answered by Esther Agunbiade, queenesther4throne@yahoo.com
13. By signing this informed consent declaration I am not waiving any legal claims, rights or remedies that I or my child/ward may have.
14. A copy of this informed consent declaration will be given to me, and the original will be kept on record.
15. Request will be made to take picture, video and voice recording of my child

I, ……………………………………………………………………….. have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of my child during the research.

I have not been pressurised in any way to let my child take part. By signing below, I voluntarily agree that my child/ward ………………………………………………………………… (Name of child), who is …………….. years old, may participate in the above-mentioned research project.

………………………………….. ………………………… ………………………….

Parent/Guardian's signature Witness Date

Appendix DI: Parent / Guardian’s Informed Consent in the Yoruba Language

Lẹta ti ifohunsi si Awọn obi ati Alagbatọ ti Awọn Ile-iwe Atẹle Gẹẹsi Meji (SSS2) awọn ọmọ ile-iwe Imọ.

Obi ati alagbato,

Gba adehun si ọmọ rẹ ti o kopa ninu iwadi lori pipeye ni stoichiometry ati awọn iwa si imọ-jinlẹ eto-ẹkọ.

Orukọ mi ni Agunbiade Esther. Akeko Ph.D. ni ile-iwe ni Universiti Rhodes ni South Africa. Mo n fi aanu beere lọwọ rẹ lati gba ọmọ rẹ lọwọ lati kopa ninu iwadi mi ti o ni ero lati ṣawari pipe awọn akẹkọ ni imọ-jinlẹ ati awọn ihuwasi si imọ-jinlẹ eto-ẹkọ.

Iwadi na yoo wa ni awọn ipele mẹta. Ipele akọkọ yoo beere fun awọn olukopa lati pari iwe ibeere kan lori awọn iwa si imọ-jinlẹ, idi ti wọn fi rii pe stoichiometry nira tabi rara ati kukuru kukuru lori awọn imọran stoichiometry. Ipele keji ni kikọlu eyiti yoo kan awọn olukopa ti n ṣiṣẹ pẹlu awọn alagidi miiran ni awọn yara ikawe wọn lati kọ ẹkọ ati pari awọn iṣẹ lakoko awọn ẹkọ kemistri. Ale se iyaworan awon eeko yi ti o ba gba . Ni ipele kẹta ti iwadii, a yoo nilo alabaṣe lati pari iwe ibeere miiran lori awọn iwa si imọ-jinlẹ ati awọn ibeere kukuru lori stoichiometry. Awọn olukopa yoo tun ṣe ifọrọwanilẹnuwo bi ẹgbẹ kan lati mọ nipa awọn iriri wọn ni kilasi kemistri.

Ikopa ti ọmọ rẹ ninu iwadi yii yoo ni riri pupọ ati pe o jẹ atinuwa patapata. Arabinrin naa le yọkuro nigbakugba ti wọn ba fẹ ṣe bẹ ati pe ko ni eyikeyi itasi lori eto ẹkọ wọn. Idanimọ ti ọmọ rẹ, ikopa, ati awọn ọrẹ inu iwadi yii ni a yoo ṣe itọju bi asiri ati pe a ko ni sọhan fun ẹnikẹni laisi iwọ ati awọn onigbagbọ wọn.

Ile iwe Rhodes University ti fi aye gba iwadi yi. Ti e ba ni ohun kohun ti oru yin loju, ele fi to Mr Siyanda Manqele, Ethics Coordinator, Research Office, Rhodes University +27 (0) 46 603 7727, s.manqele@ru.ac.za leti.

Ti o ba ni awọn ibeere tabi awọn ifiyesi eyikeyi siwaju, jọwọ kan si mi ni queenesther4throne@yahoo.com tabi 08061519126 tabi olubẹwo mi ni K.Ngcoza@ru.ac.za.

Emi ni ti yin nitoto,
Agunbiade Esther`

Alaye si obi / alagbato

Mo ti ka ati oye ti alaye ti o wa loke.

Akọle Iṣẹ-iṣe: Ṣawari oye ti awọn akẹkọ ni stoichiometry ati awọn iṣe si imọ-jinlẹ ẹkọ nipasẹ Ilana Ilana Itọsọna Ibeere Itọsọna itọsọna

Esteri Agunbiade lati Sakaani ti Ẹkọ, Ile-iwe Rhodes ti beere fun igbanilaaye mi lati gba ọmọ mi / ile-iṣẹ mi …………………………… lati kopa ninu iṣẹ iwadi ti a mẹnuba loke.

Iseda ati idi ti iṣẹ iwadi, ati ti ikede asọye nipa alaye ti ṣe alaye fun mi ni ede ti MO loye.

Mo mọ pe:

1. Idi ti ile-iṣẹ iwadi jẹ lati ṣawari oye ti awọn akẹkọ ni stoichiometry ati awọn iṣe si imọ-jinlẹ imọ-ẹrọ nipasẹ Ilana Ilana Oludari Itọju Ẹkọ

2. Ile-iwe Rhodes ti fun imukuro iwuwasi si iṣẹ iwadi yii ati pe Mo ti rii / le beere lati rii ijẹrisi imukuro. [Nọmba ijẹrisi]

3. Nipa ikopa ninu iṣẹ iwadi yii ọmọ mi / ile-iṣẹ mi yoo ṣe alabapin si idagbasoke aaye ti ẹkọ ti nṣiṣe lọwọ ati aaye imọ-ẹrọ imọ-jinlẹ ni Nigeria

4. Ọmọ mi / ile-iṣẹ mi yoo kopa ninu iṣẹ naa nipa ipari awọn ibeere, ikopa ninu ifọrọwanilẹnu ẹgbẹ-ẹgbẹ, tọju iwe-akọọlẹ kemistri ọsẹ kan ati awọn ẹkọ fidio ti o gbasilẹ

5. Kopa ti ọmọ mi jẹ atinuwa ni gbogbogbo ati ti ọmọ mi / olutọju ba dagba ju ọdun meje lọ (7), s / o tun gbọdọ gba lati kopa.

6. Ṣe emi tabi ọmọ mi / ile-iṣẹ mi ni eyikeyi ipele fẹ lati yọ ọmọ mi kuro lọwọ kopa siwaju si, a le ṣe bẹ laisi awọn abajade odi.

7. Ọmọ mi le ni ki o yọkuro kuro ninu iwadii naa ṣaaju ki o to pari ti oluwadi naa tabi eyikeyi eniyan ti o ba tọ miiran ba ro pe o wa ninu ire ti ọmọ mi, tabi ti ọmọ mi ko ba tẹle awọn itọnisọna.

8. Bẹni ọmọ mi tabi emi yoo ni isanpada fun kopa ninu iwadi naa.

9. Awọn eewu le wa pẹlu ikopa ti ọmọ mi ninu iṣẹ naa. Emi mọ pe

a. awọn ewu wọnyi ni nkan ṣe pẹlu ikopa:

emi. Olukọ le lero pe iriri iriri ẹkọ wọn tabi awọn agbara wọn wa labẹ ayewo

ii. Nibẹ ni aye ti idẹruba lati ọdọ awọn ẹlẹgbẹ bi wọn ṣe nkọ ni awọn ẹgbẹ ati lakoko ijomitoro b? awọn igbesẹ atẹle ni a ti mu lati yago fun awọn eewu naa: Emi yoo rii daju:

emi. Mo gba aṣẹ ti awọn akẹkọ ṣaaju igbese eyikeyi ti o kan wọn

ii. Awọn akẹẹkọ yẹn ni oye iwadi naa ni kikun ṣaaju ki wọn fun awọn onigbagbọ wọn

iii. Ti ṣe ijomitoro awọn ọmọ ile-iwe ni ẹgbẹ idojukọ ati ninu yara ṣiṣi kan nibiti oṣiṣẹ aabo wa tun wa

iv. Ti o pẹlẹpẹlẹ naa jiroro pẹlu awọn olukọ wọn tabi wọn ṣe aabo aabo osise ti wọn ba rii ikopa ninu iwadi naa ni eni lara tabi ni eyikeyi ibakcdun

v. Idanimọ ti awọn akẹkọ ati alaye ti o pin pẹlu mi lakoko iwadii naa wa ni igbẹkẹle lakoko ati lẹhin iwadii naa

Aye idaji ogorun (50%) ti eewu wa

10. Oniwadi ṣe ipinnu titẹjade awọn abajade iwadii ni irisi imọ-jinlẹ. Sibẹsibẹ, asiri ati ailorukọmọ awọn igbasilẹ yoo ni itọju ati pe orukọ ati ọmọ mi / idanimọ ko ni han si ẹnikẹni ti ko ba kopa ninu ihuwasi ti iwadii naa.

11. Emi ko ni gba esi ni irisi awọn lẹta nipa awọn abajade ti o gba lakoko iwadii.

12. Gbogbo awọn ibeere miiran ti Mo le ni nipa iwadi naa tabi ikopa mi ni yoo dahun nipa Esteri Agunbiade, queenesther4throne@yahoo.com

13. Nipa iforukọsilẹ ti ikede alaye aṣẹ yii Emi ko yọkuro eyikeyi awọn ẹtọ ofin, awọn ẹtọ tabi awọn atunṣe ti Emi tabi ọmọ mi / le ni.

14. Ẹda ikede ikede alaye yii ni ao fi fun mi, ati pe atilẹba yoo wa ni igbasilẹ.

15. Beere lati ya aworan, fidio ati gbigbasilẹ ohun ti ọmọ mi

Emi, …………………………………………………………………………………… .. ti ka alaye ti o wa loke / jẹrisi pe o ti salaye alaye loke yii fun mi ni ede ti MO loye ati pe Mo mọ nipa awọn akoonu ti iwe yii. Mo ti beere gbogbo awọn ibeere ti Mo fẹ lati beere ati pe a ti dahun awọn wọnyi si itẹlọrun mi. Mo ni oye kikun ohun ti o yẹ fun ọmọ mi lakoko iwadii naa.

A ko lilu mi ni ọna eyikeyi lati jẹ ki ọmọ mi kopa. Nipa iforukọsilẹ ni isalẹ, Mo ṣe atinuwa fun ọmọ mi / ile-iwe ……………………………………………………………………… (Orukọ ọmọ), toje ………. Ọdun ọdun, le kopa ninu iṣẹ iwadii ti a sọ loke.

………………………………….   ....

Obi / alagbato   ojo ibuwolu

Appendix DII: Parent / Guardian's Informed Consent in the Igbo Language

Akwụkwọ ozi nkwenye ndị nne na nna na onye nlekọta nke ụlọ akwụkwọ sekọndrị abụọ (SSS2) na-amụ sayensị.

Ezigbo nne na nna / onye nlekọta,

Kwenye na nwa gị na-esonye na nyocha banyere ogo ụlọ ahịa stoichiometry na echiche maka mmụta sayensị.

Aha m bu Agunbiade Esther. Abụ m Ph.D. nwata akwụkwọ na Mahadum Rhodes dị na South Africa. Eji m obi ọma na-arịọ gị ka ị kwenye nwa gị isonye na ọmụmụ m nke a na-achọpụta nyocha nke ụmụ akwụkwọ na stoichiometry na echiche maka mmụta sayensị.

Ọmụmụ ihe a ga-adị usoro atọ. Ala mbu gha choro ndi sonyere iji mezue akwukwo ajuju banyere omume banyere sayensi, ihe kpatara ha ji achota nnoo stoichiometry ma obu na esighi aju aju ndi ozo. Usoro nke abụọ bụ ntinye aka nke ga-esonye ndị sonyere na-arụ ọrụ na ndị ọzọ na-agụ akwụkwọ na klas ha ịmụ ma mezue mmemme n'oge ọmụmụ kemịkal. Na usoro nke atọ nke ọmụmụ a, a ga-achọrọ onye sonyere ya ka ọ mezue ajụjụ ọzọ gbasara omume gbasara sayensị na obere ajụjụ gbasara stoichiometry. A ga-agba ndị sonyere ajụjụ ọnụ dị ka otu ìgwè iji mata ahụmịhe ha na klaasị kemịkal.

Nwa gị na-ekere òkè n'ọmụmụ ihe a ga-enwe ekele dị ukwuu yana ọ bụ afọ ofufo. Onye ahụ nwekwara ike ịpụpụ oge ọ bụla ma ọ bụrụ na ha chọrọ ime ya na ọ nweghị ihe ọ ga-emetụta na mmụta ha. A ga-emeso njirimara nwa gị, ntinye ya na ntinye aka na ọmụmụ a ka ihe nzuzo na agaghị ekpughe ya onye ọ bụla na-enweghị nkwenye gị.

Ọ bụrụ na ị nwere ajụjụ ọ bụla ma ọ bụ nwee nchegbu ọzọ, biko kpọtụrụ m na Mr Siyanda Manqele, Ethics Coordinator, Research Office, Rhodes University +27 (0) 46 603 7727, s.manqele@ru.ac.za. queenesther4throne@yahoo.com ma ọ bụ 08061519126 ma ọ bụ onye nlekọta m na K.Ngcoza@ru.ac.za.

Onye nke gị,

Agunbiade Esther

Nkwupụta nke nne na nna / onye nlekọta

Agụọla m ma ghọta ihe ama dị n’elu.

Nkwupụta nkwenye nke nne na nna / onye nlekọta

Isi oru ngo: Inyocha ikike ndi akwukwo guru na stoichiometry na akparamagwa ndi mmadu n’enwe mmuta sayensi site na Ntuziaka Aguziri Omuma Nke Guzoro

Esther Agunbiade sitere na Ngalaba Mmụta, Mahadum Rhodes rịọla ka m nye m ikike ịhapụ nwa m / ngalaba ……………………… .. isonye na oru nyocha ahụ a kpọtụrụ aha n'elu.

Ndi akowara agwa na ebumnuche nke nyocha a, na nkwupute nkwenye a gwara m n'asụsụ m ghọtara.

Ama m na:

1. Ebumnuche nke oru nyocha a bụ inyocha mmụta nke ndị na - amụ ihe na stoichiometry na echiche maka mmụta sayensị site na Usoro Nduzi Ego Eduziri Ndị mmadụ.

2. Mahadum Rhodes enyerela nyocha nke ọma na nyocha a ma ahụla m / m nwere ike ịrịọ ka m hụ akwụkwọ nyocha. Nọmba akwụkwọ]

3. Site na isonye na oru nyocha a nwa m / Ward ga na-enyere aka maka ịbawanye n'ọzụzụ nke ọrụ ike yana mmụta agụmakwụkwọ na Nigeria

4. Nwa m / ngalaba ga - esonye na oru ahụ site na ịmejupụta ajụjụ, na-esonye na ajụjụ ọnụ otu, na-edebe akwụkwọ nyocha kwa izu na nkuzi vidiyo e dere.

5. Ntinye aka nwa m bụ nke afọ ofufo ma ọ bụrụ na nwa m / nlekọta ochie karịa afọ asaa (7), s / ọ ga-ekwenye isonye.

6. Ọ bụrụ na mụ ma ọ bụ nwa m / ngalaba ọ bụla chọrọ ịchọ ịhapụ nwa m ka ọ sonye na ya, anyị nwere ike ime ya na enweghị nsonaazụ ojoo ọ bụla.

7. Enwere ike ịgwa nwa m ka ọ hapụ nyocha ahụ tupu ya agwụ ma ọ bụrụ na onye nyocha ma ọ bụ onye ọ bụla ọzọ kwesịrị ekwesị chere na ọ bụ maka ọdịmma nke nwa m, ma ọ bụ ọ bụrụ na nwa m anaghị eso ntuziaka.

8. A gaghi enye nwa m ego ma o bu na m sonye na nyocha a.

9. Enwere ike ịnwe ihe egwu metụtara nsonye nwa m na oru ngo a. A ma m nke ahụ

a. ihe egwu ndị a na - esonye na isonye:

i. Ndị na-amụ ihe nwere ike iche na a na-enyocha ahụ ike mmụta ha ma ọ bụ ikike ha

ii. Enwere ohere nke egwu site n'aka ndị ọgbọ karịa ka ha na-amụkọ na otu na n'oge ajụjụ ọnụ ahụ

b. emeela usoro ndị a iji gbochie ihe egwu a: M ga - ahụ mbọ:

i. Enwetara m nkwenye nke ndị na-amụ akwụkwọ tupu emee ihe ọ bụla metụtara ha

ii. Lemụ akwụkwọ ahụ ghotara nyocha ahụ nke ọma tupu ha ekwuo nkwenye

iii. A gbara ndị na-amụ akwụkwọ ajụjụ ọnụ na otu ndị na-elebara anya na n'ime ụlọ a na-emeghe ebe ndị ọrụ nchekwa ha dịkwa

iv. Ndị ahụ na-agụ ya na ndị nkuzi ha na-akparịta ma ọ bụ na-echebe ndị ọrụ ma ọ bụrụ na ha na-ekere òkè na nyocha ahụ na-akpata nrụgide ma ọ bụ na-enwe nchegbu ọ bụla

v. Amata njirimara nke ndị na-amụ ihe na ozi m kesara n'oge ọmụmụ ihe ahụ na-abụ ihe nzuzo n'oge ọmụmụ ihe na mgbe a gbasara

Enwere ohere 50% nke ihe ize ndụ ahụ

10. Onye nyocha chọrọ idepụta nsonaazụ nyocha n'ụdị usoro ọmụmụ ahụ. Agbanyeghị, a ga-edozigharị nzuzo na nzuzo nke ndekọ yana na a gaghị ekpughere aha m / nwa m na njirimara ya onye ọ bụla etinyeghị aka na nyocha ahụ.

11. Agaghị m enweta nzaghachi n'ụdị leta banyere nsonaazụ ndị enwetara n'oge ọmụmụ ihe a.

12. Ajuju obula ozo m nwere inwe banyere nyocha ma obu ntinye aka m ga-aza Esther Agunbiade, queenesther4throne@yahoo.com

13. Site na ịdebanye nkwupụta nkwenye a, anaghị m ewepụ iwu ọ bụla gbasara iwu, ikike ma ọ bụ ọgwụgwọ ọ bụla nke mụ ma ọ bụ nwa m nwere.

14. A ga-enye m otu nkwupụta nkwenye a, m ga-edebekwa ihe mbụ dị na ndekọ.

15. Rịọ ka eserese nwata, ese vidiyo na olu m

M, ………………………………………………………………… .. agụwo m ozi a dị elu / gosi na akọwaala m nke ọma na Asụsụ m ghotara ma ama m na ihe dị n’ime akwụkwọ a. Ajujuola m ajuju niile m choro iju, azakwaju m ndia. Aghọtara m nke ọma ihe nwa m na-atụ anya n’oge nyocha ahụ.

Enwebeghị m nrụgide n'ụzọ ọ bụla ikwe ka nwa m sonye. Site na ịbanye n'okpuru, ejiri m obi m kweta na nwa m / ngalaba …………………………………………………………… (Aha nwa), onye bụ ………. . afọ, nwere ike isonye na oru nyocha a kpọtụrụ aha n'elu.

…………………………………. ………………………… … ……………………….

Bọchị ịgba akaebe nne na nna onye isi

Appendix DIII: Parent / Guardian's Informed Consent in the Hausa Language

Harafin amincewa da Iyaye da kuma Malaman Makarantar Sakandare Na Biyu (SSS2) masu koyon Kimiyya.

Ya Uwargida Mai Kulawa,

Yarda da yaranka don yin bincike a kan ƙwarewar abinci a fannin kimiyya da halayyar koyon kimiyya.

Sunana Agunbiade Esther. Ni Ph.D. dalibi a Jami'ar Rhodes a Afirka ta Kudu. Ina mai rokon ka da ka yarda da yaranka su shiga cikin karatun da nake yi don gano ƙwarewar ɗalibai a harkar siye da halayyar ɗaliban ilimin kimiyya.

Nazarin zai kasance a cikin matakai uku. Mataki na farko zai buƙaci mahalarta su kammala tambayoyin game da halaye game da kimiyya, dalilin da yasa suka sami tsayayyen stoichiometry cikin mawuyacin hali ko a'a da ɗan taƙaitaccen tambaya akan ka'idojin stoichiometry. Mataki na biyu shine sa hannu wanda zai amfani mahalarta masu aiki tare da wasu masu siye a dakunan karatun su don koyo da kuma kammala ayyukan yayin darussan ilmin sunadarai. A kashi na uku na binciken, ana buƙatar mahalarta don kammala wata ma'anar tambayoyi game da halaye ga kimiyya da taƙaitaccen tambaya akan stoichiometry. Har ila yau, za a tattauna da mahalarta a matsayin rukuni don sanin abubuwan da suka samu a cikin ilimin sunadarai.

Yankin yaranku a cikin wannan binciken zai nuna godiya sosai kuma yana da yardar rai. Shi ko ita kuma na iya janyewa kowane lokaci idan suna son yin hakan kuma hakan ba zai rasa nasaba da karatun su. Asalin yaranka, sa hannu, da gudummawarsu a wannan binciken za'a dauki sirrin sannan kuma baza a bayyana wa kowa ba tare da yardarsu ba.

Idan kuna da sauran tambayoyi na gaba ko damuwa, a iya tuntuɓar ni a Mr Siyanda Manqele, Ethics Coordinator, Research Office, Rhodes University +27 (0) 46 603 7727, s.manqele@ru.ac.za. queenesther4throne@yahoo.com ko 08061519126 ko kuma shugabana a K.Ngcoza@ru.ac.za.

Naku da gaske,

Agunbiade Esther

Sanarwa daga Iyaye / mai kula

Na karanta kuma na fahimci bayanan da ke sama.

Sanarwar Amincewa da Iyaye / Mai Kulawa

Taken Aiki: Binciken ƙwarewar ɗalibai a harkar siye da halaye ga ilimin ilmantarwa ta Hanyar Samun Ingantaccen Koyar da Ilmi

Esther Agunbiade daga Sashen Ilimi, Jami'ar Rhodes ta nemi izini na izini yata / gandun …………………………… su shiga aikin binciken da aka ambata a sama.

An bayyana mani yanayin da manufar aikin bincike, da kuma wannan sanarwar yarda da yaren da nake yi cikin yaren da na fahimta.

Na san cewa:

1. Manufar aikin binciken shine gano ƙwarewar ɗalibai a fannin kimiyya da kuma halaye wajen koyan ilimin ta hanyar Hanyar Ingantaccen Binciken Ilmi.

2. Jami'ar Rhodes ta ba da izinin aiwatarwa na wannan aikin bincike kuma na gani / na iya neman izinin ganin takardar izinin shiga. [Lambar takardar shaida]

3. Kasancewa ta wannan aikin bincike dana / yadina zai kasance mai bada gudummawa wajen bunkasa fagen ilimantarwa da kuma fannin ilimin kimiya a Najeriya

4. Yaro / gundina za ta shiga cikin aikin ta hanyar kammala tambayoyi, da halartar tattaunawar-rukuni-rukuni, adana Jaridar kimiyar sati da kuma darussan bidiyo da aka rubuta

5. Halayyar ɗana ya kasance mai son rai ne kuma idan ɗana / gdn ya girmi shekaru bakwai (7), s / shi ma dole ya yarda ya shiga.

6. Idan ni da yayana ko kangina kowane mataki muke so na cire ɗa na daga shiga gaba, muna iya yin hakan ba tare da wani mummunan sakamako ba.

7. Ana iya tambayar ɗana ya fice daga binciken tun kafin ya gama idan mai binciken ko wani da ya dace ya ji yana da ƙima na dana, ko kuma idan ɗana bai bi umarnin ba.

8. Ba za a rama yarona ko na shiga cikin binciken ba.

9. Wataƙila haɗarin da ke tattare da kasancewar yarana cikin aikin. Ina sane da hakan

a. haɗari masu zuwa suna haɗuwa da halarta:

ni. Mai koyo zai iya jin cewa ƙwarewar koyon su ko ƙarfin su yana ƙarƙashin bincika su

ii. Akwai yuwuwar tsoratarwa daga takwarorinsu yayin da suke koyo a cikin ƙungiyoyi da lokacin tambayoyin

b. an dauki matakan da suka biyo baya don magance hatsarin: Zan tabbatar:

ni. Na sami izini daga masu koyo kafin a dauki duk wani aiki da ya shafi su

ii. Wannan xaliban sun fahimci binciken gabaɗaya kafin su ba da yardarsu

iii. Ana tattauna wa ɗaliban a cikin rukuni na mayar da hankali kuma a cikin wani ɗakin bude inda ma'aikatan tsaron su ke nan su ma

iv. Wadancan jingina sun tattauna da malamansu ko kuma tsare ma'aikatan su idan sun sami shiga cikin binciken da ake musu ko kuma suna da wata damuwa

v. Sanarwar ɗaliban da bayanin da aka raba ni da shi yayin binciken ya kasance abin sirri yayin da kuma bayan binciken

Akwai damar kashi 50% na haɗarin haɗari

10. Mai binciken ya yi niyyar wallafa sakamakon binciken a hanyar karatun. Koyaya, za a kiyaye amana da kuma bayyana asirin bayanan sannan kuma ba za a bayyana sunan ko yarana da kuma asalinsu ga duk wanda bai shiga harkar binciken ba.

11. Ba zan karɓi ra'ayi ba game da sakamakon haruffa dangane da sakamakon da aka samu yayin binciken.

12. Duk wasu tambayoyin da zanyi game da binciken ko kuma halartata, Esther Agunbiade ce, za su amsa ta, queenesther4throne@yahoo.com

13. Ta rattaba hannu kan wannan sanarwar yardar ba na watsi da duk wata da'awa ta doka ba, hakkoki ko magunguna waɗanda ni ko ɗana / matsarana za su iya samu.

14. Za a ba da kwafin wannan sanarwar amincewa da sanarwar da aka bayar, kuma za a adana ainihin.

15. Nemi in dauki hoto, bidiyo da kuma yin rikodin murya na

Ni, ……………………………………………………………………………… .. na karanta bayanan da ke sama / tabbatar da cewa an yi bayanin abin da ke sama a cikin wani yaren da na fahimta kuma ina sane da abin da wannan takaddar ta ƙunsa. Na yi duk tambayoyin da na ke so in yi tambaya kuma an amsa wadannan abubuwan da na gamsu da ni. Na fahimci abin da ake tsammani na yaro a yayin binciken.

Ba a matsa mini ba ta wata hanyar da zan bar yarana su shiga. Ta sanya hannu a ƙasa, Na yarda da yardar kaina cewa ɗana / rina ……………………………………………………………………… (Sunan yaro), wanda yake ………. shekaru, na iya shiga cikin aikin binciken da aka ambata a sama.

…………………………………. ………………………… ………………….

Kwanan da aka sa hannu na Saƙon iyaye mai kula

Appendix E: Consent Letter to POGIL Facilitators (Chemistry Teachers)

Dear Sir/Madam,

Participation in my research study as a facilitator and a critical friend

My name is Agunbiade Esther. I am a doctoral student at Rhodes University, South Africa and an experienced chemistry teacher. I write to ask you to kindly assist in my study as a facilitator and a critical friend.

My research study seeks to explore learners' developing proficiency in stoichiometry and their attitudes towards learning science through the Process Oriented Guided Inquiry Learning (POGIL) approach. POGIL is an instructional strategy where learners work in small group of specially designed activities or material that follows the learning cycle. The teacher in a POGIL classroom assumes the role of a facilitator to guide learners in the learning process.

The study will be in three phases. The first phase will require the SSS2 learners to complete a questionnaire on attitudes towards science, stoichiometry difficult questionnaire and a short quiz on stoichiometry concepts. The second phase is the intervention which will involve implementing POGIL in the chemistry classroom during the teaching and learning of stoichiometry. Some of the POGIL lessons will be video-recorded if you, the learners and school authorities consent to it. Otherwise, I will be observing and taking notes of the activities and interactions during the lessons. In the third phase, learners will be required to complete another questionnaire on attitudes towards science and a short quiz on stoichiometry and they will also be interviewed as a group to know about their experience in the POGIL chemistry class.

I am kindly requesting your assistance in these three phases and in particular during the intervention phase where you will be the facilitator in the POGIL classroom and I will be an observer.

I will be conducting a POGIL training workshop with you and other chemistry teachers (facilitators) involved so as to develop suitable materials and activities for stoichiometry and implement POGIL successfully in the classroom. Your participation in this study will be highly appreciated and it is completely voluntary which means you can withdraw at any time if you wish to do so. The research will be conducted with respect to the school rules and will not disrupt the smooth running of the school, your classroom or science teaching programme.

Your identity and that of other participants will be treated as confidential and will remain anonymous.

This research has been approved by both the Rhodes University Ethical Standards Committee and the Education Department Higher Degrees Committee. During the research, any concerns may be directed to Mr. Siyanda Manqele, Ethics Coordinator, Research Office, Rhodes University +27 (0) 46 603 7727, s.manqele@ru.ac.za. Please feel free to contact me at queenesther4throne@yahoo.com or 08061519126 or my supervisor at K.Ngcoza@ru.ac.za for further enquiries.

Yours sincerely,

Agunbiade Esther

Declaration

Project Title: Exploring learners' proficiency in stoichiometry and their attitudes towards learning science through the Process Oriented Guided Inquiry Learning (POGIL) approach.

Esther Agunbiade from the Department of Education, Rhodes University has requested my permission to participate in the above-mentioned research project as POGIL facilitators

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to explore learners' proficiency in stoichiometry and their attitudes towards learning science through the Process Oriented Guided Inquiry Learning (POGIL) approach.
2. The Rhodes University has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate.
3. By participating in this research project I will be contributing towards growing the field of active learning and the field of science education in Nigeria
4. I will participate in the project by partaking in the POGIL workshop and implementing POGIL in the stoichiometry lessons
5. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.
6. I will not be compensated for participating in the research.
7. The researcher intends publishing the research results in the form of thesis. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone who has not been involved in the conduct of the research.
8. I will receive feedback in the form of notes regarding the results obtained during the study.
9. Any further questions that I might have concerning the research or my participation will be answered by Esther Agunbiade, queenesther4throne@yahoo.com

10. By signing this informed consent declaration I am not waiving any legal claims, rights or remedies.
11. A copy of this informed consent declaration will be given to me, and the original will be kept on record.
12. Request to take pictures, video, voice recordings and observation of lessons for this study

I, ………………………………………………………………………….. have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research.
I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

…………………………………. …………………………

Teacher's signature Date

Appendix F: TOSRA (adapted from Fraser, 1981)

WHAT DO YOU THINK ABOUT SCIENCE?

This survey is completely confidential and your participation is voluntary.

Gender: Male _____ Female _____ Student Name: __________________________ No_____

Grade_________ School: __________________________________

Please choose how you feel about each statement by circling the best response. This is NOT a test.

	ITEMS	RESPONSE				
1	Science can help make the world a better place	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
2	Scientists spend their free time in the laboratories	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
3	I would rather find out why something happens by doing an experiment than by being told how it works	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
4	I find it interesting to hear about new ideas in science	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
5	Science lessons are fun	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
6	I would like to belong to a science club	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
7	I enjoy doing science at school like a scientist	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
8	It is good to spend money on science	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
9	I love science because I love to know how things work	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
10	Doing experiments help me learn as much as finding out information from teachers	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
11	It is good to learn new methods of doing science experiments	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
12	I dislike science lessons	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
13	I enjoy watching science programs on TV	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
14	I would like to work with people who make discoveries in science	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
15	Doing science projects is not a waste	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree

16	Scientists are friendly like other people.	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
17	It is good to do experiments to find out about things	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
18	I enjoy reading about new things in science that change my ideas	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
19	Schools should do more practical science lessons each week	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
20	I would like to be given a science book or a piece of scientific equipment as a present	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
21	I would like a job in a science laboratory	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
22	Scientific discoveries are doing more harm than good	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
23	Scientists like sports as much as other people do.	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
24	To answer a science question, I would think it over before asking for help	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
25	It is good to repeat an experiment to check if results are correct	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
26	Science lessons are useful for learning about everyday life	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
27	I dislike reading books about science in my free time	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
28	Working in a science laboratory would be interesting	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
29	Building science laboratories is good for the society	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
30	Scientists are less friendly than other people	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
31	I enjoy scientific experiments because I learn from them	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
32	Finding out about new things in science is not important	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
33	Science is one of the most interesting school subjects	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
34	I would like to do science experiments at home	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
35	I would not like to be a scientist because it requires too much education	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree

Items and reliability coefficient of TOSRA-2 sub-scales

TOSRA-2 Subscale	No of items	Serial number of items	Reliability coefficient
Perception of science	11	1,2,15,16,22,23,26,29,30,32,35	0.84
Interest in science	12	3,4,8,11,14,18,21,24,25,28,31,33	0.89
Enjoyment of science	12	5,6,7,9,10,12,13,17,19,20,27,34	0.91

Appendix G: Stoichiometry Learning Questionnaire (SLQ)

What Do You Think About Stoichiometry?

This survey is completely confidential and your participation is voluntary.
In this questionnaire, you will find questions about your experience with learning stoichiometry topics in chemistry.
Read each question carefully and answer as accurately as possible. You may ask for help if you do not understand something or are not sure how to respond.

Gender: Male _____ Female _____ Name/No: ___________________________
School_________________________ Grade_______________________

1. What was your experience in learning stoichiometry topics?

____

____

____

2. Please choose how you feel about each topic by ticking the best response in the corresponding box. This is NOT a test.

	Items	*Not sure (NS)*	*Very difficult(VD)*	*Difficult (D)*	*Easy (E)*	*Very Easy(VE)*
1	*Atomic mass*					
2	*Molecular formula*					
3	*Empirical formula*					
4	*Balancing chemical equation*					
5	*Mole ratios*					
6	*Moles and gases*					
7	*Moles and compounds*					
8	*Moles and solution*					
9	*Molecular mass*					
10	*Percentage composition*					
11	*Limiting reagent*					
12	*Reaction yields*					

3. *How many topics do you identify as 'very difficult' or 'difficult' in the table above?*
4. *Why do you identify them as 'very difficult' or 'difficult'? Give the topic number and say why you find them difficult or very difficult* ____

____

____

____

5. *How many topics do you identify as 'very easy or easy in the table above? Why do you think they are 'very easy' or 'easy' for you? Give the topic number and say why you find them easy or very easy.* ____

____

____

____

____

6. *What do you think can help you find difficult topics easier to learn and understand?*

Thank you for completing this questionnaire.

Appendix H: Stoichiometry Learning Questionnaire (SLQ) Validation

My research study seeks to explore learners evolving proficiency in stoichiometry and attitude toward science through participation in Process Oriented Guided Inquiry Learning (POGIL). As part of the validation procedure for the data collection instruments for this study, you are designated as one of the expert panels to review the research instrument.

Please find the attached draft of the Stoichiometry Learning Questionnaire. This instrument is intended to collect data on learners' perspectives on stoichiometry and to understand their experiences with learning stoichiometry. Could you please review this tool for relevance and suitability for the purpose of the study using the checklist below?

Questionnaire validation checklist

1. Is the instrument measuring what is intended to measure?
2. To what degree are the questions representative of the domain of content?
3. How comprehensive enough is the instrument to collect the information needed to address the purpose and goal intended?
4. Is the instrument appropriate for the sample participants (SSS 2 learners)?
5. Are the questions in meaningful order and format?
6. Is the number of questions in the instrument appropriate/sufficient?
7. Does the instrument contain a balanced set of items on stoichiometry?
8. Rate the questions from a scale of 1 to 3 with questions that need revision 1 and questions of quality 3.
9. Any other comment please?

Appendix I1: SAT Pre-test (Adapted from Tigere, 2014; Denuga, 2019)

SAT · Part 1

Duration: 30 minutes

Instructions and information

1. Answer all the questions.
2. Number your answers correctly according to the numbering system used in this questionnaire.
3. Give a reason or show your working on the space provided.
4. Write your **name or pseudonymn** on your answer script provided.
5. Write the **name of your school**, **your class** and **your number**
6. Periodic table and other data are provided if necessary

Periodic Table of Elements

KEY: Atomic number (29) — Symbol (Cu) — Approximate relative atomic mass (63,5)

1 H 1																	2 He 4
3 Li 7	4 Be 9											5 B 11	6 C 12	7 N 14	8 O 16	9 F 19	10 Ne 20
11 Na 23	12 Mg 24											13 Aℓ 27	14 Si 28	15 P 31	16 S 32	17 Cℓ 35,5	18 Ar 40
19 K 39	20 Ca 40	21 Sc 45	22 Ti 48	23 V 51	24 Cr 52	25 Mn 55	26 Fe 56	27 Co 59	28 Ni 59	29 Cu 63,5	30 Zn 65	31 Ga 70	32 Ge 73	33 As 75	34 Se 79	35 Br 80	36 Kr 84
37 Rb 86	38 Sr 88	39 Y 89	40 Zr 91	41 Nb 92	42 Mo 96	43 Tc 99	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	*	72 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 Tℓ 204	82 Pb 207	83 Bi 209	84 Po 209	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	**	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 264	108 Hs 265	109 Mt 268									

*	57 La 139	58 Ce 140	59 Pr 141	60 Nd 144	61 Pm 147	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
**	89 Ac 227	90 Th 232	91 Pa 231	92 U 238	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lr 262

Constants

Volume of mole of a gas at STP = 22.4dm^3
Avogadro's Constant = 6.02 x 10^{23}
Molar gas constant = 8.31J.K^{-1}.mol^{-1}

Molar gas volume at STP = 22.4dm^3.mol^{-1}
Standard temperature = 273k
Standard pressure = 1.013 x 10^6 pa

Formula

C = m/v   n=m/M $n_a = C_a V_a$
$n_b = C_b V_b$

Quiz

1. How many grams of calcium carbonate are in 6 moles of calcium carbonates $CaCO_3$?

a. 0.06g b. 0.6g c. 6.0g d. 60g e. 600g

2. One gram of Hydrogen at STP occupies

a. 44.8dm^3 b. 22.4dm^3 c. 11.2dm^3 d. 5.6dm^3 e. 2.8dm^3

3. How many atoms of hydrogen are in 3 moles of ammonia NH_3?

a. 3 atoms b. 9 atoms c. 6.0221x10^{23} atoms e. 1.8066x10^{23} atoms
d. 5.4199x10^{24} atoms b. show how you arrive at your answer

4. How many grams of magnesium oxide (M= 40g/mol^{-1}) will be formed by the combustion of a small strip of magnesium in 16 grams of Oxygen according to the following balanced reaction?

$2Mg + O_2 \rightarrow 2\ MgO$

a. 8g b. 16g c. 20g d. 40g e. 80g

5. Balance the following chemical equations and show how you balanced the equation:

5a. $\mathbf{N_{2(g)} + H_{2(g)} \rightarrow NH_{3(g)}}$

5b. $\mathbf{2Al + HCl \rightarrow 2AlCl_3 + H_2}$

6. Write what a mole is in chemistry is in your own word.

7. What is the relative formula mass of these ionic compounds?

a. magnesium oxide, MgO b. calcium carbonate, $CaCO_3$

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

a. 0.4 moles N_2 gas at STP b. 11.2 litres of CO gas at STP

c. 1.2 grams of carbon d. 5.6 litres of Cl_2 at STP

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

a. they have equal masses b. they have equal molecular masses

c. they are the same gases d. they contain equal number of atoms.

10. Differentiate between limiting reactant and excess reactant.

b. differentiate between a mole and a molecule with an example each

11. 10g of Hydrogen and 15g oxygen react to form water molecules.

a. Write a balanced equation for the above reaction.

b. What is the limiting reagent? Show how you have arrived at you answer.

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

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

If 750g of ammonia and 750g of oxygen reacted, which reactant will be totally consumed and which will be in excess? Show how you arrived at your answer.

13. When methane is burnt in oxygen, the reaction produces carbon dioxide, water and heat.

a. Write a balanced equation for the reaction

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

14. 70cm^3 of sodium hydroxide solution of concentration 0.18mol/dm^3 reacted completely with 30cm^3 of a solution of sulphuric acid.

$2NaOH_{\ (aq)} + H_2SO_4\ (aq) \rightarrow Na_2SO_4 + 2H_2O_{\ (l)}$

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

15. Calculate the empirical formula of an organic compound containing 92.3% carbon and 7.7% hydrogen by mass.

Appendix I2: SAT Post-test

Part 2

Duration: 30 minutes

Instructions and information

1. Answer all the questions.
2. Number your answers correctly according to the numbering system used in this questionnaire.
3. Give a reason or show your working on the space provided.
4. Write your **name or pseudonymn** on your answer script provided.
5. Write the **name of your school**, **your class** and **your number**
6. Periodic table and other data are provided if necessary

Periodic Table of Elements

KEY: Atomic number: 29; Symbol: Cu; Approximate relative atomic mass: 63.5

1 H 1																	2 He 4
3 Li 7	4 Be 9											5 B 11	6 C 12	7 N 14	8 O 16	9 F 19	10 Ne 20
11 Na 23	12 Mg 24											13 Al 27	14 Si 28	15 P 31	16 S 32	17 Cl 35.5	18 Ar 40
19 K 39	20 Ca 40	21 Sc 45	22 Ti 48	23 V 51	24 Cr 52	25 Mn 55	26 Fe 56	27 Co 59	28 Ni 59	29 Cu 63.5	30 Zn 65	31 Ga 70	32 Ge 73	33 As 75	34 Se 79	35 Br 80	36 Kr 84
37 Rb 86	38 Sr 88	39 Y 89	40 Zr 91	41 Nb 92	42 Mo 96	43 Tc 99	44 Ru 101	45 Rh 103	46 Pd 106	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 122	52 Te 128	53 I 127	54 Xe 131
55 Cs 133	56 Ba 137	*	72 Hf 179	73 Ta 181	74 W 184	75 Re 186	76 Os 190	77 Ir 192	78 Pt 195	79 Au 197	80 Hg 201	81 Tl 204	82 Pb 207	83 Bi 209	84 Po 209	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	**	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 264	108 Hs 265	109 Mt 268									

*	57 La 139	58 Ce 140	59 Pr 141	60 Nd 144	61 Pm 147	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175
**	89 Ac 227	90 Th 232	91 Pa 231	92 U 238	93 Np 237	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lr 262

Constants

Volume of mole of a gas at STP = $22.4 dm^3$
Avogadro's Constant = 6.02×10^{23}
Molar gas constant = $8.31 J.K^{-1}.mol^{-1}$

Molar gas volume at STP = $22.4 dm^3.mol^{-1}$
Standard temperature = 273k
Standard pressure = 1.013×10^6 pa

Formula

C = m/v   n=m/M $n_a = C_a V_a$
$n_b = C_b V_b$

Quiz

1. 10g of Hydrogen and 15g oxygen react to form water molecules.

a. Write a balanced equation for the above reaction. What is the limiting reagent? Show how you have arrived at you answer.

2. How many atoms of hydrogen are in 3 moles of ammonia NH_3?

a. 3 atoms   b. 9 atoms   c. 6.0221×10^{23} atoms   d. 1.8066×10^{23} atoms
e. 5.4199×10^{24} atoms   b. show how you arrive at your answer

3. How many grams of calcium carbonate are in 6 moles of calcium carbonates $CaCO_3$?

a. 0.06g   b. 0.6g   c. 6.0g   d. 60g   e. 600g

4. One gram of Hydrogen at STP occupies

a. $44.8dm^3$ b. $22.4dm^3$ c. $11.2dm^3$ d. $5.6dm^3$ e. $2.8dm^3$

5. How many grams of magnesium oxide ($M = 40g/mol^{-1}$) will be formed by the combustion of a small strip of magnesium in 16 grams of Oxygen according to the following balanced reaction?

$2Mg + O_2 \rightarrow 2\ MgO$

a. 8g b. 16g c. 20g d. 40g e. 80g

6. Balance the following chemical equations and show how you balanced the equation:

6a. $\mathbf{Al_2O_3 + NaOH + H_2O \rightarrow NaAl(OH)_4}$

6b. $\mathbf{KClO_3 \rightarrow KCl + O_2}$

7. Write what a mole is in chemistry is in your own word.

8. What is the relative formula mass of these compounds?

a. Calcium hydroxide, $Ca(OH)_2$ b. Zinc chloride, ZnCl2,

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

a. 0.4 moles N_2 gas at STP b. 11.2 litres of CO gas at STP

c. 1.2 grams of carbon d. 5.6 litres of Cl_2 at STP

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

a. they have equal masses b. they have equal molecular masses

c. they are the same gases d. they contain equal number of atoms.

11. Differentiate between limiting reactant and excess reactant.

b. differentiate between a molecule and a mole with an example each

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

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

If 750g of ammonia and 750g of oxygen reacted, which reactant will be totally consumed and which will be in excess? Show how you arrived at your answer.

13. When methane is burnt in oxygen, the reaction produces carbon dioxide, water and heat.

a. Write a balanced equation for the reaction

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

14. $70cm^3$ of sodium hydroxide solution of concentration $0.18mol/dm^3$ reacted completely with $30cm^3$ of a solution of sulphuric acid.

$2NaOH_{(aq)} + H_2SO_4\,(aq) \rightarrow Na_2SO_4 + 2H_2O_{(l)}$

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

15. Calculate the empirical formula of a compound containing 4g of hydrogen and 64g of oxygen

Appendix I3: SAT Memo

Marking Guide
SAT Test A

Please make 4 cop's thank you.

Total Mark = 60 marks (see mark allocation on the question script sent).

1. E – 600g
$CaCO_3$ = 100g
1 mole = 100g
6 mole = 600g 3m

2. C – Given weight / Molecular weight = 1g / 2g = 0.5
0.5 × 22.4 dm^3 = 11.2 dm^3 3m

3 D – NH_3 = 3 Hydrogen atoms
1 mole NH_3 = 6.023×10^{23}
3 moles of NH_3 contains
$3 \times 3 \times 6.023 \times 10^{23}$
= 5.421×10^{24} 3m

4 $2Mg + O_2 \rightarrow 2MgO$
2 : 1 : 2
$\frac{16g}{32} O_2$ = 0.5 moles $O_2 \rightarrow$ 1 MgO
Mass of 1 moles of MgO = 40g
D = 40g

5 $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$ 3m
$2Al_{(s)} + 6HCl \rightarrow 2AlCl_{3(aq)} + 3H_{2(g)}$ 3m

6. Various answers: Amount of substance containing the same number of specified entities or particles as there are carbon atoms in exactly 12g of Carbon – 12.
Avogadro number

7. MgO = 40g $CaCO_3$ = 100g

8 D – $n = \frac{m}{M} = \frac{8}{16 \times 2} = 0.25$ moles

$0.25 \times 6.02 \times 10^{23} = 1.505 \times 10^{23}$

$\frac{5.6}{22.4} \times 6.02 \times 10^{23} = 1.505 \times 10^{23}$.

9. D – The volume of a gas is proportional to the number of moles and the number of particles is proportional to the number of moles if it is an ideal gas – Avogadro's-law stated is accepted.

10. Limiting reactant – various answers.
Must include: reactant completely used up, the quantity limits the amount of product formed.
Excess Reactant: various answers.
Must include: Reactant that are not used up when the reaction is completed

6. Mole: various answers such as
Mole is the avogadro number of molecules
Mole is given in the unit 'mol'
The value is given as 6.023×10^{23}
Quantity of substance that has the same number of atoms present in 12g of C-12 isotope

Molecule: various answers such as
~~A~~ group of atoms bonded together that can take part in chemical reactions
Example: $HCl_{(g)}$, CO_2 etc.
mole example. E.g $2H_2 + O_2 \rightarrow 2H_2O$
1 mole of oxygen. 2 mole of hydrogen

11. $2H_2 + O_2 \rightarrow 2H_2O$

2 : 1

b. $10g\,H_2 \times \frac{1\,mol\,H_2}{2.0g} = 4.96$ moles H_2

$15g\,O_2 \times \frac{1\,mole\,O_2}{32g} = 0.468$ mole O_2

4.96 moles $H_2 \times \frac{1\,mole\,O_2}{2\,moles\,H_2} = 2.481$ moles O_2

0.468 moles $O_2 \times \frac{2\,moles\,H_2}{1\,mole\,O_2} = 0.9376$ moles H_2

Hydrogen will be excess

12. $4NH_{3(g)} + 5O_{2(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(l)}$

$n = \frac{m}{M}$ = $NH_3 = \frac{750g}{17g} = 44.12$ moles.

$O_2 = \frac{750g}{32g} = 23.44$ moles

4 moles NH_3 : 5 moles O_2 (from equation)

$(44.12 \times 5) = 4x$ moles

$\therefore x = 55.15$ moles of O_2.

O_2 is the limiting reagent.

55.15 moles of O_2 is needed but not available.

13. a. $CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(l)}$

b. $n = \frac{m}{M} = \frac{20g\,CH_4}{12 + 4\ (1.0 \times (4 \times 1))} = \frac{20}{16} = 1.25$ moles

1 mole $CH_4 \rightarrow$ 2 moles H_2O (equation)

$1.25 \times 2 = 2.5$ moles

2.5 moles $\times 18 = 45g$ $(H_2O = 2 \times 1 + (16))$

14 $\frac{n_a}{n_b} = \frac{C_aV_a}{C_bV_b} = \frac{1}{2} = \frac{C_a \times 30}{0.18 \times 70}$

$C_a = 0.21 mol dm^{-3}$

15. Convert mass into moles.

$C = \frac{92.3}{12} = 7.69$ mol

$H = \frac{7.7}{1.01} =$ ~~7.62~~ mol. 7.62 mol

$C = \frac{7.69}{7.62} = 1.01$ (Divide by the smallest).

$H = \frac{7.62}{7.62} = 1.$

Empirical formular = CH.

Appendix I4: SAT items and the proficiency strands that were assessed

Proficiency Strands	No of items	Item no on SAT
Conceptual Understanding (CU)	6	6, 9, 10a, 10b, 11b, 12a
Procedural Fluency (PF)	6	1, 3, 7, 12b, 14, 15
Strategic Competence (SC)	8	2, 4, 5a, 5b, 8, 11a, 13a, 13b

Appendix J: Stoichiometry Achievement Test (SAT) Validation

My research study seeks to explore learners evolving proficiency in stoichiometry and attitude toward science through participation in Process Oriented Guided Inquiry Learning (POGIL). As part of the validation procedure for the data collection instruments for this study, you are designated as one of the expert panels to review the research instrument.

Please find the attached draft of the stoichiometry achievement test. This instrument is intended to examine learners' proficiency in stoichiometry. Could you please review this tool for relevance and suitability for the purpose of the study using the checklist below?

Questionnaire validation checklist

1. Is the instrument measuring what is intended to measure?
2. To what degree are the questions representative of the domain of content?
3. Is the instrument comprehensive enough to collect the information needed to address the purpose and goal intended?
4. Is the instrument appropriate for the sample participants (SSS 2 learners)?
5. Are the questions in meaningful order and format?
6. Is the number of questions in the instrument appropriate?
7. Rate the questions from a scale of 1 to 3 with questions that need revision 1 and questions of quality 3.
8. Any other comment, please?

Appendix K: Semi-Structured Interview Guide

1. How do you feel about chemistry? Would you say chemistry is interesting and enjoyable, difficult and boring? What made you feel that way?
2. Can you tell me what you understand by stoichiometry? What can you use to describe stoichiometry simply?
3. How do you feel about stoichiometry topics in chemistry? What made you feel that way?
4. Could you please explain what your experiences were with learning stoichiometry for the past two terms?
5. How will you describe your experience of the group in the stoichiometry class?
6. Tell me about your experienced while dealing with collaborative work in the classroom?
7. If you had an opportunity, what would you most like to change in the collaborative work? Explain.
8. What would you not change in the collaborative work? Explain.
9. How would you describe the method used by your teacher in teaching stoichiometry in relation to your understanding of the topics?
10. What do you think about being a scientist or pursuing a science related career?

Appendix L: Interview Transcripts and Initial Coding of Data

L15, Female

Interview transcripts	Initial description	code
I: What do you think of chemistry as one of your subbjects? L: chemistry? I: yes? Is it boring, interesting, difficult….?	Perception of chemistry	26
L: ok, I would say chemistry is interesting, some topics are boring and difficult but I think if you got more explanation from the teacher you might understand it better and think how things are in your head I: I do not understand that think how things are in your head…?	Perceived difficulty of chemistry Facilitators' support Explanation facilitates understanding	31 1 2
L: what I mean is that …(*silence and thinking*) when you understand you will be able to explain it without cramming it,especially if you do chemistry with some practicals it can be so much fun I: ok, so, how would you describe your feelings about chemistry? L: I like it …sommmmetiiimes (*laughed*) I: ok, I: you've been learning stoichiometry before the locked down, am I right? L: yes, I think almost throughout the term I: can you tell me what you understand by stoichiometry	Practical is interesting Understanding eliminates rote learning	37 3
L: hmm… (*laughed*) stoichiometry is… calculating the mass or molecules of reactant or products in a reaction. I: thank you. Let's say I do not know so much about science or chemistry, how would you describe stoichiometry to me in a simple way? L: can I tell you how we explain it in our group? I: yes, please go ahead	Understanding of concept	32
L: ok, (*excited*), so..ooo stoichiometry is like making a sandwich with bacon and lettuce. You will need 2 bread slices, one piece lettuce and two bacon. But if you now want to make may be 4 sandwiches, you will have to multiply the bread, lettuce and bacon 4 times. The amount of the ingredient should be the amount of the sandwich I: yes, I'm listening L: ok, so 2 slices of bread times 4 is 8 and 2 bacon times 4 is 8 and lettuce will be 4. you will use 8 slices and 4 pieces of lettuce and 8 bacon to make 4 sandwiches. I: so, what is bread, bacon and lettuce in chemistry terms?	Engaging learning materials Knowledge retention	4 5
L: Yes,… the bread and bacon are the reactants and the sandwich is the product.	Understanding of concept	32

I: Thank you I: What do you feel about topics on stoichiometry in chemistry?		
L: they are sometimes confusing, you know sometimes you will not know what they are asking for. Most times I am confused about moles and molecules or atoms or the equation to use to solve the problem.	Confusing concepts	33
I: Do you always get confused with what formula to use in solving stoichiometry problems?		
L: yes, sometimes, and stoichiometry is just maths, there are lots of calculations and conversion you need to do, if not you will miss the answer.	Mathematical calculations involved	34
I: Do you want to tell me about your experiences learning stoichiometry for the past two terms? L: Do you mean since we started this group work? I: Yes,		
L: I think we do a lot of work in the class now and we do it step by step. We sometimes have to do quiz or make some things following a guide. My teacher sometimes gives us questions from what we did in the last lesson and ask each group to solve the problem together. So it's' like…… errm' this thing….	Engaging class activities Engaging learning materials Collaborative learning	28 4 6
I: what thing please?		
L: I mean my teacher breaks down the work in a simple way, he revises what he taught us before, before we start another class by giving us some questions or something to do. Sometimes we start with questions about the last topic and even after every lesson there are some questions that you can do on your own on the worksheet	Teacher support Problem solving activities	8 7
I: Ok, tell me about your learning team in the stoichiometry class		
L: the team 'thing' is good… we teach each other so that we can understand how we want to complete the work we are given. Sometimes my team finish early.	Sharing of knowledge/ideas	9
I: How do you work together to complete the task given to your group?		
L: What I like is that we teach each other how to do the work so that we would finish and be able to present. We are all make sure we do the work and everyone is participating in the group. Our work. We do ask our teacher questions though if everyone do not understand and she explains. She even explain better than when she does before. Sometimes she just want us to think and explain why we have given an answer	Making effort to learn Mutual support within team Teacher support Analytical thinking	30 8 10
I: Can you tell me more of the difference you see between her explanation now and before?		
L: errmm...I, just think that she takes her time to explain than before when she just ask the whole class if		8

we understand but nobody will say they don't. I will say she is more interested that we understand now. I: What was your role in your learning team? L: I was the presenter before but later I was made the timekeeper I: If you had an opportunity, what would you most like to change about your collaborative work in the classroom L: *silence* …the collab…. (*sounding confused*) I: I mean the learning team, your group work L: ok collaborative. hmmmn… nothing…. Ok, I think there should be more time to finish up our group work. I: Can you tell me more about that? L: we enjoy doing the work together and because we discuss and try to explain to everyone so that everybody will understand because when your group is presenting, my teacher can ask anyone in the group to answer a question but we do not have much time before the teacher ask us to stop. I: Why do you think it is important for you to complete your task together? L: beecaause … when we work together even if you are wrong someone will correct you and you will know why you got it wrong. We share our ideas and different method to do some questions. And at the end you will learn even a better way of solving the question than what you know before. I: What would you not change? L: I will not change the class activity that we do together and I like the questions and those classwork we are given to do in our lessons but the question should not be much (*laughs*) I: Can you explain why? L: Because doing those questions with other people makes us to practice more and help with understanding it…errm we all discuss how to answer the questions, it is better than doing it on my own because I do struggle at times. Though sometimes we still don't agree in our group but we are given the chance to explain why we have a different opinion. I: How would you describe the method used by your teacher in teaching stoichiometry in relation to your understanding of stoichiometry? L: I think I'm enjoying the method very well I: Why do you think so? L: I think my teacher gives us more question to solve and he is very much patient to explain how to do it. He also gives us chance to explain why we think our answer is correct or wrong. I like the question papers	Teacher support Insufficient learning time Enjoyment of teamwork Making effort to learn Mutual support within team Insufficient learning time Collaborative learning Explanation from peers Teamwork facilitates understanding Sharing of knowledge /ideas Engaging class activities Collaborative learning Problems solving activities Engaging learning materials Teamwork facilitates understanding Sharing of knowledge/ ideas Enjoyment of lesson Problem solving activities	11 12 8 30 11 6 13 35 9 6 28 7 4 13 9 14 7 1 4

he always gives us because it helps us practice many questions and how to solve them.	Teacher’s support Engaging learning materials	
I: Do you mean worksheet?		
L: Yes, yes the worksheets, the things to do in the worksheets are very useful, we always have something to do together before each lesson and each group will explain how they get their answers. Even during the practical class, we use the worksheet, so it makes one to understand why we are doing the practicals. Some of the work and other things we do always help me to remember what we did. Like… I cannot forget some of the short form of remembering the formula that we learnt	Engaging learning materials Collaborative learning Interactive games and activities Practical work enhance understanding Knowledge retention	4 6 36 38 5
I: Can you give an example of that?		
L: Yes .. alligator chew visitor		
I: What is that?		5
L: It means amount, concentration and volume. We arrange it in a triangle. The A is at the top and concentration and volume is multiplied below.	Knowledge retention	
I: So how do you use that?		5
l: You just cover the unknown so that you will know the formula to calculate		
I: Can I share some comments in your journal with you?	Knowledge retention	
L: Yes ma’am		
I: In your journal, you wrote on the 12th of February that, “*some of the people in my group are not nice at all but we learnt a lot of things in a different way that I understand*”, could you explain what you mean by that please?		
L: Yes, it was our team captain that was trying to boss everyone but my teacher had sorted that and…. we… did so many things to explain in an easy way to us		4
I: Ok.		
I: What do you think about being a scientist or pursuing science career?	Engaging learning material	
L: Scientist are great people. So it’s kind of mixture of what I enjoy and like and what I am very good at.		
I: Could you explain what you mean by that please?		39
L: What I mean is that I enjoy some of the science subject especially chemistry, I like what we do, and just everything generally. But I’m kind of not so good at it. I still struggle a bit and I am more concerned about that	No/Interest in science/career	40
I: Hmnn.. why are you concerned?		
L: I want to be a pharmacist., it involves lot of chemistry and the part that I still struggle with is the is the mathematical part	Poor achievement in science	26 34
I: Why do you choose to be a pharmacist?		
L: I just love it. My brother told me that if I want to be a pharmacist I must be very good at chemistry. I am	Perception of chemistry	41 15

trying, I think stoichiometry is one of the topics I don't like before but I think it is not that difficult. I: You think it's not that difficult, why? L: Yes, because…..(*paused*) I think it is just knowing what you are being asked and what to do first. Before I normally cram the way to answer some questions, sometimes guessing but I now understand why I must use a particular formula to solve a problem. I am getting more confident in balancing equations I: good. Thank you, do you have anything you would like to share with me? L: hmmnn,… nothing again. Ok I have one question ma'am I: ask please L: are we going to continue with the group work when we resume back at school? I: I cannot say, we can discuss that with your teacher. L: please I want to be interviewed again when you are doing the next one …please please please….. I: I am not sure I will have any other interviews but if need be I will let you know, all right? L: ok. Thank you I: what can you say about answering the questions in the stoichiometry quiz? L: Is it the quiz that you gave us last? I: yes, both the one you completed initially and the last one L: I think the questions are simpler in the second test that the first one I: why do you think so? L: some of the questions in the first test are in some way difficult but I think I know how to answer the questions in the second test. I: Ok. Thanks. How have you been coping with learning chemistry during this lockdown L: hmmmm…. It's ok. Just that it's a bit different from schoolwork I: What is different now? L: *silence*….. I miss the group work and the worksheet though some work sheet are sometimes sent but not so much explanation, no friends to work it… I: yeah, I understand, it such a difficult time.	Mathematical calculation involved Family influence Understanding facilitates confidence Understanding eliminates rote learning Learn new ways of doing things Understanding facilitates confidence Preference for teamwork Preference for teamwork Engaging learning materials Preference for teamwork	3 29 15 16 16 4 16

L40, Male

Interview transcripts	Initial description	code
I: How do you feel about chemistry? L: Chemistry is kind of ok I: Ok, what do you mean by ‘kind of ok? I would like you to describe your feelings.		
L: I mean chemistry not a very hard subject and not too easy. I think chemistry is a little bit interesting. It depends on some topics anyway I: Could you tell me more about that please?	Perceived difficulty of chemistry	31
L: Yes, there are some topics that I like in chemistry, they are very interesting and easy to understand. There are some that are very difficult and I don’t like them. I: Can you tell me some of the topics you like, and the ones you find difficult or hard? L: Ok, for example periodic table and atomic structure is very easy. I: Can you give example of the ones that are difficult? L: Ok, I remember, properties of matter, physical and chemical changes of matter is also easy. I: Ok.. L: The ones that are difficult, like chemical laws especially calculating moles and molecules, many of them. No matter how you try, you still miss it. I: What would you say about stoichiometry? L: it’s also difficult. Or let me say in between. I: why do you think it’s difficult or in between?	Perceived difficulty of chemistry	31
L: there are a lot of calculations involved. If you don’t know how to calculate and convert very well or even	Mathematical calculations involved	34
when to convert, you cannot understand stoichiometry. You need to be able to covert moles, molar mass, like that and when you should convert I: ok, can you tell me what you understand by stoichiometry	Require mathematical skills	45
L: stoichiometry is calculation of moles, mass, molecules of reactant and products. I kind of not know how to define it but I know what it is I: ok, how would you describe stoichiometry to me in a simple way? L: hmmm…. (*silent*) I: ok, could you explain what your experiences were with learning stoichiometry for the past two terms? L: yes I: can you tell me please?	Understanding of concept	32
L: we have been doing a lots of work in group, we discuss	Collaborative learning	6
our ideas together, we try to listen to other people though too and we learn from that to complete our worksheet. I	Sharing of knowledge/ ideas	9
think I enjoyed it. I: tell me more	Engaging learning materials	4
L: we help each other to do the worksheet. One of the things I like is that no one if proving itk, we all work	Mutual support within team	8

together and understand how to do it before we submit for the group.	Teamwork facilitates understanding	13
I: I do not understand what you meant by no one is proving itk?	Collaborative learning	6
L: I mean, (laugh) itk, I too know. Before we do our classwork by ourselves, the itks finish up the work quickly and those that do not know it will be left. So now since our teacher instructed us that everyone must participate and we must respect everybody's idea, no one is rushing and we are all taking time to learn from one another. I think it is more fun.	Positive perception of peers Mutual support within team Sharing of knowledge/ ideas Enjoyment of teamwork	21 8 9 12
I: ok, I understand.		
I: what was your role in your learning team?		
L: I am the timekeeper		
I: good, tell me about your learning team in the stoichiometry class. How would you describe your experience?		
L: well, to be honest at the start I don't like my group. Because some of the girls in the group always think they know more. But, I would say that later on we enjoyed working together even after the class, I still go to some of them to explain some of the other activity we are asked to do to me. What we do is that we all cooperate and think of how to answer the questions. If one person knows the answer, he will explain to everybody. The worksheet actually helped us too. I think it helped me.	Domineering peers Sharing of knowledge/ ideas Mutual support within team Engaging learning materials	17 9 8 4
I: if you had an opportunity, what would you most like to change about your collaborative work in the classroom	Explanation from peers	35
L: I think I like everything, oh...sorry, can I say something please?		
I: go on please		
L: ok.. I want to say sometimes the extension activity are harder and different from the ones in the class. So it becomes very difficult to do it own your own because the question are a bit different from the other things we do in the class	Knowledge transferability/ application	18
I: are they totally different?		
L: sometimes, I just think they are harder. If I have understood one then the next is more difficult and requires you to think and use the idea of the ones you know. I sometimes understand when I saw how to do it the I realised it is same but just that it is not a straight forward question	Knowledge transferability/ application	18
I: How do you normally solve the problem since they are harder and you are to do it on your own?		
L: we can also ask our friends to help us if we are struggling. So most times we still solve the extension activity together as a group when we are on break.	Explanation from peers Mutual support within team	35 8
I: ok.	Preference for teamwork	16

I: what would you not change about your collaborative work in the classroom? L: I will not change working as a group I: can you explain why you would not want to change that? L: I will not want to change working as a group because we learn from each other and somehow we have become friends, we cooperate a lot.	Sharing of knowledge/ ideas Positive perception of peers	8 21
I: how would you describe the method used by your teacher in teaching stoichiometry in relation to your understanding of stoichiometry? L: You mean how she teaches now? I: yes, L: I think I love it.	Enjoyment of lessons	14
I: can you tell me why you love it? L: Because we have opportunity to solve more problems on the topics we are taught. We do not just sit and scared or even shy of asking questions but …erm we talk, we ask questions and enjoy learning at the same time.We brainstorm together to find answers. I don't feel bored (*laugh*s). Then it makes us to study more because the worksheet are full of difficult questions that you have to think deeply and explore options. I: ok.	Problem solving activities Enjoyment of lessons Engaging learning materials Engaging activities promotes regular study Analytical thinking	7 14 4 19 10
I: in one of your journal entries, you drew a diagram (*I showed him the diagram*) L: ok… (*paused and laughed*), it was when I did not like the group and they were annoying. But now we are good.	Positive perception of peers	21
I: you also wrote, "fuji house of commotion", what were you trying to say? L: I didn't really mean it like that…ermm..It was because people were just talking and arguing and it doesn't look like we were in a normal class..so that was why I wrote that but it was later better	Noisy environment	25
I: there is another one where you drew a crocodile with people L: (*laughed*)... that was an alligator. We learn a new trick to remember some the formulas. It is alligator eating people. The formula is alligator chew visitor. It is a over c times v I: ummh, that's lovely	Knowledge retention Engaging class activity	44 43
I: how would you describe your experience with learning stoichiometry with your teacher' new method? L: I think I will say I don't just cram some of the stuff for test and exams again, I have more understanding and try to remember how we solved a question that was similar in the group. My last chemistry test was very good. I will say… errm I think I am more confident in chemistry now, I practice more of the questions and I can tackle many questions because I have seen something related before.	Understanding facilitates confidence Understanding enhances positive attitude	31 39

Those scary topic like all these moles are easier for me now I: that's fantastic I: what do you think about being a scientist or pursuing science career? L: I don't think I would like to be a scientist o. many people who are in the sciences do not find good job after the course and the science study are difficult compared to the pay when you even get job. If it were to be someone in business or administrative course, they would have gotten a good job. Though, I can say some of the science subjects are interesting especially chemistry and even biology. I: can you tell me more why you said some science subject are interesting but you do not want to be in the field? L: what I mean is that ok, I think I do enjoy chemistry class, I mean I enjoy it now, it is something I can imagine, mostly because we've got more times learning and it quite fun. It appeals to me especially the practicals, our group discussions and but I still don't think I am interested in science courses. But I don't see myself going for any science profession. If I go for any science course, I will still change later. I: why would you change later? L: because, .. well I am still thinking about it. I might change my mind later. I: ok. Thank you for your time, do you have any other thing you would like to share with me? L: ok ma'am. Is it possible for us to also have physics class like the chemistry class? I mean theee… group work and having those kind of activities also for physics and even maths? I: hmmnn… I cannot say now, but it is possible. L: ok. Thank you	Perceived difficulty of chemistry No/interest in science/career Enjoyment of lessons Lack of jobs Low pay for scientist Understanding eliminates rote learning Knowledge retention No/interest in science/career Enjoyment of lessons Hands-on experience	14 28 3 5 15 46 5 28 14 20

L44, Female

Interview transcripts	Initial description	Code
I: How do you feel about chemistry? L: I love chemistry. Chemistry is about everything around us. I: could you tell me more about that please? L: chemistry is more practical, it is what we see around us. For example when we do some practical work, we record what we observe not what we crammed it makes me to understand better. It's just fun. I enjoy everything about it. The practicals are very interesting and it's just fun I: can you tell me what you understand by stoichiometry	 Perception of chemistry Hands-on experience Understanding eliminate rote learning Enjoyment of lesson	 26 20 3 14

L: stoichiometry is about calculation of the number of reactants that makes up a product in a balanced chemical reaction. You either calculates moles or mass, it depends on what you are given I: ok. How would you describe stoichiometry to me in a simpler way if I do not understand some of your chemistry terms? L: hmmn… (*pause)*, yes. I can describe it using how we prepare some food I: ok, go ahead please	Understanding of concept	32
L: let's say the product we want is sandwich. So, stoichiometry is knowing the quantities of the ingredients we use to make the sandwich. For example, I want to make sandwich with bread and bacon and tomatoes. I will use 2 slices of bread, 3 bacon and one lettuce. I: ok, go on please	Understanding of concept Knowledge retention	32 5
L: it means 2 slices of bread plus bacon and lettuce equal 1 sandwich. If you want 2 sandwiches it will be 4 slices and 6 bacons. The amount of bread and bacon for the ingredient is the same as the amount the sandwich will have. So you can now use the amount or the quantity to calculate the ratio I: ok, thank you. Could you explain what your experiences were with learning stoichiometry for the past two terms?	Understanding of concept Knowledge retention	32 5
L: yes, I have started to understand that stoichiometry is not that difficult as we always think. When we were taught ermm…..topics like mass and percentage formula all that SS1 I do not understand so many things, I just cram a lot of things just to pass my test and exams. I: can you tell me what has changed?	Perception of chemistry Understanding eliminates rote learning	26 3
L: yes, what I enjoy now is that our teacher some takes things slowly with us helping us to understand better. We do a lot of activities that explains the topic step by step and helps us to understand the topic. That has really helped me I: please tell me more about the activities	Enjoyment of lesson Teacher's support Interactive games/activities Explanation facilitates understanding	14 1 36 2
L: ok… for example I do not really understand the limiting reagent and calculating. Even though we have not learnt it in class but I try to study ahead. When we started it in the class. We did one simple practical with bread slices and all that. We used the balance equation of the food to calculate which ingredient will run out first. I cannot forget the explanation when I talk about stoichiometry because since then I understand that all reactions must be correctly balanced before doing any calculation and knowing how to identify the limiting reagent just became so clear to me. If I have to explain	Engaging learning materials Knowledge retention Enjoyment of lesson Collaborative learning Interactive games/activities Engaging learning materials	4 5 14 6 36 4

limiting reagent I can easily remember the bread and lettuce practical. I: that is good, how would you describe your experience with the team in the stoichiometry class L: my team is so lovely. I always look forward to chemistry class. We work together on the questions in the worksheet but we have our own separately. Truly, I always think all this stoichiometry and all that are so difficult. I think they are quite difficult but we help ourselves and those that knows it teach the other ones we understand a lot of things. We've got to think a lot sometimes because the questions, the work we do and the practicals all that we need you to think deeply because they are tricky. We were allowed to discuss and help one another in the group. It just make chemistry class fun and lively. It's not boring…I do enjoy it.	Analytical thinking Enjoyment of lesson Teamwork facilitates understanding Knowledge retention Engaging learning material	10 14 13 5 4
I: ok. if you had an opportunity, what would you most like to change about your collaborative work or the team in the classroom L: hmmm…. Maybe we need more time to discuss and finish the work. Sometimes we cannot finish up some of the classwork during the class and we are asked to do it later. I: what would you not change? L: what I will not change is the … errm the worksheet let's say.	Insufficient learning time	11
I: can you explain why you would not want to change that? L: I enjoyed our group work and how everyone got to say what they understand and learn more. Sometimes I have to explain and teach the other people in my group and it actually helps me to remember too. The worksheet is very useful because I use it to practice more after the class and it gets registered in my brain. I got 18 out of 20 in my last chemistry test. I: Wow! That's fantastic. I: in one of your journal entries, you drew a balance scale with some boxes on it, do you remember? L: Yes, I do	Knowledge retention Engaging learning materials	5 4
I: can you explain what you were trying to say with the diagram L: I think it was in one of our worksheet when we learn about balancing equation. The reactant and product side must be the same just like the balance scale. I: ok, thank you.	Knowledge retention	5
L: there is another I drew about the experiment we did about balancing equations also. If we do not have enough of the vinegar or baking soda the reaction will not inflate the bag to the maximum, so we have to keep trying	Understanding of concept	32

different quantities until we got the maximum volume in of the bag I: you are right, I saw that also I: in another entry, you said your confidence in chemistry has improved, can you tell me about that too? L: yes, I know that I am more confident to solve many chemistry questions now.	Understanding facilitates confidence	15
I: why do you think so? L: bee..cause…I can solve many questions in stoichiometry now without blinking. Chemistry or let me say stoichiometry is very difficult like people say. Many of stoichiometry questions need maths I know I struggle with maths and but I realised because we work it together in our group over time, they became somehow easy or let say, I know what to do. I would even say I got better in maths, I still do somehow.. .we do it almost every day, and I get used to it and understand it. I don't usually forget.	Engaging activities promotes regular study	19
I: what do you think about being a scientist or pursuing science career? L: scientist are very smart people and very important to the society.	Perception of science	47
I: why do you think scientist are very important? L: hmm… Science is very important for in every aspect of the world. … it's quite interesting especially when you understand and can reason why somethings happens and how it happens. Its's something that I enjoy, I am the only one in science class in my family. I actually want to be a medical doctor, the whole world cannot do without doctors. For example with this corona, the doctors are the one helping and risking their lives. So, doctors as scientist and are helping the world in their own way.	No/Interest in science/career Understanding enhances positive attitude Linking science to everyday life Perception of science	39 46 48 47
I: hmmn, that's good to hear. Thank you for your time, do you have anything you would like to share with me? L: Nothing more. I: ok. Thank you		

L45, Male

Interview transcripts	Initial description	Code
I: How do you feel about chemistry? L: Chemistry is cool. Not so hard …errmm, chemistry is very interesting subject, it is the study of matter, everything around us and how they react. It's just about everything around us	Perception of chemistry	26
I: ok, can you describe what your experiences were with learning chemistry? L: I will say it's not that difficult but it is voluminous. And it can be interesting too especially if it is the aspect	Understanding enhances positive attitude Perception of chemistry	46 26

that I understand very well, I enjoy it and doesn't look so hard for me I: what do you mean by voluminous? L: I mean we have a lot of stuff and many things to learn, it's quite so much I: ok, can you tell me what you understand by stoichiometry		
L: stoichiometry is learning about the quantities of reactant that makes up a product…like knowing the moles or grams of a reactant that forms a product and all that. I: ok. How would you describe stoichiometry simply to a friend of yours who is not in the science class?	Understanding of concept	32
L: errrmmm… (*pause*), well, I will explain to him that stoichiometry is about calculating the amount may be the moles or volume of the reactants or elements that reacted to make up a product. The two sides must be balance before you can calculate correctly. I: ok, what do you mean by the two sides must be balance	Understanding of concept	32
L: the equation must be balance. The reactant side should be equal to the amount of the product formed. Because in a chemical reaction, no element is lost. So the amount of sodium atom on the reactant side should be amount on the product side too. I: ok…how do you feel about stoichiometry topics in chemistry?	Understanding of concept	32
L: stoichiometry involves a lot of calculations. The first thing with stoichiometry is that you must know how to balance the equation and also remember to be able to convert to moles. Stoichiometry is basically maths .You have to be very good at maths to be able to understand it. I; so, what made you feel that way?	Mathematical calculation involved Require mathematical skills	34 45
L: I think.... I get confused with some questions sometimes like empirical and molecular formula. But with the classes we have been having, my teacher gives us step by step instruction on how to solve them and explain better.	Confusing concept Facilitators' explanation	33 29
I: Can you tell me more on how your teacher teaches you? L: I think I will say we are more free in the class, we do a lot of things in the class. We are allowed to talk and ask questions, not boring. we practice the questions together and…he gives us some problems to solve or experiments that we do together as a group. Then each group will choose someone to represent them to explain how you solve the problem. Sometimes he also explains to us if we are stuck in the group or correct us.	Problem solving activities Understanding facilitates confidence Facilitators' explanation Facilitators' support Explanation facilitates understanding	7 15 29 1 2
I: ok, how has that method helped you with understanding stoichiometry?	Engaging learning materials	4

I: we always do some activities or experiment that is related to the topic we are learning. At first it always look like we don't understand what we are doing but our teacher then explains how that what we have done is to be used to understand the topic. It makes us to understand better. Like the alligator chew visitor and mass moles in number helped me to remember what formula to use for some question	Hands-on experience Knowledge retention	20 5
I: how do you use that? L: we draw a triangle and divide it into two horizontally. The upper part we put the a which the amount, the down part the concentration and ….errmm the volume is multiplied. So you will cover the one you want to calculate	Learn new way of doing things Leadership skills Teamwork facilitates understanding	29 22 13
I: ok. Good. how would you describe your experience with the team in the stoichiometry class?		
L: I am the team captain. So I have to coordinate whatever we are doing in the team and make sure we finish our work. And everybody must participate in the group. It's been so interesting. We actually create our own method that we use in solving some questions in stoichiometry questions which made it easier to remember and I found it very easy	Making effort to learn Learn new way of doing things	30 29
I: Can you tell me about the method?		
L: yes, it is Bid unknown and given angle g to m I: I do not understand, what does that mean? L: let me write it and show you ma'am	Learn new way of doing things	29
I: ok. (*wrote on a piece of paper and showed me*) *B ID unknown & Given* Δ *G 2 M* I: how do you use that? L: ok, let me explain what it means. B is Balance the equation, ID means identify unknown and given I: and the triangle G2M? L: triangle means change then given to moles, so change	Teamwork facilitates understanding	13
the given to moles I: oh, I see hmmn.. that's fantastic, do you use that often? L: yes, I remember and just write it down when I am solving any question that is related to it.	Knowledge transferability / application Knowledge retention	18 5
I: ok. if you had an opportunity, what would you most like to change about your collaborative work in the classroom? L: I think there should be more space between the teams. Some teams that are closer to us try to spy on our work. Sometimes they are too noisy and this sometimes distract us.	Noisy environment Distraction	25 24
I: I can see that you wrote about that a lot in your journal too. L: yes, because, because… the noise and distraction disturbs us a lot. The class is very interesting if other	Noisy environment Distraction	25 24

groups can keep their voices down when discussing. Sometimes, when I am trying to think, because some of the questions need you to think deeply, I get distracted by their talking.	Positive perception of peers	21
I: Hmmn… ok. what would you not change?		
L: I think every other thing is fine. My team is very cooperative.	Enjoyment of teamwork Collaborative learning	12 6
I: can you tell me more about that please?	Explanation from peers	35
L: yes, we understand each other, and we try to help each other, if anyone does not know how we got the answer, we explain to him or her. We do not laugh at anyone if they do not know.	Mutual support within team Sharing of knowledge/ ideas	8 9
I: you also wrote in one of your journal entries that you "*look forward to the next lesson… this is a great day*".		
L: yes, I think it is one of the questions in the worksheet that says we should differentiate between a mole and molecules and… I think atoms and we are to give examples to support our answers. There were lots of confusion and argument in the group and we couldn't finish that day so our teacher said we should finish and we would present it in the next lesson.	Insufficient learning time	11
I: did you get it right afterwards?		
L: yes		
I: what do you think about being a scientist or pursuing science career?		
L: I like to be a scientist.		39
I: can you tell me why?	No/Interest in science /career	
L: scientist are doing great jobs, building and construction, manufacturing, everything around the whole world revolves around science.	Perception of science	47 39
I: what career path would you choose?	No/interest in science /career	
L: computer engineering		
I: hmmn, I love that. Thank you for your time, do you have anything you would like to share with me?		
L: Nothing more.		
I: ok. Thank you		

L2, Male

Interview transcripts	Initial description	Code
I: How do you feel about chemistry?		
L: chemistry is not… my favourite.	Perception of chemistry	26
I: could you tell me why?		
L: It deals with a lot of maths and I don't like maths.	Mathematical calculations involved	34
I: do you find it boring or interesting?		
L: it's not boring, just that it involves lots of calculation, I enjoy those part with no calculation.	Require mathematical skills	45
I: can you tell me what you understand by stoichiometry	Mathematical calculations involved	34 31

L: stoichiometry is about calculation. Calculating empirical formula, balancing equation, moles. Limiting reagent all that. A lot of maths. I: what can you use to describe stoichiometry simply, let say you want to describe to some of your friends who are not in the science class? L: arrr... (*silence*) I: ok, could you explain what your experiences were with learning stoichiometry for the past two terms? L: my experience with stoichiometry is that it involves a lot of mathematics and calculations, although some questions are not. But I think I do not like stoichiometry.. I: why don't you like stoichiometry, if I may ask? L: I get confused with a lot of way to answer some of the questions. Sometimes I know what to do but I miss one step and then I will get everything wrong. You need to remember a lot of stuff I: do you feel that way before and also now? L: ye..es. I think before I am always scared of answering any questions on stoichiometry. Balancing of equations is one the things I still get wrong, though I sometimes get it right but for some compounds especially those that are fractions, I still get confused how it is balanced. Sometimes they will say it is an atom , sometimes it is errrmmm… molecule or something I: hmmn, did you ask anyone for help? L: yes, we do it all the time when we are having any chemistry class but just that sometimes I still miss it. There is one game that we played that sometimes helps me to remember I: what game was that? L: I have forgotten the name now but in the game, we have list of equation that you must balance and you have to think fast to know what is not balanced. If one person balanced it they will change the number and you will have to balance the other ones. L: how has that helped you? I: it was initially confusing but I still play the game with my friends when we are less busy and I eventually understood I: ok. for the past two terms, your chemistry lessons has been taught in a different way from what it was before, am I correct? L: yes I: can you tell me what the difference is? L: yes, during chemistry lessons now, we go into our different groups, we do some work in the worksheet sometimes it might be practicals or a kind of activity and	Perceived difficulty of chemistry Mathematical calculations involved Perceived difficulty of chemistry Confusing concepts Perceived difficulty of chemistry Mathematical calculations involved Engaging learning material Interactive games /activities Engaging learning material Interactive games/activities Engaging learning material Interactive games/activities	34 31 33 31 34 4 36 4 36 4 36 4

we have to compare and explain our answers with other groups. Just that it is tiring and makes the class rowdy		
I: how would you describe this method in relation to your feelings or understanding of stoichiometry? L: it's two things. Though I have I learnt some things from the group. But I do not like working with the group, I will prefer to do those on my own. They like to waste a lot of time talking and arguing trying to find the correct answer. It just takes a lot of time. Everybody want to show that they know.	Domineering peers Independent learning	17 23
I: can you tell me some of the things you learnt from your team members? L: things like…, some questions that we solved from the worksheet and because we did it together and I saw how it was done, I understood it.	Problem solving activities Sharing of knowledge/ ideas	7 9
I: ok, if you had an opportunity, what would you most like to change about your collaborative work or the team in the classroom L: I don't, really like the group work, it's better if we have the worksheet but everyone should work on their own or maybe the teacher can allow us to ask anyone we want if we are stuck instead of group work.	Independent learning	23
I: why would you want to change that? L: because … (*paused*) I just see that sometimes we waste a lot of times and some people always think they know better and want to control everybody.	Domineering peers	17
I: ok, what would you not change? L: I will not change the… I think I still like using the worksheet	Engaging learning material	4
I: why would you not want to change that? L: because I keep those worksheet and use it to revise or study and sometimes there are step by step method that helps me to understand better. The activities we are given to practice on our own gives me more questions to practice I: ok, thank you	Problem solving activities Engaging class activity	7 28
I: in one of your journal entries, you wrote "*now it's making sense, let's ride on*". Could you explain what you mean by the statement please?	Understanding enhances positive attitude	46
L: yeah… I was talking about some of the ways we were doing the calculation that I just got to understand that day. I think it was converting moles to grams or so. Some of the questions I always get wrong before was because I get confused with the formula to use for the conversion. I: ok. What do you think helped you to understand? L: we were given many question, so when we are solving it, we asked each person to solve it. I think they were four questions and we were four, so we asked each person to do one each and we will now explain our	Confusing concepts Sharing of knowledge/ideas Collaborative learning Teamwork facilitates understanding Making effort to learn	33 9 6 13 30

answers to others. The other people explained before me so I got how they did it. That was when I knew how to do the calculation. I: did that change how you feel about your team? L: hmmn… yeah a bit.		
I: what do you think about being a scientist or pursuing science career?	No/Interest in science/career	39 47
L: scientist are very great people, but I am not sure. It depends	Perception of science Perceived difficulty of chemistry	31
I: what depends? L: I still think science is more like mathematics, I am not a fan of maths. That is why I prefer biology to physics and chemistry.	Mathematical calculations involved Require mathematical skills	34 45
I: But biology is also science L: yes, I know. What I am saying it that it depends if I later find chemistry and physics easy I might decide on science courses later on. Science exams are not easy, we've got a lot of textbooks to read and many topics. It's just too much for me. I don't want to register a course that I will struggle with. I just want to keep my options open.	Perceived difficulty of chemistry	31
I: hmmn… L: my parents want me in sciences though, because in our family everyone is into science but I don't think science is what I like.	Family influence No/Interest in science/career	41 39
I: But everyone in your family is a scientist? L: yes, but some of them are not working as a scientist, it is always difficult to get job with science except you do courses like medicine, pharmacy like that. My brother who did engineering is working as a banker. Soo… I don't know, I would prefer some other options more creative	Lack of job	44
I: ok. Thank you for your time, do you have anything you would like to share with me? L: none. I: ok. Thank you		

L19, Female

Interview transcripts	Initial description	Code
I: How do you feel about chemistry? L: chemistry is very interesting, I enjoy chemistry classes it is one of my favourite.	Perception of chemistry	26
I: hmmn, could you tell me why? L: Chemistry is fun, chemistry is about everything in the world. It is about our food, clothes, drugs, everything and how they are produced.	Perception of chemistry Linking science to everyday life	26 48
I: why do you say chemistry is your favourite?		48

L: I just enjoy chemistry. Chemistry is a subject you can understand because it is everything around us especially many of the things we study is what we can find examples of around us.	Linking science to everyday life	
I: ok… can… (*interrupts*)		38
L: like when we were taught states of matter and how they changes. This is something that I can understand, water changing into ice, it is what I see every day and that is why I cannot forget it. And even separation of mixtures.	Practical work enhance understanding Knowledge retention	5
I: is that what makes it interesting?		48
L: yes, because I can see how it relates with everything I see in my environment every day. It is what we see everyday	Linking science to everyday life	
I: ok, can you tell me what you understand by stoichiometry		32
L: it is about chemical reaction, the moles and molecular mass of reactants	Understanding of concepts	
I: ok, what can you use to describe stoichiometry simply to some of your friends who are not in the science class?		
L: I will explain to them that stoichiometry is when reactants react together to form the same amount of product.		
I: ok, could you explain what your experiences were with learning stoichiometry for the past two terms?		14
L: it has been very interesting, I know that I am finding some questions very difficult but it is getting better now	Enjoyment of lessons	
I: can you tell me more?		4
L: we spend a lot of time now to practice more and we do not errrm … our teacher takes time to explain what we need to I think I enjoy how we work together to learn from each other. Sometimes it doesn't look like normal class but at the end you will learn something.	Engaging learning materials Making effort to learn Preference for teamwork Facilitators' explanation	30 16 27 25
I: why do you say it is not like a normal class?	Noisy environment	24
L: because people will be talking and some will be disturbing other with their discussion	Distraction	
I: ok.. erm….		
I: how would you describe your experience of the team in the stoichiometry class?		8
L: I like my team. We are so supportive of each other. We help everyone and we cooperate. Everyone has something to do, we have the captain, the speaker, timekeeper and emmm… we became friends and help each other	Mutual support within team Positive perception of peers Engaging class activity	21 28
I: Tell me about the challenges you experienced while dealing with collaborative work in the classroom?		

L: sorry, I don't understand I: I mean you're learning team, tell me about your challenges, things that you think did not go well?		
L: ok, My learning team is ok. Everyone support each other. People that are very good and knows the best method to solve the question teach people that do not understand it. The only problem is that sometimes we do not have time to finish the work during the class and you are to do it on your own, especially the extension activity. If there is anything you don't understand, there would be nobody to explain it to you.	Mutual support within team Explanation from peers Insufficient learning time Preference for teamwork	8 35 11 16
I: how do your friends or members of your teams explain to you that you think is different from that of your teacher?		
L: not really, but you know in the group, we explain to each other gently and break things down the way we understood it ourselves so it is that way that we explain to others not like the teacher will explain it.Just in simple way that others will understand.	Enjoyment of lesson Collaborative learning Making effort to learn Knowledge transferability/application	14 6 30 18
I: ok. if you had an opportunity, what would you like to change about your collaborative work or the team in the classroom L: nothing I: what would you not change? L: I will not change everything I: can you explain why you would not want to change anything?		
L: because the way we work together makes the class very interesting and not boring. Another thing I can say is that it makes it easier to understand things, we are not in haste but like learning and playing. Even now that the school is on lockdown, I use the class worksheet to remind myself of how we solved some of the questions in my group to answer the questions that our teacher sent to us.	Making effort to learn Understanding enhances positives attitude	30 46
I: ok, thank you I: how would you describe the method used by your teacher and the teamwork in relation to your feeling or understanding of stoichiometry?		
L: I love it …. I understand better. I always try to read and study some of the things we did in the last class before our next class. It makes me to think and try to read more so that I can participate in the group discussion. I am somehow more motivated… something like that	Engaging activities promotes regular study Teamwork facilitates understanding	19 13
I: why do you think it is important to participate in the group discussion?		
L: when I participate in the group activities, It helps my understanding of the lesson. Because we just		30

don't write down any answer we must be able to explain how we got our answers. So when we discuss in the group, we think deeply and it has helped me to understand. I usually force myself to understand because our teacher might call anyone in the group to answer any question	Making effort to learn Analytical thinking Facilitators support	10 1
I: ok. I: I would like to read out some part of your journal entries and I would like you to explain some aspect further? L: ok… I: you wrote "*I was able to help my group with the starter work. and I am confident that I can do most of the questions*" I: Why do you think you could help your group with the starter activity?		
L: because …. I have been practicing with the worksheet and since we started using the work sheet we always have the extension activity to do as homework so, I have been studying more and reading ahead so that I can participate more in the group work	Problem solving activities Engaging learning materials Engaging activities promotes regular study Making effort to learn	7 4 19 30
I: that's good to hear. Thanks I: what do you think about being a scientist or pursuing science career?		
L: science is very interesting. I love to be an industrial chemist	Positive perception of science	47
I: hmmn…that's lovely I: why do you choose that career path?		
L: because I love to be in the lab and I like what they do, they manufacture drugs and other chemicals, analyse them and use it to produce many product we use daily.	Positive perception of science No/Interest in science/career Positive perception of science	47 39 47
I: ok. Thank you for your time, do you have anything you would like to share with me?	Linking science to everyday life	48
L: have we come to the end of the interview? I: yes L: awwww…. I: do you have anything you would like to share with me? L: yes, I: ok, I'm all ears L: are we having another interview later? I: I do not think so. Why do you want another interview? L: because you are asking about our schoolwork and what can help us. I just enjoyed our discussion and talking about our schoolwork I: ok, that's good to hear. Thank you for your time and sharing your experience with me		

L31, Female

Interview transcripts	Initial description	Assigned number
I: How do you feel about chemistry? L: I like chemistry. it's a fascinating, it is what I enjoy I: hmmn, can you tell me more about that?	Perception of chemistry	26
L: chemistry is a subject I can relate with. It is the study of matter and its properties. In chemistry we study how different elements or compounds can be changed or react with other compounds to form another product. It is very interesting to me because I can understand or apply it to what I see in the real world around me. It is the study of everything around us and what we do every day.	Linking science to everyday life	48
I: ok, can you tell me what you understand by stoichiometry L: stoichiometry… I cannot give an exact definition… but I know what stoichiometry is I: yes, you can tell me what you know about it	Understanding of concepts	32
L: stoichiometry is calculating the amount of reactant and product in a reaction using a balanced equation. The ratio from the balanced equation is used to calculate the amount of the product and reactant.	Understanding of concepts	32
I: ok, what can you use to describe stoichiometry simply, let say you want to describe what it is to some of your friends who are not in the science class?	Practical work enhance understanding	38
L: (*paused*) ok..errmmm… for example if… ok. If I want to make cookies, the ingredients are the reactant and the cookies is the product. The amount of each of the ingredients I used like the butter, flour, egg to make let's say 20 cookies is the equation. So you need to know	Understanding of concepts	32
the amount of butter, flour to use and how many eggs will make 20 cookies. The mass of all the ingredients should be equal to the mass of the 20 cookies you have made because no mass should be lost. Then the amount of each of the ingredient is their ratio. I: hmmn. Why is there no loss of mass? L: it is the law of conservation of .. mass or no matter	Knowledge retention	5
I: ok. Thanks. How did you come about that example? L: it was one of the group activities we did in the class sometimes ago. We are asked to prepare our favourite sandwich or cookies using different ingredients. Our teacher asked us to state the quantity of the ingredient we used and the quantity of the food it will make and write the chemical formula for the food. I: What food did your team picked? L: we picked cookies.	Engaging class activity	28

I: ok, could you explain what your experiences were with learning stoichiometry for the past two terms? L: I just so love it. I have been enjoying it so well.	Enjoyment of lesson	14
I: can you tell me why you feel that way? L: the chemistry class is so lively and everyone participates, and I think if we continue like this some of the topics that we think are very difficult to understand will be easier. We got to understand a lot better	Teamwork facilitates understanding	13
I: yes,… you can… (*interrupts*)	Perceived difficulty of chemistry	31
L: initially I think stoichiometry and all the other topics on calculating moles and molecules are a bit difficult. And I think they are somewhat difficult truly. But the groups and we've got a lot of worksheet and activities to do, it explains each of the topic sometimes we have practicals it's… everything just changed.	Teamwork facilitates understanding Understanding facilitates confidence	13 15
My sister that just started learning about balancing equation in her class and I taught her using one of our class worksheet… where we did lots of balancing of equation	Understanding facilitates confidence	
I: How did it go? L: she loved it and she said it made things simpler for her. She even went ahead to teach her friend. She is always asking if I have any worksheet related to any topic they learn in her class.	Analytical thinking Making effort to learn Enjoyment of teamwork	15 10 30
I: hmmn…that's good. Seems you became more confident with teaching your sister	Mutual support within team	12
L: yes, I think so. I think the more I teach her or even when I try to teach my friends the more I understand something that I overlooked before I don't want to sound overconfident but I think there is no question in stoichiometry that I will not at least answer more than half of it successfully now. I became curious and what to understand, not just to know the answers	Leadership skills Enjoyment of lesson	8 22 14
I: how would you describe your experience of the team in the stoichiometry class? L: I enjoyed our teamwork. Everyone participates and we try to explain or teach other people that do not understand what we are doing. We asked each other questions and we organise ourselves to plan how we want to do our work. Everyone is just free.	Positive perception of peers	21
I: Tell me about the challenges you experienced while dealing with collaborative work in the classroom? L: I don't think there is any challenge. Everything is just fine. I am actually missing my group now.		
I: aww… it's ok. if you had an opportunity, what would you like to change about your collaborative work or the team in the classroom L: I think maybe we should have same group with other subjects like maths and physics too	Preference for teamwork Engaging class activity	16 28
I: why do you want to have same team in your physics class?	Enjoyment of lesson	

L: because…. I actually enjoyed our working together, the class is not boring… and…. there are so many things we just discuss together and understand immediately but if the teacher is teaching you can't just stop her and ask questions anyhow.	Teamwork facilitates understanding	14 13
I: ok, what would you not change?		
L: I think I will not change the group, I will not change anything	Engaging activities promotes regular study	
I: can you explain why you would not want to change anything?		
L: I think everything is fine, we cooperate, we always want to work harder. We all challenge ourselves to read more so that we don't let the group down and everyone is ready to participate.		19
I: how would you describe this method used by your teacher and the teamwork in relation to your feeling or understanding of stoichiometry?	Making effort to learn Enjoyment of teamwork	
L: yes, I think it better, it … errrmm…it kind of motivates me to study more , the class became very interesting . or worksheet activity on its own keeps us busy and concentrating in the class... even if I forget some things, since I kept all my worksheets, I'll go over it again I remember. Our teacher takes her time to explain what we are doing and correct our answers on the worksheet.	Engaging activities promotes regular study Facilitators' support Engaging learning materials	30 12 19 1 4
I: ok.		
I: what do you think about being a scientist or pursuing science career?	No/Interest in science/career	
L: maybe		
I: why is it maybe?	Scientists are not rich	
L: ah!.. They don't have money, they are not rich. I wasn't thinking of being in science line because I always think people in science don't pass well in the final exams because they struggle. And most people in science also don't get a good job afterward. My brother and parents encouraged me that once you do science you can easily crossed to other line. That's what my sister did. She studied Biochemistry but now she works as HR. So, I like accountancy. .. it would be so rare for you to see any accountant without a job.	Lack of job Family influence Lack of job	39 42 44 41 44
I: hmmn…you said maybe, has anything changed now?	Perception of science No/Interest in science/career	
I: not really. I enjoy some of the science subject like chemistry and biology but I am still in love with accounting, I might change my mind anyway.	Scientists are not rich Low pay for scientist	47 39 42
I: what could make you change your mind?	Perception of science	43
L: science profession can be soooo boring though I know that science is very important and needed in our environment...ermm.. the medical doctors, engineers all of them they eventually go into business or banking because their job is so boring or they don't get good pay.	Enjoyment of lesson	47

The same way some science classes are boring and not lively. I: what would make the class lively? L: the group work, doing so many interesting activities, not just sitting down. Something like what we are doing now in chemistry class. We are always doing one activity or games or some classwork during chemistry class to break the topic down for us to understand better. I: ok. Thank you for your time, do you have anything you would like to share with me? L: nothing I: ok. Thank you for sharing your experience with me L: you're welcome ma'am	Engaging learning materials Preference for teamwork Interactive games/ activities	14 4 16 36

Appendix M: Extract from some Learners' Journal Entries: January to March

Participants	January 20th – February 14th		February 17th – March 26th	
L1	Some of the people in my group are not nice at all. We learn a lot of things in a different way that I understand anyway but I think it will be better if we can choose our groups.	We did some interesting experiment with oxygen and some activities that I enjoyed. We started the class by doing starter activities and then we compared our result with other groups in the class. We figured out all the answers but I forgot how we did some of the questions when I was presenting our result. I will not let my group down again	I am loving chemistry. We were busy with lots of worksheet activities, many questions and it was fun. I do not mind if the chemistry period is increased.	I finished the extension activities on my own without my group. I am excited. I think I am more confident doing all the activities on my own now
L40	Fuji's house of commotion. (with a diagram of people pointing fingers)	We spent so much time talking and arguing about the questions. Some people think they know more. ITKs at work. We did practicals with baking soda and vinegar. It was an interesting lesson. The baking soda experiment makes it easier to understand how to calculate mass and balance the equation	Alligator chew visitor (With a diagram showing alligator with people) Mass moles in number.	
L47	(Balance scale diagram) We had an interesting chemistry lesson today. Everyone	We did some starter activities that helped me to understand mole and molar volumes.	I represented my group and solve the question written on the board and I got it. I think my confidence in	I enjoyed our class today but some of the questions are getting tough. We did some work on mass

	wanted to talk and explain what they think We Finished all the extension activity and got all of them correctly. Our teacher was impressed	Our teacher was quite patient explained to us and was going round each group to see how we are learning. It was a lovely lesson though very tough and tiring.	chemistry has improved. I finished the extension activities on my own within 5 minutes	and volume relationship and it was quite interesting. Through the practical we did, I could figure out how to find the concentration, the mass etc. My knowledge of balancing equation has really helped me also.
L5	We are shared into group. We solved some questions together. The activities are broken into different stages. I was made the group captain	We made up the formula of solving questions on mole mass and molar volume Everyone participated so that we can finish on time. I look forward to the next lesson. This is a great day *B ID unknown & Given* *∆ G 2 M*	The class was very lively. We had a lot of argument in our group but we later agreed on the same thing. It helped me to think about the questions.	I am really tired after the end of the class because we did some experiments, completed the starter activities, a very long one. But the class is very lively. We distributed the work and helped ourselves
L26	There were lots of distractions as people were just talking and making so much noise. There were so much work and questions to do. They get harder and they were just so much.	The change one activity helped me to understand the how to balance equation the more. It was interesting game but you have to be a fast thinker and know the trick	I enjoyed practicing with the question in the worksheet. Particularly the starter activities, do it yourself and extension activities. It makes me to understand step by step than just cramming it	We had some time in the lab. We played the flashcard games before the titration. it was easy for me to calculate the mole ration and get the calculations for the unknown NAOH. I like todays activity. I promised myself to read more so as to be able to answer all the questions easily

L3	The class is fun and lively but is difficult because we have to think more and come up with the ideas ourselves		We had some practical experiment using the questions in our worksheet. We were to answer the question in the worksheet using the result of our practical work. The worksheet was very useful to understand what we are learning and explain step by step than just coping notes and cramming it	
L43	Everyone in my group wanted to have a say and it was not just organised. We tried to do some work which we could barely finish because of lots of argument. I prefer to do the starter activity and extension activity myself.	We did a practical experiment with baking soda and vinegar. It was interesting as we keep increasing the amount of baking soda until our bag is filled with gas.The bag got bigger and busted We use the practical for calculation of the sodium acetate and water. We got the ratio from the balanced equation of the reaction	We had fun learning. I was able to help my group with the starter work and I am confident that I can do most of the questions	The class was very helpful because I didn't know how to solve many questions on quantitative analysis. I realised that it is very important and other topics we have learnt now makes it easier to calculate molarity and solve other questions after the titration
L31	We were given questions and some work that makes us to think more carefully about our answers and to be able to defend our answers. I	We did an experiment with sodium carbonate and acetic acid. It actually gives better understanding of calculating mass and moles of reactant and	The extended activity in the worksheet was a big challenge to us today. We have to think and reason deeply. Our teacher came to explain some of the bit to	I shared my ideas with others and encouraged others to share their ideas too. It is so lovely to see that everyone is ready to understand what we are doing

	enjoyed every bit of what we did because it made me to think and participate more	product. We calculated the amount of CO2 and sodium acetate that is produced to increase the volume of the bag to the correct size.	us. We later got it but we couldn't finish on time	
L52	We were introduced into a different way of learning. We struggled a little bit because we do not understand what we are asked to do. Our teacher helped us by explaining what the tables are and how to complete the work. I enjoyed how we all discussed our work together	We used the starter activity to understand what limiting reagent and excess reactants are. The making of the sandwich and the ingredient quantities is like finding the number of excess reactants and limiting reactant in a reaction	I put all my effort in the doing the activities. This helped me to understand and I got the questions we did personally correct.	My group finished the activity first today because everyone was serious and committed to doing all the activities.
L14		We were given questions and the extended activity makes us to think more carefully about our answers and to be able to defend our answers	I learn a lot more difficult things from the worksheet and it was really fun because it challenge us the more and makes me to want to learn more. The class is l	
L8	The class was boring and so noisy. The worksheet is too much and the time we had was not enough to finish up.	We discussed how to do the starter activity and group work and we helped ourselves to complete our group work. It is easier and simpler because we explain to ourselves. We	I love the games we played with the flashcards, identifying the unknown and given substance and picking the correct mole ratio. It helps with understanding	We played a game with marshmallows and toothpicks to build molecules of different atom and how to balance them on each side. It was a tough task to know how to

		worked together to on the worksheet and teach everyone our own ideas so that everyone will understand.	the steps in solving stoichiometry problems	balance the equation on the product side.
L6	Class was fun today. Everyone in the group participated in the group work and we understood what we are learning	We learnt the tips to calculate moles and molar mass. We must always convert to moles and how to convert moles to mass	We were busy in the laboratory today, lots of experiment on the activities in the worksheet. So straight forward experiment and not copying other people. Perfect! It is easy to understand because I just need to remember those things we did.	I solved most of the questions in the extension activity on my own.
L25	I learn a lot more difficult things from the worksheet and it was really fun because it challenge us the more and makes me to want to learn more	We understood each other and helped ourselves to understand the group work. We learn from each other and we are all happy		We have been busy with titration and volumetric experiment today. The flashcard game was useful in calculating in different ways and I was able to have a go at some challenges on the worksheet.

Appendix N: Analytical Memo A: SLQ

The analytical memo drawn from the open-ended section of the SLQ. The excerpt are examples of statements that relates to the emerged themes.

Theme: Teacher/ Instructional characteristics

Description	Excerpts	Sources
Teacher-centered teaching Lack of appropriate teaching strategy	Because I don't understand many of these topics. I just copy what is written on the blackboard and the explanation from the teacher….. I do not understand them	L34
	These topics are difficult to understand because the class is so boring, we just listen and copy notes or questions written on the board and I don't understand how it is done.	L15
	Because we just listen to what I don't know, copy notes and try to memorize it for exams, I don't like stoichiometry at all	L20
Fewer problem-solving exercises in the classrooms	I find it difficult because I do not understand what some of the topics mean or what type of question it is talking about, because we were taught the theory, but was not given question in the class. I hate it because we only see these hard questions in the exams. Most of the time I don't know what the question is asking me to do. It is so difficult	L27
	These topics are difficult for me because when we are taught we just copied some example and we do not understand how it is done. We just try to cram it for our test and exams.	L14
	I think it is difficult because we do not do enough practice questions	L42
Boring stoichiometry lessons Loads of learning outcomes	The class is always so boring. Mole ratio, chemical equation learning them together is so boring and does not make much sense to me	L44
	"Many of the topics are difficult because we learn many of the topics within a period and it is not enough to learn them very well. It always a quick explanation and that is all".	L9
	First, stoichiometry topics are difficult because we learn so many topics in one class and I don't know how they are	L51

expected in a single lesson	related. Second, it is because stoichiometry topic are boring and we are taught the definition in the class but we will be asked to solve questions in the exam	

Theme: **Nature of the subject (stoichiometry)**

Description	Excerpts	Sources
Confusing meanings of stoichiometry concepts Abstract nature of stoichiometry topics	This topics are difficult because they are not what you can experiment or see to understand how it is like other topics such as change of matter or organic chemistry where you can see what happens	L41
	Empirical formula, molecular formula, molecular mass, moles and gases… they are confusing and I do not see any difference between them. They are difficult	L6
	I get confused with some questions sometimes like empirical and molecular formula	L11
Too many calculations/mathematics involved	These topics are boring and are just pure mathematics, full of equations and many things	L2
	They are difficult because they are more like maths which is also hard. You have to be very good at maths before you will understand them	L5
	There are a lot of calculations involved. If you don't know how to calculate and convert very well or even when to convert, you cannot understand stoichiometry	L40
Too many concepts with no meaningful connections between them	They are difficult to me because they do not make so much sense. Why can't we just learn things that we know we can make use of in the future at work. Not just calculating stuff that is not useful later	L47
	These topics are difficult for me because I do not understand most of them and why we are doing it. It	L19

	is not like other topics that we understand its usefulness in the whole of chemistry	

Theme: Learners' attributes

Description	Excerpts	Sources
The pre-conceived notion of difficulty of science/stoichiometry	Because it needs high level of smartness to be able to understand this topics. All topics are difficult and a lot of calculations and formula	L30
	I find all of them difficult because I know that science topic are difficult and it is only for the intelligent people	L50
Lack of interest in stoichiometry concepts Preference for rote learning	I do not know why but I know they are just difficult and I do not like them	L49
	They are all difficult and I hate them. I just do cram pour and forget for the exams, I hate the topics	L23
	I don't like stoichiometry!!!	L17
Interest in science/science careers Coaching from family members and friends	They are easy because I try to study and I ask my sister to help me with the difficult part that I do not understand	L16
	These topics are easy for me because I started learning them before we were taught in the class so that it will be easy for me to understand	L45
	They are easy because I study hard to understand them. I know they are important topics in chemistry	L7
	"I think these topics are easy for me because I just try to learn them using many textbooks and other ways. This is because I need to understand it and use it in other chemistry topics	L52

Analytical memo B: interview transcripts and journal entries

The analytical memo drawn from both interviews and journal entries. The excerpt are examples of statements that relates to the emerged themes.

Theme: Facilitators'/ learning environment features

Preliminary themes	Excerpts	Sources
Collaborative learning	Everyone support each other. People that are very good and knows the best method to solve the questions teach people that do not understand	L19
	I enjoyed how we all discussed our work together	L52, J
	When we work together even if you are wrong, someone will correct you and you will know why you got it wrong. We share our ideas and different method to do some questions. And at the end you will learn even a better way of solving the question than what you know before	L15
	we learn from each other and somehow we have become friends, we cooperate a lot	L40
Teacher support	she takes her time to explain more than before; when she just ask the whole class if we understand but nobody will say they don't. I will say she is more interested that we understand now	L15
	What I enjoy now is that our teacher some takes things slowly with us helping us to understand better	L44
	But with the classes we have been having, my teacher gives us step by step instruction on how to solve them and explain better.	L45
Peer tutoring	We have been doing a lot of work in group, we discuss our ideas together, we try to listen to other people's thought too and learn from that to complete our worksheet. I think I enjoy it…if anyone knows the answer, he will explain to everybody	L40

	the team is good… we teach each other so that we can understand how we want to complete the work we are given.	L15
	but you know in the group, we explain to each other gently and break things down the way we understood it ourselves so it is that way that we explain to others not like the teacher will explain it	L19
Nature of learning environment	Because the way we work together makes the class very interesting and not boring. Another thing I can say is that it makes it easier to understand things. We are not in haste but like learning and playing	L19
	Class was fun today. Everyone in the group participated in the group work and we understood what we are learning	L6, J
	the class is fun and lively but is difficult because we have to think more and come up with the ideas ourselves	L3, J

Theme: Instructional characteristics

Preliminary themes	Excerpts	Sources
Engaging learning material	we are more free in the class, we do a lot of things, we are allowed to talk and ask questions, not boring	L45
	the class became very interesting, our worksheet activity on its own keeps us busy and concentrating in the class	L31
	we do not just sit and scared or even shy of asking questions but… we talk, ask questions and enjoy learning at the same time… I don't feel bored	L40
	I learn a lot more difficult things from the worksheet and it was really fun because it challenge us the more and makes me to want to learn more. The class is lit.	L14, J
	I learn a lot more difficult things from the worksheet and it was really fun because it challenge us the more and makes me to want to learn more	L25, J

Hands-on experience	for example, I do not really understand the limiting reagent and calculating it… when we started it in class, we did one simple practical with bread slices and all that… how to identify the limiting reagent became so clear to me. If I have to explain limiting reagent I can easily remember the bread and lettuce practical	L44
	We had some practical experiment using the questions in our worksheet. We were to answer the question in the worksheet using the result of our practical work. The worksheet was very useful to understand what we are learning and explain each bit step by step than just cramming stuff	L3, J
	Even during the practical class, we use the worksheet, so it makes one to understand why we are doing the practicals.	L15
	For example when we do some practical work, we record what we observe not what we crammed it makes me to understand better. It's just fun. I enjoy everything about it. The practicals are very interesting and it's just fun	L44
	But the groups and we've got a lot of worksheet and activities to do, it explains each of the topic sometimes we have practicals it's… everything just changed.	L31

Theme: Learners' perception of science

Preliminary themes	Excerpts	Sources
	it is always difficult to get job with science except you do courses like medicine, pharmacy like that… my brother who did engineering is working as a banker. So…, I don't know	L2
	I don't want a course I will struggle with	L2
	science profession can be soooo boring though I know that science is very important and needed in our	L31

Perception of science/careers	environment...ermm.. the medical doctors, engineers all of them they eventually go into business or banking because their job is so boring or they don't get good pay. The same way some science classes are boring and not lively	
	I don't think I would like to be a scientist. Many people who are in the sciences do not find good job after their study and science courses are difficult compared to the pay when you even get a job…Though I can say some science subjects are interesting especially chemistry and even biology	L40
	Scientist don't have money, they are not rich. I wasn't thinking of anything science line because I always think people in science don't pass well in their exams, they struggle…most people in science also don't get a good job afterward	L31
Perceived difficulty of science	I think my confidence in chemistry has improved. I finished the extension activities on my own within 5 minutes	L25, J
	stoichiometry is basically maths	L45
	I have started to understand that stoichiometry is not that difficult as we think, when we were taught topics like mass and percentage formula in SS1 I do not understand so many things. I just cram a lot of things just to pass my test and exams	L44
	and it can be interesting too if it is the aspect that I understand very well. I enjoy it and doesn't look so hard for me	L45
	Science exams are not easy, we've got a lot of textbooks to read and many topics. It's just too much for me	L2
	Chemistry or let me say stoichiometry is very difficult like people say. Many of stoichiometry questions need maths, I know I struggle with maths, but I realised because we work it together in our group over time they became	L44

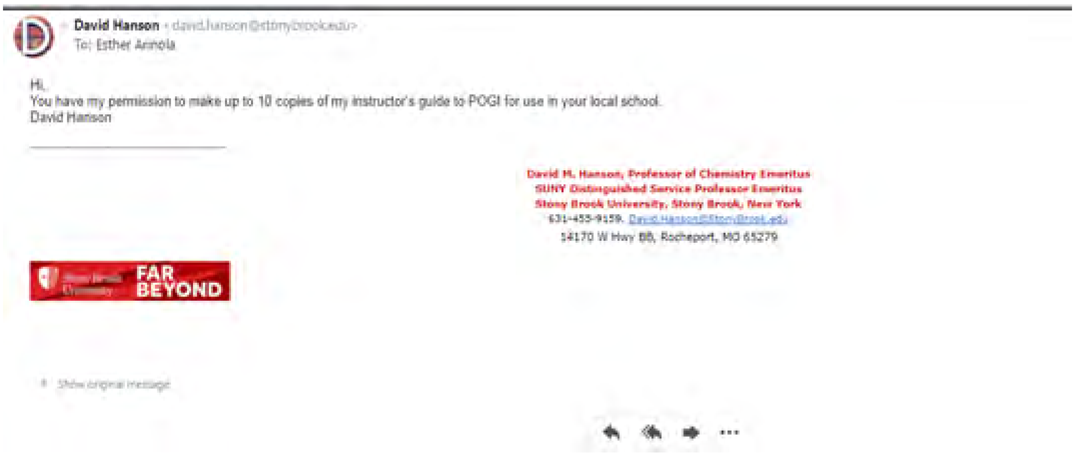
	somehow easy or let say I know what to do, I would even say I got better in maths	

Theme: **Learners' comprehension/mastery of concepts**

Preliminary themes	Excerpts	Sources
Comprehension or mastery or concepts	I don't just cram some of the stuff for test and exams again, I have more understanding and try to remember how we solved a question…, my last chemistry test was very good,… I think I am more confident in chemistry now	L40
	The class was very helpful because I didn't know how to solve many questions on quantitative analysis. I realised that it is very important and other topics we have learnt now makes it easier to calculate molarity and solve other questions after the titration	L43, J
	it's quite interesting especially when you understand and can reason why somethings happens and how it happens. It's something that I enjoy	L44
	I represented my group and solved the question written on the board, and I got it. I think my confidence in chemistry has improved. I finished the extension activities on my own within 5 minutes	L47, J
	I would say chemistry is interesting, some topics are boring and difficult but I think…when you understand you will be able to explain it without cramming and you will like it more	L15
	I always look forward to chemistry class. We work together on the questions in the worksheet but we have our own separately. Truly, I always think all these stoichiometry and all that … were so difficult. I think they are. But we help ourselves and those that knows it teach the other ones we understand a lot of things. .. It	L44

	just makes chemistry class fun and lively. It’s not boring I enjoy it	

Appendix O: Permission Email for Copies of the POGIL Handbook


David Hanson <david.hanson@stonybrook.edu>
To: Esther Arinola

Hi,
You have my permission to make up to 10 copies of my instructor's guide to POGI for use in your local school.
David Hanson

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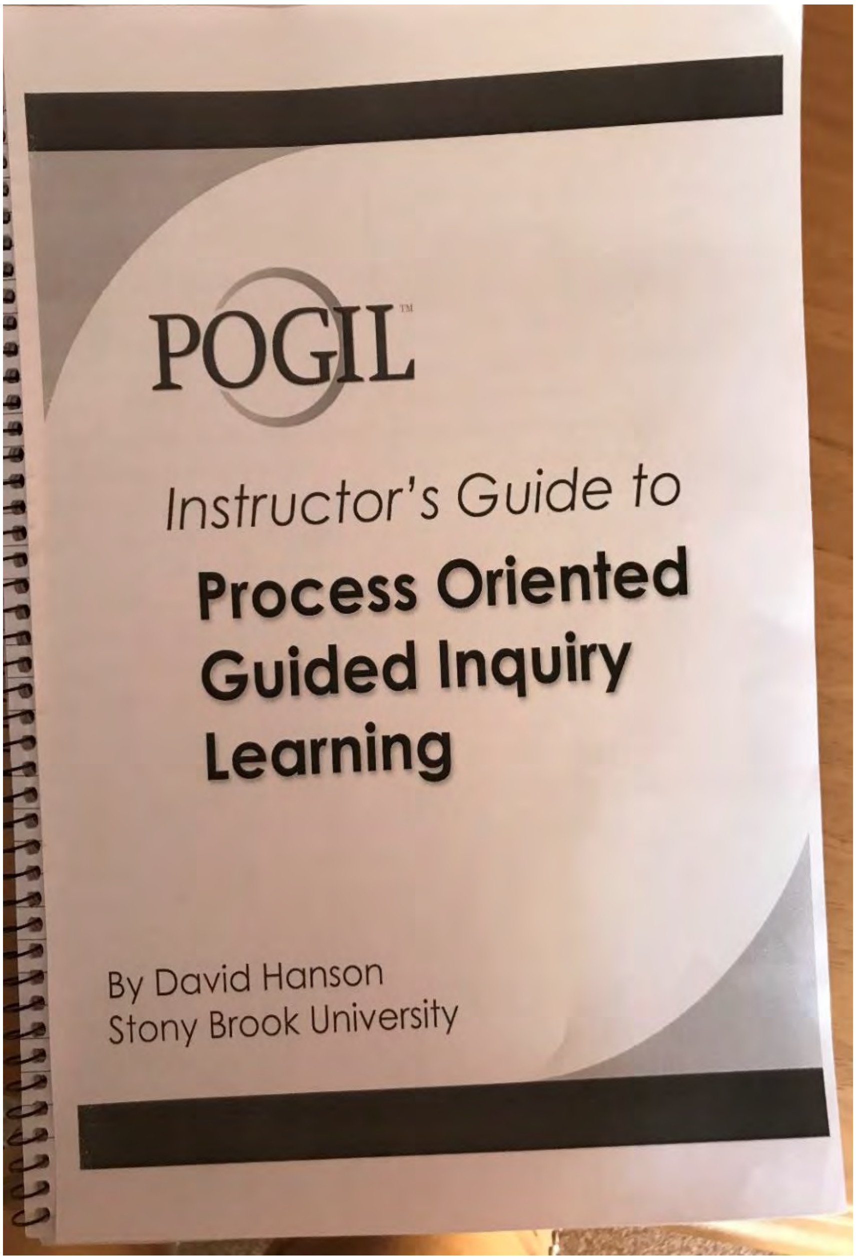

POGIL™
Instructor's Guide to
Process Oriented
Guided Inquiry
Learning
By David Hanson
Stony Brook University

Appendix P: Sample POGIL Learning Materials

Worksheet A Mole ratio

Starter activity

- I made a bacon and lettuce sandwich. I used 2 slices of bread, 3 bacons and 2 lettuce to make 1 sandwich. The total mass of all the ingredients is 240g

1. What is the mass of the sandwich? Hint: principle of conservation of mass
   a. Explain your answer
2. Can you write the food equation for my sandwich? Give each ingredient a chemical symbol
3. From the chemical symbols you have given the ingredients, what will be the chemical formula of the sandwich?
4. Write the chemical equation for making the sandwich
   a. What is the ratio of the bread, bacon and lettuce?
      i. What tells you the ratio of each of the ingredients?

- **Stoichiometric ratios are also useful in problems involving the mass of a reactant or product.**

5. If I put different amount of bacon and lettuce in the sandwich, would the sandwich have a different chemical formula or remain the same? Explain your answer

Try this on your own. You can ask for your team member's help if need be.

1. Coefficients are ....
2. Avogadro's No is ....
3. One mole of a substance is ....
4. Balance these chemical equations: $NaI + Br_2 \rightarrow NaBr + I_2$
   $H_2SO4 + NaOH \rightarrow Na_2SO4 + H2O$

Extension activity: Can you balance this equation? $Fe_2O_{3(s)} + Al_{(s)} \rightarrow Fe_{(l)} + Al_2O_{3(s)}$

$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$

The coefficient for the balanced equation tells us that 1 mole of Fe_2O3 will react with 2 moles of Al to yield two moles of Fe and 1 mole of Al_2O3.

If the mass of Fe_2O_3 is 10.8g, we can calculate amount of moles of unknown (Al) needed to fully react with Mass (g) of given (Fe_2O_3) using the ratio of their coefficients:

Ratio of coeff 2 mole Al / 1 mol Fe_2O_3

We need to.

1. Convert the mass Fe_2O3 to the corresponding number of moles using its molar mass. (check the periodic table)
2. Obtain the number of moles of unknown (Al) from the number of moles of given (Fe_2O3) using the mole ratio (the ratio of their coefficients from the balanced equation).

Mass of given → moles of given → moles of unknown

Worksheet B - Mass-volume relationship

Starter: Can you calculate the molar mass of each of the following. Show your workings!

1. water H_2O
2. Calcium chloride $CaCl_2$
3. Potassium chlorate $KClO_3$
4. Lead (II) nitrate $Pb(NO_3)_2$

Let's continue with the Fe_2O_3 example:

Mass of given → moles of given → moles of unknown

If the mass of Fe_2O_3 is 10.8g, calculate the amount of moles of Al needed to fully react with Fe_2O_3.

$10.8 g Fe_2O_3 \times \frac{1 mol Fe_2O_3}{159.70 g Fe_2O_3} = 6.7 \times 10^{-2} mol Fe_2O_3 \times \frac{2 mol Al}{1 mol Fe_2O_3} = 1.35 \times 10^{-1} mol Al$

Fe = 111.7 × 2, O 16 × 3 = 48, 159.7

We can convert the moles of Al from above to mass in grams. What is your answer?

Converting amounts of substances to moles and vice versa is the key to all stoichiometry problems, whether the amounts are given in units of mass (grams or kilograms), or volume (liters or gallons).

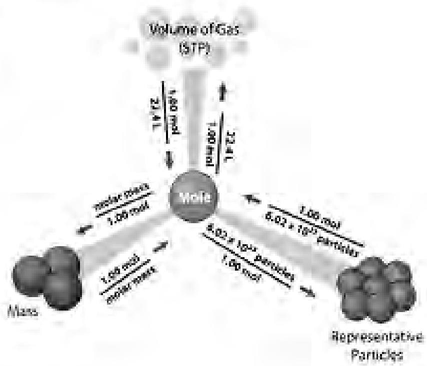
Lets' try this:

How many litres of ammonia will be produced from 10g of hydrogen? The equation of the reaction is

$H_2 + N_2 \rightarrow NH_3$ (Check the equation, balance or not?)

$3H_2 + N_2 \rightarrow 2NH_3$

*Given = 10g H_2 *Unknown = litres of NH_3



Strategy

1. Convert mass given of H_2 to moles of H_2

2. Compare moles of H_2 to moles of NH_3 using the mole ratio or coefficient from the balanced equation (**What if the equation was not balanced at this point?**)

3. Convert moles of NH_3 to litres. One mole of gas occupies 22.4dm3 at STP.

$10 g H_2 \times \frac{1 mol H_2}{2.02 g H_2} \times \frac{2 mol NH_3}{3 mol H_2} \times \frac{22.4 \text{ Litres } NH_3}{1 mol NH_3}$

73.9 L NH_3

Can you try these with your friends ?

True or False

T or F One mole of HCl has a molar mass of 6.02×10^{23} g/mole

T or F The molar mass of a substance is needed to convert from moles to grams.

T or F Two moles of O_2 have a mass of 32.0 grams

T or F The mole is the SI unit for number of particles in a substance.