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Exploring how process oriented guided inquiry learning elicits learners' reasoning about stoichiometry

by

Charles Mamombe

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in the

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UNIVERSITY OF PRETORIA

Supervisor: Dr. K.C. Mathabathe

Co-supervisor: Prof. E. Gaigher

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Declaration

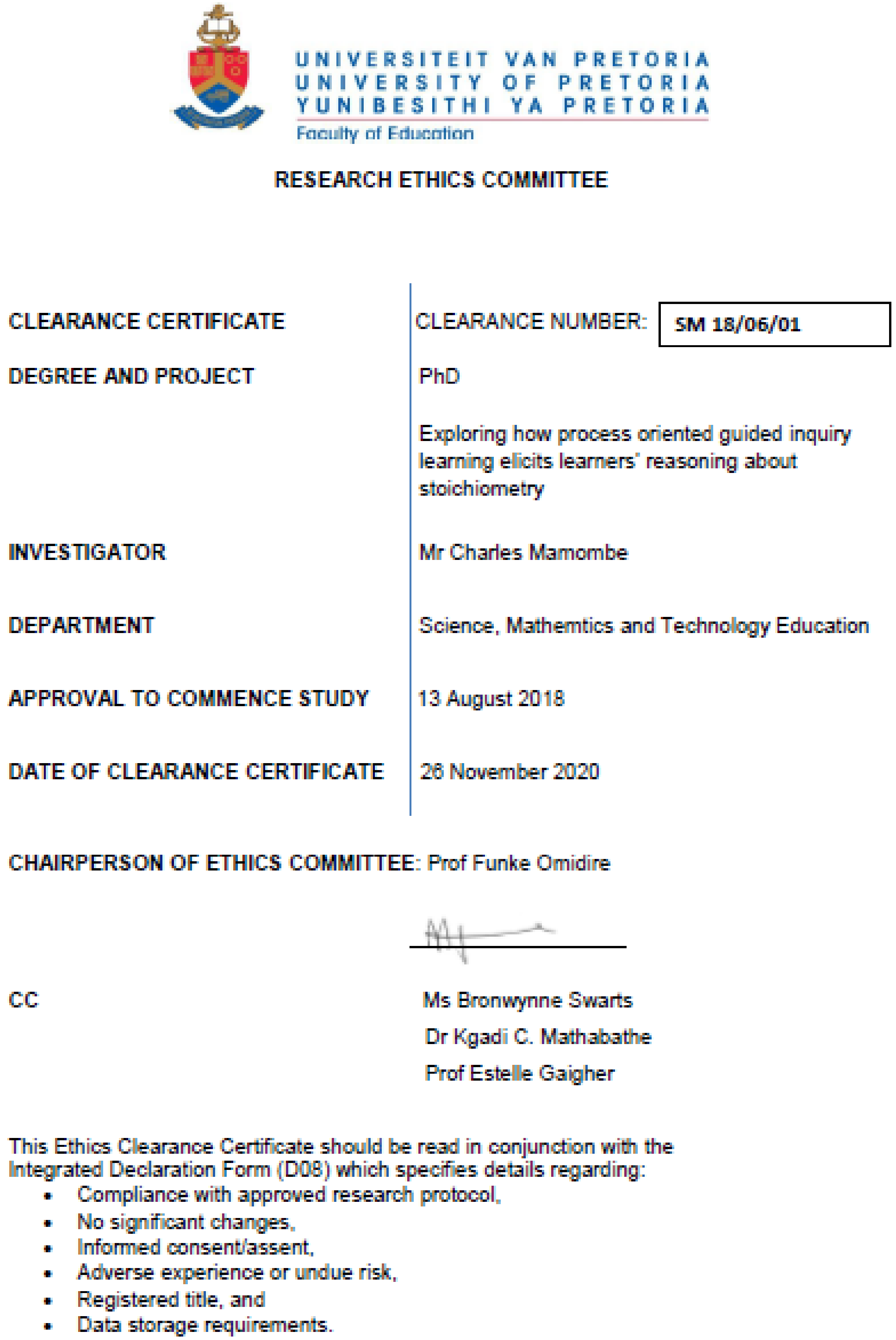
I declare that the thesis, which I hereby submit for the degree Philosophiae Doctor in science, mathematics, and technology education at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Student: Charles Mamombe

Signature

26 February 2021

Ethical clearance



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DEGREE AND PROJECT	PhD Exploring how process oriented guided inquiry learning elicits learners' reasoning about stoichiometry
INVESTIGATOR	Mr Charles Mamombe
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- Compliance with approved research protocol,
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- Informed consent/assent,
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- Data storage requirements.

Dedication

I dedicate this research to all teachers, lecturers, and researchers in general, who thrive to seek effective teaching methods which lead to meaningful learning I dedicate this work to organizations who sponsor research which aim to provide improvement of understanding of learners. Most importantly I dedicate this work to the parents who gave consent for their children to participate in the current study, and to the teachers and learners who took part in this study.

Acknowledgements

I acknowledge the financial support from the National Research Foundation (NRF), which enabled the study to materialize. Studying, especially where travelling is involved, demands a lot of money. I sincerely thank the NRF for considering my study worthwhile for financing. I got encouragement from that support.

I would like to acknowledge the principals, the teachers, and the learners of the two schools who participated in this study. I also acknowledge the parents of the grade 11 learners who participated in this study. Without them, I would not have made it.

I also express my gratitude to my supervisors, Dr. K.C. Mathabathe and Prof. E. Gaigher for supporting me throughout the study. Their support and constructive criticism motivated me to produce this thesis.

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Above all, I thank the Lord God Almighty for the grace and strength He gave me to do my studies. I would not have managed to do anything if God's Grace was not upon me.

Abstract

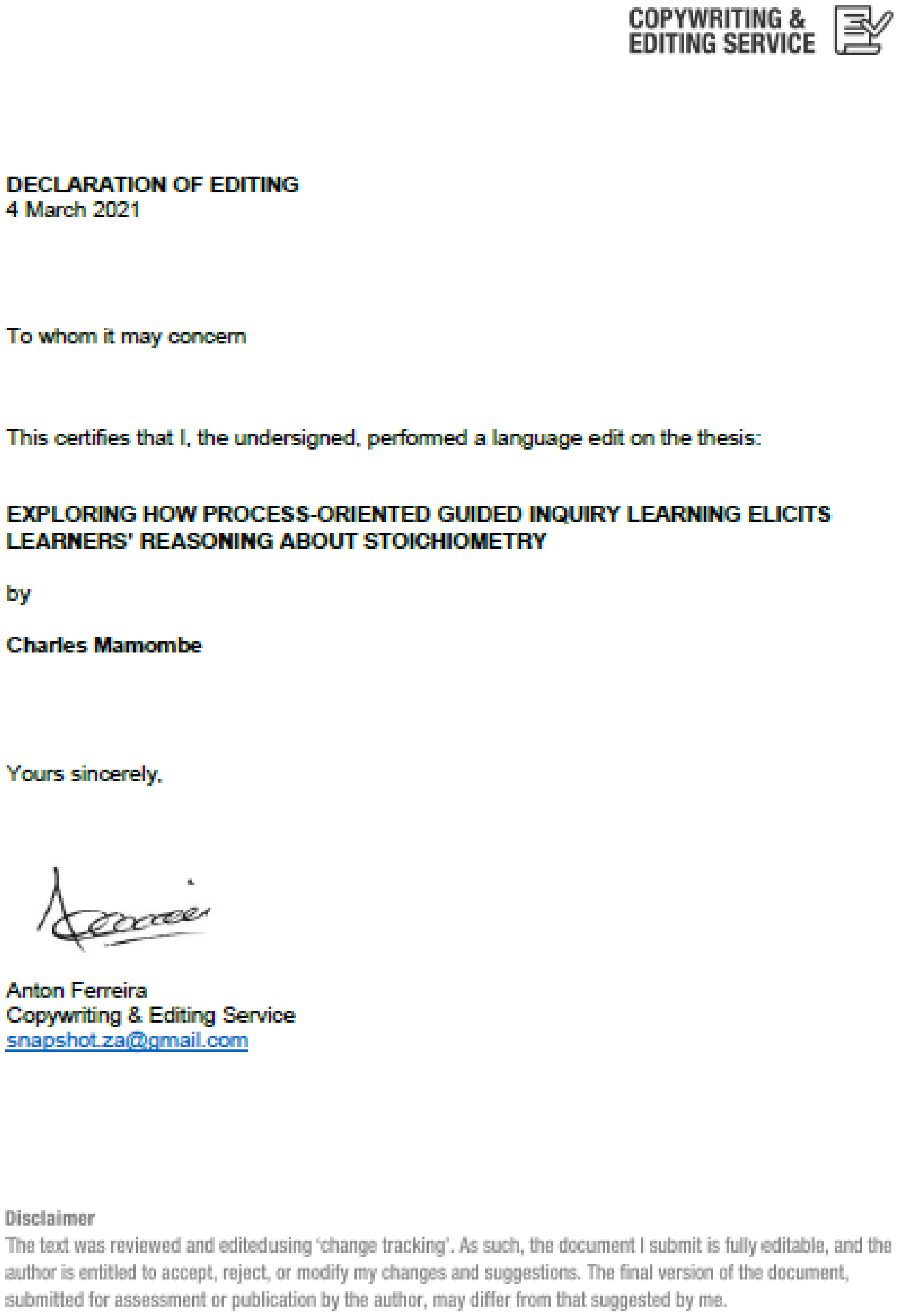
This study explored how Process-Oriented Guided Inquiry Learning (POGIL) elicits learners' reasoning about stoichiometry. The study further explored the perceptions of both teachers and learners over the use of POGIL in the field of stoichiometry. A qualitative case study was carried out at two conveniently and purposely sampled township schools in Pretoria, South Africa. For this purpose, two 11th grade physical sciences classes (N=48) and their respective teachers who were previously trained to teach using POGIL, gave consent to participate in the study. Data were collected using pre-intervention test, post-intervention test and lesson observations, as well as focus group interviews for learners and individual interviews for teachers. All data were coded and analysed with the aid of ATLAS.ti software for qualitative data analysis.

The pre-intervention test indicated that the learners lacked reasoning in solving stoichiometry questions. The post-intervention test results indicated that the learners improved their mathematical reasoning and achievement. The findings from the observations indicate that the learners were excited, motivated and actively engaged in their work, assisting one another by endeavouring to answer questions supported with justification. The findings from the focus group interviews indicate that the learners were excited to learn using POGIL and wished to use it in other subjects such as mathematics. The learners anticipated an improvement in their grades and understanding of stoichiometry. The findings from the teachers' interviews indicated that they too appreciated using POGIL. They found POGIL useful in reducing misconceptions, increasing learner participation, increasing understanding and achievement, and felt that their learners were interested in utilising POGIL as a learning tool. The results indicated that POGIL increased learners' reasoning, understanding, achievement, active participation, and interest in learning.

Keywords:

Process oriented guided inquiry learning (POGIL), active learning, reasoning, understanding, learning cycle, perception, cooperative learning

Language editor’s disclaimer



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To whom it may concern

This certifies that I, the undersigned, performed a language edit on the thesis:

EXPLORING HOW PROCESS-ORIENTED GUIDED INQUIRY LEARNING ELICITS LEARNERS' REASONING ABOUT STOICHIOMETRY

by

Charles Mamombe

Yours sincerely,

Anton Ferreira
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Acronyms

CAPS – Curriculum and assessment policy statement

DoBE – Department of Basic Education

GIL – Guided inquiry learning

ICAP – Interactive, Constructive, Active, Passive framework

ICAPD – Interactive, Constructive, Active, Passive, Disengaged framework

LC – Learning cycle

NCS - National curriculum statement

POGIL – Process oriented guided inquiry learning

PO – Process oriented

SACMEQ – Southern and Eastern African Consortium for Monitoring Educational Quality

TIMSS – Trends in International Mathematics and Science Study

ZPD – Zone of Proximal Development

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Structure of the thesis

The first chapter discusses the background, the statement of the problem, the rationale and aim of the study and the research questions. The second chapter reviews the literature relevant to the study. In the third chapter, the research methodology is outlined while chapter four presents an analysis and discussion of the results. In conclusion, chapter five discusses the findings and limitations of the study, as well as areas for further research. The list of references and the appendices then follow for easy cross-referencing.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Contemporary science education is more focused on the learners' understanding than mere lesson delivery (Abd-El Khalick, et al., 2004). Current approaches are more concerned with the mental constructs and learners' cognition of what they are learning (Furtak, Seidel, Iverson, & Briggss, 2012) as properly structured mental constructs and cognition are the basis of the learners' reasoning (McGuire & McGuire, 2015). When reasoning, learners engage in problem-solving, data processing, critical thinking, and verbal and written communication (Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2012). These skills are essential to the learners' work as they interact with each other while studying and are believed to develop into life-long habits in their future careers (Dudu & Vhurumuku, 2012; Hein, 2012). These skills improve learners' scientific literacy, prepare them for future careers (McGuire & McGuire, 2015) and help motivate them to develop into future researchers who may well contribute to the body of knowledge during their careers.

In South Africa, there is a need for more students to pursue scientific careers. Therefore, one of the main targets of the Department of Education is to increase the pass rate of physical sciences (Department of Basic Education [DoBE] Report, 2020). Performance and pass rates may be enhanced by employing teaching strategies that can improve cognition. Learner-centred approaches such as POGIL have been observed to enhance such development of learners' cognition (Simonson, 2019; McGuire & McGuire, 2015). The current study sought to explore the extent to which a learner-centred approach such as POGIL elicits learners' reasoning in grade eleven stoichiometry. The topic of stoichiometry at grade eleven has been selected as it is essential in chemistry due to its application in many topics at grade twelve – including acids and bases, equilibrium, rate of reaction and electrochemistry, to mention but a few (Department of Basic Education [DoBE] Report, 2016; Passmore, Stewart, & Cartier, 2009; Mullis, Martin, Foy, & Hooper, 2016). Therefore, the current study emerged on the quest to explore the extent to which learner-centred approaches elicit learners' reasoning.

1.2 Background

POGIL is a research-based learner-centred guided-inquiry pedagogical strategy where learners work in collaborative groups of three, four or six. The learners actively engage in activities exploring content that results in concept formulation and understanding (Elmore, 1991; Hein, 2012; Koopman, 2017; Moog & Spencer, 2008). POGIL elicits critical thinking skills such as analysing, evaluating, synthesizing and problem-solving skills (identification, planning and executing a strategy). POGIL also elicits other process skills such as communication, teamwork, management, information processing and assessment (Simonson, 2019). Past studies have established that POGIL is an effective teaching approach that results in improved academic performance and achievement as compared to traditional methods of teaching (DuBert, et al., 2008; Hanson, 2006; Hein, 2012; Moog & Spencer, 2008; Nadelson, 2009; Villagonzalo, 2014). However, no research has taken on the task of qualitatively gauging how POGIL fosters reasoning through critical thinking skills and how it develops problem-solving skills for the conceptual understanding of stoichiometry.

My teaching experience and appreciation for inquiry approach led me to discover the American inquiry method POGIL as one of the methods that develops learners' understanding (Simonson, 2019). This study focused on how POGIL elicits learners' reasoning in stoichiometry. POGIL is a type of inquiry learning based on John Dewey's philosophy that education begins with the curiosity of the learner (Harvey & Daniels, 2009). The POGIL teaching approach places the learner at the centre of learning (learner-centred) (Anderson, 2002) and develops a deeper understanding of concepts through critical thinking and reasoning, thereby developing mental constructs (Abd-El Khalick, et al., 2004; Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2012). The POGIL method guides learners through learning cycles embedded in carefully designed worksheets (Barthlow & Watson, 2011; Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). These worksheets elicit learners' interest and attention to the information, leading to concept development (Kurumeh, Jimin, & Mohammed, 2012). The worksheets are designed to progressively build from simple to more complex concepts so that learners base their understanding on familiar concepts. The learners are exposed to learning material with necessary resources and are guided through a series of activities designed to promote analytical thinking and reasoning.

POGIL is a constructivist model as it acknowledges that learners already have some knowledge about almost anything they may have encountered in the past, formally or informally (Villagonzalo, 2014; Vygotsky, 1934/1986). Science learners' prior knowledge may be correct or incorrect, or a mixture thereof (Coetzee & Imenda, 2012; Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2012). Suitable teaching approaches which pay attention to learners' cognition may effectively correct the incorrect ideas initially held by learners (Bybee, 1997; Process Oriented Guided Inquiry Learning, 2010).

As with the general inquiry method, POGIL emphasizes reasoning and understanding rather than memorization (Hein, 2012; Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2012; Process Oriented Guided Inquiry Learning, 2010). It also focuses on the generation of useful and applicable knowledge through investigation (Furtak, Seidel, Iverson, & Briggss, 2012).

1.3 Research context

South Africa is currently facing challenges with regards to the proficiency of teaching and learning of science and mathematics. The evidence for the challenges faced by learners is the poor performance of learners in physical sciences at Grade 12, particularly in the chemistry paper (Department of Basic Education [DoBE] Report, 2016). The DoBE report also indicates that learners primarily struggle with topics related to stoichiometry. The report from the Southern and Eastern African Consortium for Monitoring Educational Quality (SACMEQ) Grade 6 tests show South Africa ranked in the lower 50% of the 16 participating countries in numeracy and literacy (Moloi & Chetty, 2011). The results indicate that most learners in South Africa lack the necessary mathematical skills to solve multi-step calculations. The results of the Trends in International Mathematics and Science Study (TIMSS) for Grades 4 to 9 placed South Africa among the lowest in mathematics and science achievement of the 64 participating countries (Mullis, Martin, Foy, & Hooper, 2016). The achievement of South African grade 9 learners is among the lowest, with science being lower than mathematics. The TIMSS results suggest that schools of low socioeconomic level performed worse than schools from higher socioeconomic levels (Mullis, Martin, Foy, & Hooper, 2016). Schools with low socioeconomic status are prevalent in the South African context and likely contributes to the low achievement of learners.

It is without doubt that teachers contribute to the educational achievement of learners (Arends & Phurutse, 2009; Malcolm, Mavhunga, & Rollnick, 2019). The competency of the teacher as well as the teaching approach and resources used by the teachers are all worth considering for successful learning to occur. Teachers should be experts of the content they teach, as well as the methodology they employ, for effective learning to occur. Previous studies show that some South African teachers have challenges related to the content knowledge of their speciality (Vhurumuku & Dudu, 2017). This may be a cause for concern because effective teaching may be compromised by the teachers' lack of subject content expertise.

South African high schools, particularly those of low socioeconomic level, are not conducive for science teaching due to a lack of material resources and qualified teachers (Moloi & Chetty, 2011; Mullis, et al, 2016). For this reason, both SACMEQ and TIMSS recommend in-service training of teachers in science and mathematics content knowledge and methodology. Under-resourced laboratories and low qualified teachers, or absence thereof, are a common phenomenon in South African schools of low socioeconomic status (Stott, 2020).

In the following paragraphs I describe the findings of the previous studies on stoichiometry in the South African context.

1.4 Stoichiometry in the South African curriculum

While stoichiometry is a major chemistry topic at high school, it is at this stage, important to note that the South African curriculum places this topic in a subject called physical sciences which consists of the physics section and the chemistry section. The DoBE's diagnostic reports on Grade 12 examinations have for the past few years indicated the difficulties faced by learners in identifying limiting reactants, calculating moles, and applying the mole ratio, among other challenges (DoBE Report, 2019).

A study by Malcolm, Mavhunga and Rollnick (2019) identified stoichiometry as a topic that is difficult for teachers to teach and for high school learners to understand. The study further indicated the need for professional development in the topic to improve the Grade 12 pass rate (Malcolm, Mavhunga, & Rollnick, 2019). A similar study by Vhurumuku and Dudu (2017) revealed that the learners' and teachers' understanding of the nature of science did not differ significantly. This finding is concerning because the subject matter knowledge of the teachers needs to be well above that of the learners if the teachers are to assist learners effectively. That study highlighted the necessity for teacher training to focus more on pre-service teacher understanding of subject matter knowledge and teacher pedagogical skills. The study recommends that the authorities should value the teachers' pedagogical skills and their pedagogical content knowledge of the nature of science (Vhurumuku & Dudu, 2017). A similar study revealed that most teachers use the lecture method regardless of the expectations of the new CAPS curriculum which is aligned to inquiry (Dudu, 2014; Ramnarain & Schuster, 2014).

Chemistry, and stoichiometry in particular, was discovered to be most difficult for first-year university students (Marais & Combrick, 2009). These students were identified to memorize the formulae or definitions without understanding the concepts. Some difficulties identified in that study included students failing to balance equations of reactions, failing to calculate the limiting reactant and the reaction yield. In that study, the researchers indicated that many conventional lecture methods failed to improve the pass rate of the first-year students in chemistry. The study assumes that the students lacked reasoning skills, problem-solving skills to solve stoichiometry calculations (Marais & Combrick, 2009). These findings concur with previous findings indicating that first-year tertiary students perform poorly in stoichiometry (Potgieter, Rogan, & Howie, 2005; Potgieter & Davidowitz, 2010). Their poor grasp of stoichiometry may be the reason they fail to apply appropriate reasoning to solve problems.

Statistically speaking, a recent study by Stott (2020) revealed that there were significantly higher levels of stoichiometry knowledge among teachers serving 'advantaged' communities. This was also true for teachers with over three years' teaching experience and those possessing a B.Sc. degree. The study suggests content deficiency among teachers serving poor communities (which may represent a large population in South Africa), less experienced teachers or less qualified teachers (Stott, 2020). This physical sciences content deficiency contradicts the South African education system's emphasis on teacher competency in knowledge skills, methods, and procedures relevant to each phase (Molefe & Stears, 2014).

Based on the previous findings, this study sought to improve learners' reasoning in the broad chemistry topic of stoichiometry, using POGIL. This research was done to identify the learners' competence during problem-solving of stoichiometry calculations.

1.5 Problem statement

The academic achievement of South African Grade 12 physical sciences learners is below the expectation of the Department of Basic Education. In the past five years, for instance, less than 18% of matric candidates achieved marks which were 60% and above in physical sciences (Department of Basic Education [DoBE] Report, 2019). More details are shown in table 1.1 below.

Table 1:1

Grade 12 physical science results in the past 5 years

Year	**Number wrote**	**Number achieved 60% plus**	**% Achieved at 60% and above**
2014	167 997	22 007	13.1%
2015	193 189	24 728	12.8%
2016	192 710	28 714	14.9%
2017	179 561	29 089	16.2%
2018	172 319	30 328	17.6%

Only learners who achieve above 60% in physical sciences stand a chance to meet the minimum requirements for university entry for medical and engineering programs (Department of Basic Education [DoBE] Report, 2019). This shows that most high school learners do not make it into university and those who do, hardly qualify to access engineering and medical programs. Though there has been a gradual increase in the numbers of learners who achieve above 60%, the numbers are still exceptionally low compared to the number of candidates enrolled.

The low achievement rate (Department of Basic Education [DoBE] Report, 2020) can be attributed to many factors, including inappropriate teaching methods where teachers use the lecture method too frequently (Ramnarain & Schuster, 2014). Topics such as stoichiometry are abstract and difficult (Marais & Combrick, 2009; Potgieter & Davidowitz, 2010), while schools in socioeconomically disadvantaged areas may lack resources (Stott, 2020). In other cases, learners may lack motivation due to a combination of factors (Yiga, et al., 2019; Masista, 2006). The learners may fail to understand, or the teachers may have inadequate content knowledge (Vhurumuku & Dudu, 2017).

For learners to succeed in studying chemistry they require sound reasoning skills, the ability to visualize abstract ideas and being skilful in problem-solving techniques (Marais & Combrick, 2009). Stoichiometry looks at chemical calculations related to limiting reagents, percentage yield, percentage purity, and the number of moles, atoms, volume, concentration, or mass of substances used or produced during a chemical reaction (Department of Basic Education [DoBE] Report, 2016; Department of Basic Education [DoBE NCS-CAPS], 2012). When learners are proficient in stoichiometry, they are most likely to do well in chemistry.

1.6 Rationale and significance of the study

As an experienced high school science teacher, I have noticed that most learners experience challenges with the chemistry paper as compared to the physics paper. This is a general observation made by most physical sciences teachers. I also noticed that my learners did better in recall questions than questions that need higher-order thinking skills. Similarly, I observed that in multi-step calculations learners faced challenges such that they did not complete all the steps in the calculation. In some cases, the learners mixed up the steps and ended up with incorrect answers. Most learners faced challenges in answering descriptive questions.

After working hard as a teacher, explaining repeatedly, I saw only slight improvements in my learners, and I was not satisfied. Careful inquiry led me to discover that my learners simply did not understand the underlying concepts. The learners would pick a formula and start substitution values without reasoning. As such, many of them answered questions that were never asked or answered correctly by mere coincidence. The chances of unjustified procedure being correct decreased as the complexity of the questions increased. I, therefore, believe that when learners understand concepts, they will be able to reasonably apply their understanding to problem-solving and describing processes. Reasoning in stoichiometry requires that learners assess the available data to find the unknown. This includes selecting the appropriate formula to use and doing proper substitution before solving the calculation. In multi-step calculations, it involves the reidentification of data and the use of a second, third or even fourth formula and repeating the same process. Often, they need to use the ratio technique to link up the formulae to proceed from one step to the next. Such reasoning can only be developed by a carefully structured learning approach.

The problems I have faced with my learners appear to be common among most learners in high school. Teachers have tried implementing a range of strategies to help their learners in the best ways they could. Some teachers have tried morning, afternoon, or weekend classes. Some gave extra homework, and some did extensive revision towards the examination. All these helped to some extent, but not entirely.

The failure of high school learners to solve stoichiometry problems impacts negatively on their success in physical sciences (DoBE Report, 2019). This is so because stoichiometry is a major topic in chemistry constituting a large percentage of the chemistry paper. Therefore, when learners struggle in stoichiometry, they are likely to fail the chemistry paper. Learners with weak knowledge of stoichiometry seem to struggle with related subject modules at university level (Marais & Combrick, 2009; Malcolm, Mavhunga, & Rollnick, 2019). Some learners who fail stoichiometry usually fail to achieve in the subject and may fail to pursue programmes of their choices. This could result in a low number of professionals in science-related courses such as medicine and engineering.

Previous research has revealed that learner-centred modern teaching approaches may help to reduce misconceptions and increase understanding (Department of Basic Education [DoBE NCS-CAPS], 2012). Learner-centred approaches such as POGIL, encourage learners to have direct observations and develop lasting problem-solving skills and habits of the mind that will aid their future study, work and life experiences (Dudu & Vhurumuku, 2012; Hein, 2012; Hanson, 2006; Moog & Spencer, 2008).

These learners may therefore perceive science as easy, understandable, interesting, and motivating (Avery & Meyer, 2012; Minner, Levy & Century, 2010).

Learners' understanding and reasoning are mental traits embedded in the learners' mind and not easily accessible by direct observation. Research on learners' cognition has revealed that learners' hidden ideas can be revealed through verbal or non-verbal actions when learners write tests or engage with each other during discussions (Veenman, 2012; Zohar & Dori, 2012). While previous studies have observed that POGIL and inquiry methods in general result in increased understanding and achievement of learners, not many have investigated how this teaching approach makes these achievements possible.

The current research, therefore, investigates this gap to establish how the use of POGIL during an intervention may influence learners' reasoning in stoichiometry. Essentially, this study seeks to provide results on the effectiveness of collaborative learning on South African learners' reasoning, which previous research found favoured by learners (Allers, 2007). Such results might inform the DoBE on whether to invest in POGIL or other cooperative teaching methods for use in the classroom. That investment may include training of teachers and the provision of resources.

The results of this study might also be important for the Department of Basic Education of South Africa, who have noted the low pass rate in physical sciences and stoichiometry (DoBE Report, 2019). My assumption is that if learners improve their achievement in stoichiometry, they are likely to pass the subject at high school because it is such a major part of physical sciences. A potential increase in the pass rate may lead to increased numbers of professionals in engineering and medicine. Significance of the current study to me include that I may use POGIL in my own classes to improve understanding and reasoning of my learners. I may as well recommend other teachers to make use of POGIL in difficult and abstract topics in science and mathematics. I may ultimately learn how to develop other POGIL worksheets for use in science and mathematics at different grades if POGIL demonstrated to be effective in improving reasoning and understanding of learners.

1.7 Aim and research questions

The study aimed to establish how POGIL influences learners' reasoning about stoichiometry. Therefore, a POGIL intervention was introduced to achieve this aim.

The primary research question has been formulated as follows:

How does POGIL influence learners' reasoning about stoichiometry?

The following secondary research questions have been formulated to answer the primary research question:

1. How do Grade 11 physical sciences learners reason before exposure to POGIL?
2. How do POGIL-trained physical sciences teachers engage learners during POGIL activities?
3. How do Grade 11 physical sciences learners engage and reason during stoichiometric POGIL activities?
4. How do Grade 11 physical sciences learners reason after exposure to POGIL?
5. What are the learners' perceptions of POGIL as a teaching and learning strategy?
6. What are the teachers' perceptions of POGIL as a teaching and learning strategy?

1.8 Assumptions

The assumptions underlying the study were:

- That the teachers trained during a three-day workshop were well equipped with the expertise to teach their learners effectively with the use of POGIL. This assumption was supported by my visits to some of the POGIL-trained teachers' classes before the actual data collection. The two participants in this study were part of those teachers initially visited to ascertain their use of POGIL and willingness to participate in the study.
- That the analysis of the learners' scripts in the pre-intervention test provided information about their reasoning and problem-solving skills in stoichiometry. The pre-intervention test provided insight into the learners' reasoning capacity before the intervention. The learners were taught the same concepts in Grade 10 the previous year, so the topic was not new to them.

- That the participating learners were well trained in POGIL and aware of the different group work roles they should assume during POGIL lessons.
- That the video recording and lesson observations during the POGIL intervention provided richer insights into how learners reasoned during interactive learning in groups. It was also assumed that it provided information about how learners argue based on evidence in support of their ideas and that the answers provided in the worksheets represented the views of the group and not the individual.
- That as learners engaged during the intervention, they sharpened each other's views and collectively achieved better than any one of them would have individually.
- That any improvement in learners' reasoning in the post-intervention test results is attributed to the effects of the intervention.
- That the learners' post-intervention test scripts demonstrated their mathematical reasoning and problem-solving skills after the intervention. The comparison of the post-intervention test and the pre-intervention test results provided information about how POGIL elicits reasoning in stoichiometry.
- That the intervention would provide an environment for learners to develop understanding, critical thinking, and reasoning as they interact with each other and the worksheets. Each learner would be able to express their ideas before the group and justify them through reasoning.
- That the interviews with the teachers and learners conveyed their true perceptions about the use of POGIL as a teaching approach.

1.9 The scope of the study

This case study was undertaken in two South African schools, and as such the results cannot be generalized. It can, however, provide insight into how the use of POGIL influences teachers' and learners' reasoning and thinking in stoichiometry. Its scope is limited to the manifestations of learners' mathematical and conceptual reasoning as they solve stoichiometric problems. The learners' mathematical reasoning was initially observed in written form by their responses in the pre-intervention test and lastly in the post-intervention test. The results from pre-intervention tests at the two schools were limited to the topic of stoichiometry, which the learners had previously done in Grade 10. As such, the learners may have forgotten what they were taught the year before.

The learners' written work in the pre- and post-intervention tests revealed their reasoning skills and approach to answering stoichiometry calculations based on available data using provided formulae. When solving multi-step calculations, the tests represented how learners made individual decisions as to the steps required during the problem-solving process. Since the learners were taught the topic during the previous year, they may have forgotten how to follow the multi-step problem-solving procedures. This may have negatively impacted the learners' responses to the high-level questions in the pre-intervention test.

During the intervention, the learners' reasoning and conceptual understanding were inferred from their oral discussions and from their collectively compiled written scripts of worksheets. Though the group responses were assumed to be a representation of the ideas of all members in the group, it is possible that some learners may not have understood some concepts during their discussions. That lack of understanding may have negatively impacted their responses in the post-intervention test. The comparison of their reasoning in the pre- and post-intervention test, as well as their arguments based on justifications during the intervention, revealed the effectiveness of POGIL as a way of teaching. This may have been a limitation because some learners may not seriously consider the opinions of other learners during group discussions and merely take them as opinions. Such learners may be waiting for the teacher's view on each question, which is rare in a POGIL class.

1.10 Researcher's personal perspective

The experience of the researcher plays a leading role in the ethical and personal issues in the qualitative research process. As a researcher, I declare my background to reveal possible biases related to my personality which may have shaped or affected my data interpretations in the current research (Creswell, 2014). I therefore describe my position in terms of race, gender, class, beliefs, and other dimensions which are influential in one way or another, in my research process.

I am a black male living in Pretoria and working in Soshanguve, a black township in South Africa. I was born in a rural village in Zimbabwe in 1971 in the middle of a guerrilla war. I lost my mother at the age of 3 years during an attack at our home that also left my father, a teacher at a local primary school, injured and crippled. I attended numerous primary schools and at some point, did not go to school for almost a year, as all schools were closed due to the war. At the time of independence in 1980, I attended school with former freedom fighters and war collaborators. That same year, I lost my father, the only breadwinner I had. I lived a miserable life that nearly wiped out my natural intelligence. My grandfather came to stay with me when I was in the fourth grade, as did my younger brother until he passed on in 1986. During those years I was quickly trained to be the cook for the three of us.

In 1985, I was taken into high school by a senior cousin to start Form 1 (Grade 8) at a boarding school. This was a strategy by my grandfather to separate me from my brother as we had made several failed attempts to run away from home to seek employment in town. The boarding school was a prison for me, as I lacked basic items like soap although my fees were fully paid and sometimes paid in advance. After completing Form 6 in 1990, I got a government scholarship to train as a teacher in Cuba. I took up the offer and did well in my studies during those five years. I learned chemistry, physics, mathematics, methodology, pedagogy, philosophy, and psychology. The final year was dedicated to full-time teaching practice and dissertation. I came among the top learners in my class of 1996.

When I returned to Zimbabwe in 1996, I taught at three rural high schools and a fourth school located in town. Those years were again marred by poverty due to Zimbabwe's economic decline. I furthered my education by acquiring a teachers' diploma and though I wanted to continue studying, the education system was overpopulated and there were only two universities offering master's degrees in Zimbabwe. Due to the ongoing economic decline, I got employment in South Africa in 2007 where I have been working ever since. I did my honours bachelor's degree in science education in 2012 and my master's in science education from 2013 to 2015. In my masters, I graduated with a score close to a distinction and earned an award in the Golden Key group of academics. In 2017 I started a doctorate degree in science education for which I am submitting this thesis.

Having lived as an orphan and being exposed to strife from a young age made me realise that unless I work for something, I will get nothing. I worked hard to get to where I am today, and I am extremely grateful for reaching the completion of my doctorate. I always preferred to work alone except when I worked with my late wife. In time, I came to cherish working in teams. I know that there is power in teamwork and have applied group work in my classes, although I continue to enjoy working alone. For that reason, I am not frustrated if I do not get praise, a gift or acknowledgement for anything I may have achieved.

I have been a teacher since 1996, a total of 25 years of teaching experience. I followed the lecture method until I discovered that learner-centred teaching approaches are less stressing for the teacher and provide the best recipe for the learners. For my masters' degree, I did a dissertation on inquiry-based science education where I prepared lesson plans used by experts to teach during the intervention. Further reading led me to discover POGIL, which uses ready-made worksheets that serve as teaching tools during lessons. I explored that direction with the help of my supervisor who brought in a POGIL expert to train high school teachers, including myself, on teaching using POGIL.

I attended the three-day workshop with 25 high school teachers, the one-day workshop with about 20 university lecturers, and a class demonstration with about 14 pre-service students at the University of Pretoria. I followed up with some of the trained high school teachers and assisted and encouraged them to continue using POGIL in their classes where possible. The two teachers who participated in the current study are among those I previously trained and assisted. To gain even further insight into POGIL, part of this study included travelling to the USA for two weeks in 2019. That journey opened my eyes to the POGIL way of thinking and helped me in my data analysis. In the two 5-day workshops I attended, I was the only one from Africa and the only black attendee. I was happy that the direction of my study was a window not only on my African ethnicity but on Africa and African approaches to teaching. My wish as a teacher has always been to guide other teachers in the modern ways of teaching, although I know that certain parameters may hinder me in achieving that. My second choice of action would be to do research or to be an advisor to the education department on teaching methods and the science syllabus. But as the saying goes, "*a noble man may have good ideas but who will listen to him*?"

My worldview perspective is constructivist, a notion I have pursued in my masters' degree as well as this doctorate. I believe that when learning happens in the mind of the learner, it is more profound and grounded than when the learner is told concepts. I believe in learner-centred approaches where learners construct their own ideas. Such ideas are then polished by the teacher who acts as a facilitator of the learning process. I believe active learning results in deep understanding and I have learned that interactive learning results in deeper understanding. I cherish the qualitative study of how much knowledge a learner has acquired. I am inclined to employ evidence-based research methods and arguments which support ideas through tests, interviews, or observations.

1.11 Outline of thesis

My thesis consists of five chapters. Chapter 1 is the overview of the study which entails the introduction, background of the study, research context, stoichiometry in South Africa, the research problem statement, the rationale, the aim, and research questions of the study. This is followed by the assumptions, scope of the study, and the researcher positionality. Chapter 1 concludes with the chapter outline.

Chapter 2 discusses the literature on stoichiometry and previously identified learner difficulties in stoichiometric calculations. It includes the description of the POGIL teaching approach as a type of learner-centred collaborative learning method, and related past studies and findings. Chapter 2 discusses previous study findings on stoichiometry, Bloom's taxonomy of cognitive domain, active learning, inquiry learning and POGIL as a type of learner-centred collaborative learning used in the current study. Thereafter, previously identified advantages and disadvantages of using the POGIL as well as information- and cognitive processing, reasoning, and metacognition are discussed. It concludes with the conceptual and the chapter summary.

Chapter 3 describes the methodology I chose for the study. This includes the philosophical stance, approach, design, sampling, instruments, data collection, data analysis and methodological norms. The description of the data collection procedures entailed the description of the test instruments and the POGIL intervention as well as the methodology that underpinned the POGIL intervention for data collection (the ICAP). Chapter 4 is the data analysis of all data obtained from tests, intervention, and interviews. Chapter 5 is the conclusion of the study which entails the description of the answers to the research questions.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The chapter commences with a discussion of the literature related to the teaching and learning of stoichiometry. This is followed by a description of Bloom’s taxonomy of cognitive domain on which the reasoning that is investigated in this study is analysed. Afterwards, a thorough description of active learning as a type of learner-centred approach is described, connecting it to inquiry learning, POGIL and a description of the process skills. Information processing, cognitive processing and reasoning are discussed thereafter. Lastly, the description of metacognition and the conceptual framework underpinning the study is described.

2.2 Stoichiometry

Stoichiometry is a wide-ranging topic in physical sciences. It covers the calculations of the relative molecular mass, the number of moles, the unknown mass, the number of atoms, the number of electrons, the concentration of solutions, limiting reactant, the volume of solutions, the percentage of mass of an element in a compound or mixture among others (Department of Basic Education [DoBE NCS-CAPS], 2012).

In the study by Sunday, Ibemenji, & Alamina (2019), learners who were taught stoichiometry using problem-solving techniques performed better than those taught using the lecture method. Problem-solving techniques had more efficacy and enhanced learners’ understanding, rather than the traditional method used in stoichiometry (Sunday, Ibemenji, & Alamina, 2019). The use of multiple levels of representations which entailed macroscopic, sub-microscopic and symbolic, also improved learners’ achievement in stoichiometry (Mocerino, Chandrasegaran, & Treagust, 2009; Pikoli, 2020). The use of such multiple levels of representations is the basis of inquiry learning, where learners are guided towards developing an understanding of concepts (Colburn, 2009).

The studies by Kimberlin and Yezierski (2016) showed that inquiry-based learning in stoichiometry led to statistically significant improvement in conceptual understanding (Kimberlin & Yezierski, 2016). Hadar and Al Naqabi (2008) observed that learners’ overall use of metacognitive strategies (awareness of cognition, monitoring, planning, self-checking, self-appraisal, and engagement) predicts the learners' understanding of stoichiometry. The study revealed that learners used planning more than any other metacognitive strategy and it had a direct impact on the understanding of stoichiometry (Hadar & Al Naqabi, 2008). The metacognitive strategies seem to have a direct relationship to learners' reasoning since they cannot plan or monitor themselves without reasoning. Another study by Schmidt (1990) revealed that many learners do not understand stoichiometry. The learners responded to questions while confusing the number of moles and reacting mass or reacting mass and molar mass (Schmidt, 1990). The confusing of quantities during calculations imply that such learners lacked understanding and were not using reasoning to solve the questions.

A study by Adigwe (2013) analysed the relationship between mathematical skills and achievement and discovered that learners taught mathematical skills achieved better in chemical stoichiometry. The same study revealed that male learners had a greater improvement in chemical knowledge and mathematical skills than female learners (Adigwe, 2013). In a study by Chandrasegaran et al. (2009), it was revealed that high-achieving learners claimed to use memorized formulae to deduce the limiting reactant by comparing mole ratios. The average learners deduced from the balanced chemical equation and generally, learners displayed limited confidence in calculating the limiting reactant (Chandrasegaran, et al., 2009). This suggests that memorizing, which is a low-order cognitive skill, yielded effective achievement in that study. Literature consulted in this section suggests that the active-learning methods were effective in improving learners' understanding of stoichiometry.

In the following paragraphs, I describe Bloom's taxonomy of cognitive domains. This relates to my study on the cognitive levels and the reasoning which is embedded with cognition. Bloom's taxonomy is important for this study because the learners' tests were marked and classified based on the level of cognition revealed in their responses. More details about the cognitive levels are discussed in the following paragraphs of chapters 2 and 3 of this study.

2.3 Bloom's Taxonomy

The cognitive development of learners during POGIL activities is underpinned by the revised version of Bloom's taxonomy of cognitive domain (Anderson & Krathwohl, 2001; Bloom, 1956). Bloom's revised taxonomy of cognitive development is an active process-oriented hierarchy of learning levels (McGuire & McGuire, 2015; Bloom, 1956). According to this taxonomy, the lowest stage is *remembering*, where a learner is expected to provide basic knowledge from memory. The learner at this stage is expected to define, state, name, and record knowledge from simple recall. This is the most basic stage. Any learner is expected to remember what they were told or what they previously studied. There is no reasoning expected at this stage, only the recall of previously learned knowledge (McGuire & McGuire, 2015). The learner is expected to state that information in either, the same words, or in their own words, but accurately keeping the meaning of the concept.

The second stage is *understanding*. In this stage, the learner now discusses, interprets, and describes their understanding of what they know (McGuire & McGuire, 2015; Bloom, 1956). The learner now explains in their own words and elaborates on their knowledge. The learner is not merely reproducing the remembered knowledge but demonstrates understanding of the knowledge. That understanding is shown by the learner being able to interpret content based on prior knowledge. The learner can describe a phenomenon by relating it to the previously learned concepts. When the learner interprets, discusses, or describes concepts they will be reasoning in the way they understand the concept. They will be applying all logical reasoning according to their own view (Bloom, 1956; McGuire & McGuire, 2015).

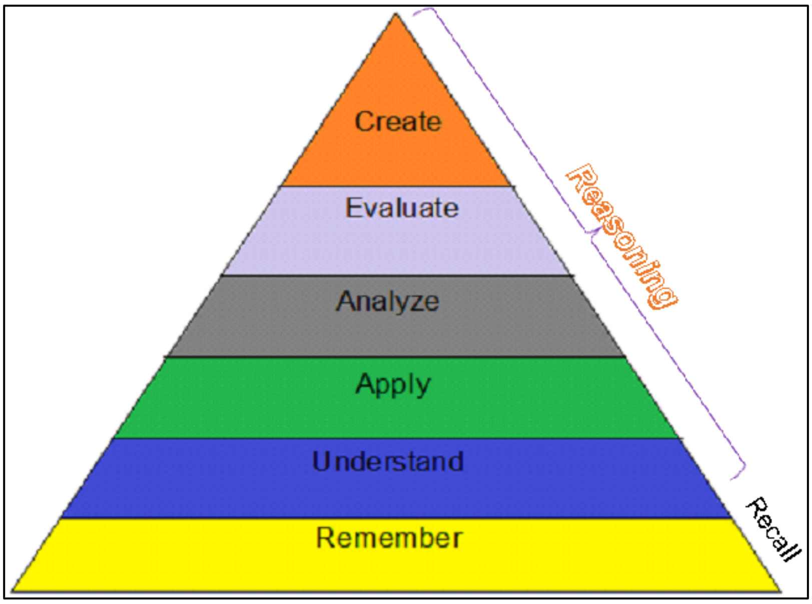
The third stage is *application*. Here, the learner applies their understanding in new situations and demonstrates understanding by interpreting, calculating, and developing concepts in ways they understand best (Bloom, 1956; McGuire & McGuire, 2015). The learner relates the links between concepts and applies knowledge in new situations. A lot more reasoning is involved as the learner applies their understanding to new situations and begins making connections between the concept they understand and its relation to the new situation at hand. They, therefore, apply their previous understanding to explain, calculate and to develop concepts in new situations.

In the fourth stage, referred to as the *analysing* stage, the learner breaks down the concept into smaller parts and reorganizes them in a manner they most clearly understand (Bloom, 1956; McGuire & McGuire, 2015). The learner differentiates, scrutinizes, inspects, dissects, and develops deductions. The learner can appropriately split the concept into its constituent parts. The learner can see the connections between the parts of the concepts and can appropriately relate them to each other. In calculation problems, analysing is necessary when the learner is performing multi-step calculations. In such situations, the learner must know the connections between the many parts of a concept in question. The learner applies reasoning to analyse concepts.

In the *evaluating* stage, the learner uses the identified parts of a concept to evaluate, to critique and produce recommendations and reports. The learner uses their profound understanding of the multi-stage connecting parts of a concept to evaluate the outcomes of certain calculations and may evaluate two or more responses by comparing them. The learner may apply reasoning to evaluate their answers or other learners' answers or a set of given responses to the same question (Bloom, 1956; McGuire & McGuire, 2015).

The highest stage of cognition is the *creating* stage. A learner at this stage can now put together all the parts of a concept or process and create a new form of design. At this stage, new knowledge, principles, methods, and designs are developed. The learner can come up with new approaches to solving problems, and not necessarily depend on methods that are already known (Bloom, 1956; McGuire & McGuire, 2015).

Figure 2:1 Revised Bloom's taxonomy of cognitive domain (McGuire & McGuire, 2015)



The higher stages of cognition, which include understanding, applying, analysing, evaluating, and creating, are components of reasoning. These stages constitute the reasoning of learners as they demonstrate their understanding by applying it in different situations and analysing it and evaluating the processes. Finally, the learners may create their own models and/or designs.

For a high school learner to get As or Bs, they need to be strong on the lower levels of cognition, which are, remembering, understanding, and applying. University-level students, however, may only get such grades if they master higher levels of cognition from analysing and upwards (McGuire & McGuire, 2015; Bloom, 1956; Anderson & Krathwohl, 2001). Such levels are part of the high levels of critical thinking which is an essential type of reasoning. For that reason, learners need to think according to the expected outcomes for that level.

The South African syllabus has an assessment table used to analyse the validity of examinations and tests, according to the requirements of the examinations board (Department of Basic Education [DoBE] Report, 2016; Department of Basic Education [DoBE] Report, 2020). The guidelines provided are normally known as levels or cognitive levels. These were drawn from Bloom's taxonomy of cognitive domain.

Evidently, the way the levels were made is skewed negatively, as 50% of the marks are allocated to levels 1 and 2 of Bloom's taxonomy. According to the Department of Basic Education, levels I and II correspond to cognitive levels 1 and 2 respectively, on Bloom's taxonomy. Level III is a combination of cognitive levels 3 and 4 on Bloom's taxonomy while level IV is a combination of cognitive levels 5 and 6 on Bloom's taxonomy (McGuire & McGuire, 2015; Bloom, 1956; Anderson & Krathwohl, 2001). Table 2.1 below summarizes the expected outcomes per level and the corresponding taxonomy level according to Bloom's taxonomy of cognitive domains.

Table 2:1

DoBE cognitive levels as related to Bloom's taxonomy (Anderson & Krathwohl, 2001)

Level	Expected outcome	Related Bloom's taxonomy
I	Learner makes simple and obvious connections. Recalls and remembers facts. Can tabulate, list, name, match.	Remembering
II	Learner has first level understanding of concepts, recalls, and describes meaning, can interpret, summarize, predict, and write in order.	Understanding
III	Learner has deeper understanding of all the constituent parts, their relationship and hidden meaning, and can use related knowledge skills to answer questions with reasoning. Use the knowledge in new situations.	Applying Analysing
IV	Learner makes connections between concepts, generalizes, and transfers principles, works with relationships of abstract ideas, compares, and makes judgements and arguments based on reasoning.	Evaluating Creating

The examinations and tests are prepared using the weighting prescribed by the examination board. Levels 1 and 2, remembering and understanding, constitute between 50% and 55% of the marks in the examination. As such, a learner who can remember and understand should already be able to pass. The other 50% of the marks are for the higher order cognitive skills, where critical thinking and problem-solving skills are indispensable because they require evidence-based reasoning (McGuire & McGuire, 2015; Bloom, 1956; Anderson & Krathwohl, 2001). Such high order thinking skills are needed dearly at tertiary level and ought to be developed at high school level for the future success of the learner. These skills need to be developed gradually through mini-research, reports and assignment that require analysis, create application, and evaluate the text or concepts provided. Table 2.2 shows the recommended percentage of marks allocation per cognitive level in the physical sciences papers.

Table 2:2

The weighting of papers according to cognitive levels (DoBE, 2016)

Paper	**Weighing of questions across cognitive level**			
	Level I	Level II	Level III	Level IV
Paper 1 (Physics section)	15%	35%	40%	10%
Paper 2 (Chemistry section)	15%	40%	35%	10%

In section 2.3, I described active learning methods as learner-centred approaches. I identified POGIL as a type of active learner-centred approach which enables the development of the higher levels of cognition required by the DBE, relating it to the conceptual framework which shall be described in section 2.5.

2.4 Active Learning

Active learning is the process of involving learners in activities while they are thinking about what they are doing (Bonwell & Eison, 1991); or an instructional method that engages learners through a learning process where they do meaningful activities that require them to think critically (Michael, 2006; Prince, 2004). Pestalozzi (2012) studied active learning, hands-on experimentation, and higher order thinking skills while adopting the viewpoint of teacher guidance (Pestalozzi, 2012). Active learning engages learners in a series of activities through a learning process that engages in discussions and activities as opposed to passively listening to an expert (Freeman, et al., 2014). In active learning, learners work in pairs or groups discussing and giving reasons for their responses to the questions (Chi & Wylie, 2014). This reflection enhances metacognitive strategies which have been shown to improve learning (Frey & Shadle, 2019; Bjork, Dunlosky, & Kornell, 2013; Donker, De Boer, Kostons, van Ewijk, & van der Werf, 2014). Several techniques have been developed to support active learning, including the pause method (Rowe, 1986), learners doing note comparisons and short activities in groups, such as think-pair-share (Lyman, 1981), concept tests (Crouche & Mazur, 2001; Mazur, 1997), and using personal response systems like cell phones (Cadwell, 2007; Gauci, Dantas, Williams, & Kemm, 2009). During active learning, part of the time is spent by learners working in groups such as inquiry-based learning, problem-based learning, case study, and team-based learning (Elberlein, et al., 2008; Pedaste, et al., 2015; Sweet & Michaelsen, 2012).

When active learning is used, it would change the teaching method currently used by most teachers and hence it is imperative to know the efficacy of active teaching methods to justify the proposal to implement it (Frey & Shadle, 2019). Active learning is regarded as good practice because it has been shown to increase learning (Chickering & Gamson, 1987). Such methods have been shown to increase critical thinking skills by encouraging verbalization and discussions (Tsui, 2002; Chickering & Gamson, 1987). A study performed in history and political science revealed that learners engaged in collaborative exercises performed better than those exposed to teacher-centred methods (McCarthy & Anderson, 2000). Learners have also displayed learning advantages in active learning in science, mathematics, and technology (Freeman, et al., 2014; Vickrey, Rosploch, Rahmanian, Pilarz, & Stains, 2015).

Active learning methods such as the use of short activities; activities that engage learners in the learning process; the use of collaborative and cooperative learning; and the use of problem-based learning; have been found to be effective (Prince, 2004). All five forms of active learning support the notion that active learning results in improved learning with cooperative and collaborative learning being the best (Elberlein, et al., 2008; Michael, 2006; Prince, 2004). It was also found to increase learner exam performance in science, mathematics, engineering, and technology as compared to the traditional lecture method (Freeman, et al., 2014). Further studies have revealed that active learning increases attention and the retention of the learned concepts (Bennett, 2010; Chi & Wylie, 2014). It seems that active learning is an approach worthwhile exploring and using in modern classrooms. The outcomes of teaching may be increased, and more learners may be enrolled in science-related programmes at universities as a result.

Successful implementation of active learning requires careful training of facilitators on how learners learn, how the material must be structured, how to facilitate learning to effectively support the learners (Andrews, Leonard, Colgrove, & Kalinowski, 2011). Modifications of the active learning strategies without proper knowledge of the purpose of the original evidence-based practice may render the approach less effective (Andrews & Lemons, 2015).

2.5 Inquiry-based Learning

Inquiry-based learning is a collection of pedagogical practices of learning that are stimulated by a driving question (Lee, 2012). This particular type of active learning has been found to be effective in supporting learning (Hmelo-Silver, Duncan, & Chinn, 2007; Prince & Felder, 2006). Inquiry as a pedagogical principle is an old philosophical concept that can be traced back to Plato. The study by DeBoer (1991) describes the idea of inquiry and its implication to learning. This approach addresses the question by involving learners in the construction of knowledge and understanding (Bell, Urhahne, Schanze, & Ploetzner, 2009; Minner, Levy, & Century, 2010). Learners will, therefore, be engaged in doing things and thinking about what they are doing (Frey & Shadle, 2019).

The inquiry-based teaching and learning approach is an inductive method like case-based learning or problem-based learning where learners use models, data, or a problem through which the needed information is provided (Prince & Felder, 2006). The driving question provides the context for learning. The inductive methods help learners to make use of data, models, text, or pictures provided to make specific observations and discerning patterns, leading to general conclusions (Frey & Shadle, 2019). Based on the role of the teacher and the learner, inquiry-based learning can be classified as open inquiry, guided inquiry, or structured inquiry. Open inquiry is where the learner formulates both a question and the procedure for solving it (Martin-Hansen, 2002; Staver & Bay, 1987). The conclusions drawn by the learners will be based on data gathered from their own procedure. On the other hand, guided inquiry provides the learners with a teacher-generated problem where the learner designs the procedure to solve it and provides general conclusions (Martin-Hansen, 2002; Staver & Bay, 1987). Structured inquiry provides the learners with both teacher-generated problems and the procedures that can be used to solve them. The teacher provides the focus and guiding questions the learners must answer, thereby uncovering the general ideas and concepts.

Previous research by Levy and Petrulis (2012) distinguished between approaches that facilitate learner exploration of their existing knowledge base and those that invite learners to build new knowledge (Levy & Petrulis, 2012). So, inquiry was classified as either for building new knowledge (inquiry for knowledge building) or to explore what is known (inquiry for learning). Four inquiry models that emerged in that study are Producing, Identifying, Authoring, and Pursuing (Levy & Petrulis, 2012). More details about these inquiry models are explained in table 2.3.

Table 2:3

Inquiry-based learning framework adapted from Levy and Petrulis, (2012)

	Driving question/problem framed by	
	Teacher	**Learner**
Inquiry for building new knowledge	Producing – the learners answer new questions formulated by the teacher Question How can I answer this open question?	Authoring – learners answer their own new questions. Question – How can I answer my own question?
Inquiry for learning-exploring existing knowledge base	Identifying – Teacher formulates and asks questions. The learners explore the knowledge base by answering questions formulated by the teacher Question What is the existing answer to this question?	Pursuing – the learners explore the knowledge base by answering their own questions. Question What is the existing answer to my question?

In Identifying Inquiry, learners explore the knowledge by responding to the guiding questions, problems, scenarios, or models formulated by the teacher. In Producing Inquiry, learners solve new problems formulated by the teacher so that they find the unknown answers. In Pursuing Inquiry, the learners explore the knowledge base by analysing problems, scenarios, or models they have formulated themselves with the goal to find what is already known. During Authoring Inquiry, learners formulate their own driving questions or problems with the aim that their findings will contribute to the knowledge base (Levy & Petrulis, 2012).

Research by Tornee, et al. (2019) shows that high school learners who were taught using guided inquiry improved their chemistry knowledge, science process skills, and scientific attitude. They also improved problem-solving competency, unlike learners who were taught using traditional methods (Tornee, Bunterm, Lee, & Muchimapura, 2019). This suggests that guided inquiry may be effective in improving achievement and problem-solving skills. A similar study by Wilujeng and Hastuti (2020) showed that technology embedded scientific inquiry on stoichiometry improved the problem-solving skills and curiosity of high school learners (Wilujeng & Hastuti, 2020).

Literature shows that inquiry learning has been extensively practiced and researched. Countries all over the world including the United States, Europe, Asia, Australia, and Africa have practiced one form of inquiry or another (Areepattamannil, 2012; Avery & Meyer, 2012; Cakici & Yavuz, 2012; Marx, et al., 2004). Some research has been done in South Africa on the Grades 10 and 11 as well as college levels (Dudu & Vhurumuku, 2012). In most cases, inquiry has been observed to yield better results, better understanding and better motivation towards the learning of science (Harvey & Daniels, 2009; Oche, 2012). Inquiry-based education has been found to increase Grade 4 learners' understanding of the particulate nature of matter (Mamombe, Mathabathe, & Gaigher, 2020). Many approaches are effective in promoting active learning but some lack the inquiry component where learners use provided information to construct meaning. In the next section, I describe POGIL as a type of inquiry on which the current study is based.

2.6 POGIL

POGIL is a type of inquiry learning based on John Dewey's philosophy that education begins with the curiosity of the learner (Harvey & Daniels, 2009). This constructivist teaching approach places the learner at the centre of learning (learner-centred) and encourages learners to arrive at a deeper understanding of concepts by themselves, through critical thinking and reasoning, thereby developing mental constructs (Abd-El Khalick, et al., 2004; Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2012). POGIL is a guided inquiry learning method that guides learners through learning cycles embedded in carefully designed worksheets (Barthlow & Watson, 2011; Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). According to Simonson (2019), the characteristics that define POGIL are working in collaborative groups of three or four students, the use of guided-inquiry activities where learners work in the presence of a POGIL facilitator, and a learner-centred method of instruction. The carefully designed worksheets elicit learners' interest and attention to the information, leading to concept development.

POGIL is also defined as an active learning method, carefully designed for getting learners to consciously do activities while thinking about their actions (Bonwell & Eison, 1991); or an instructional method that engages learners through learning cycles as they do meaningful activities (Prince, 2004; Michael, 2006). POGIL is a guided inquiry method consisting of the process oriented (PO) and the guided inquiry learning (GIL) components. Both components will be explained.

POGIL is a learner-centred teaching approach in which learners work in organized groups answering carefully prepared worksheets aimed at developing specific concepts in the minds of the learners (Moog & Spencer, 2008). During POGIL activities, learners work through the four stages of active learning (passive, active, constructive, and interactive) constructing their own understanding through active interaction. During discussions, learners justify their ideas to the group with reasons so that their ideas make sense to the group. POGIL is carefully designed to improve content mastery and hence improve grades (Farrell, Moog, & Spencer, 1999). It also helps to develop life skills; the process skills which are important for learners. These life skills are teamwork, effective communication, problem solving, critical thinking and information processing (Simonson, 2019). Currently, POGIL is mainly used is science, technology, engineering, and mathematics and in other disciplines.

Because the teacher organises activities around a specific problem that must be solved through a series of steps, POGIL is defined as a form of guided inquiry (Kurumeh, Jimin, & Mohammed, 2012; Staver & Bay, 1987). Its activities are designed to guide the thinking of learners during the lesson, while the implementation of POGIL requires active participation of learners as they actively construct ideas (Bodner, 1986; Driver, Osoko, Leach, Scott, & Mortimer, 1994). It is imperative for the POGIL activities to be embedded with the guiding component in them so that implementation will be easy (Frey & Shadle, 2019).

POGIL is most aligned to the Identifying Inquiry of Levy and Petrulis (2012) because the teacher selects the concepts and focuses in helping the learners uncover ideas that are already known. Its design also introduces inquiry in which pre-existing disciplinary content is already known and learners are supposed to master and build their own understanding (Frey & Shadle, 2019). The teacher selects guiding questions to support inductive reasoning using the learning cycle. POGIL also has the advantage of being adaptable and can be used in any classroom setting and to cover specific content of a course (Frey & Shadle, 2019). These activities replace all the content that a normal lecture lesson or a laboratory exercise might have covered.

POGIL develops special inquiry skills such as communication, presentation, teamwork, critical thinking, problem solving and reasoning and enables learners to get a deeper understanding of the concepts (Hein, 2012; Furtak, Seidel, Iverson, & Briggss, 2012; Process Oriented Guided Inquiry Learning, 2010). These skills improve learners' scientific literacy, prepare them for future careers (McGuire & McGuire, 2015) and may also motivate learners to develop into future researchers who may possibly contribute to the body of knowledge in their future careers.

POGIL has been successfully used at primary, high school and up to university level with all the learners demonstrating improved understanding and achievement in science, engineering and mathematics (Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). POGIL captures the curiosity of young learners by starting from the known concepts and working toward the unknown concepts, from the easy to the difficult concepts, and from exploration to application. The learners become motivated to learn science and develop understanding because they perceive science concepts to be within their cognitive reach (Vygotsky, 1934/1986).

During POGIL, learners most typically work in groups of 3, 4 or 6, but they can also work in pairs if the learners are still learning the process or if they are slow learners (Simonson, 2019). The activities are carefully structured to enable cooperation in small, self-managed teams that help develop process skills. The work is also scaffolded through activities and investigations that help them construct their own knowledge. The activities have specific roles, steps, and targets that help develop responsibility and metacognition on the part of the learner (Simonson, 2019). The role of the instructor is to facilitate consistency in the development of concepts

Another recent study revealed that learners' performance was improved by using POGIL rather than lecture methods (Bodner & Elmas, 2020). Some recent research revealed that POGIL and modified POGIL failed to build argumentation skills in buffer solutions but improved by incorporating Polya's problem-solving model (Laily, Prastika, Marfu'ah, & Suharti, 2020; Oktaviani, Prastika, Fajaroh, & Suharti, 2020). This suggests that even though the current study focused on how POGIL elicits learners' reasoning about stoichiometry, previous studies show contradicting effects of POGIL with relations to problem-solving and performance.

During POGIL activities, learners are assigned roles in their teams. Activities are designed as the first introduction of a topic or for specific content which the learners are not expected to have done previously. The groups are expected to complete all the questions during the lesson (Simonson, 2019; Moog & Spencer, 2008) although there may be additional problems to solve outside of teaching time.

During the activities, learners gradually develop the concepts by themselves instead of having information transmitted to them as with the lecture method. The activities promote learners to develop process skills within and outside of the content area. While the traditional methods provide definitions, laws, and rules, POGIL provides data in the form of photos, graphs, text, and tables which the learners use to develop an understanding of the concepts (Simonson, 2019). The process leads to the powerful learning 'aha moment'.

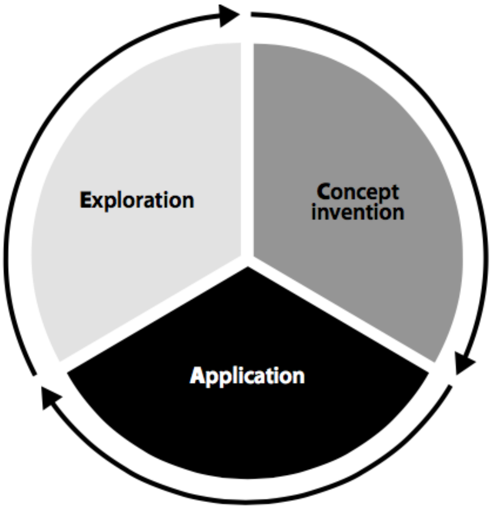
2.6.1 The Learning Cycle

The learning cycle (LC) is a strategy employed by POGIL in the delivery of classroom and laboratory activities. It is based on Piaget's ideas of learning. The basic model for cycle learning was proposed originally by Karplus and Their (1967) as a basic model for teaching elementary science.

In the study by Karplus and Their (1967), a teaching unit was made up of several class sessions where learners were engaged in exploratory activities. The learners analysed both new and familiar materials to deepen their understanding of previously formed concepts. The instructor monitored comprehension, skills, and attitudes as the learners were working. After enough time was given for exploration, the learners were given the name of the concept they were investigating. This type of lesson was called the invention lesson. After concept invention, the learners were encouraged to apply the concept in new experiments and experiences. These were called the discovery lessons. Much of the time in elementary school was spent on discovery lessons. The learning cycle by Karplus and Their (1967) was later studied by (Abraham & Renner, 1986) using six sequences that consisted of one normal and five altered. The study concluded that the normal learning cycle order (exploration, invention, and discovery) was for developing content knowledge. Lawson (1988) worked with the ideas of Karplus and Their (1967) and adapted invention as introductory phase and discovery as concept application. Figure 2.2 shows a diagram of the learning cycle model adapted from Lawson, (1988) which is used in POGIL.

Figure 2:2

The learning cycle model (adapted from Lawson, 1988)



The learning cycle provides the structure for POGIL activities. As such, POGIL activities are generally referred to as learning cycle activities. The Guided Inquiry Learning (GIL) portion of POGIL is usually completed in one class period. During exploration, the learners examine a model which can be data, text, a figure, or suitable learning tools. The exploration phase is inductive and takes advantage of the need by humans to identify patterns in a phenomenon. During exploration, learners examine data, a figure, or text which guides them through a series of observations and discoveries that aim to capture the prior knowledge of the learners and introduce new knowledge to them. This helps learners to notice the relationship between the prior and new knowledge and identify the meaningful knowledge to assimilate. The activity, which is known as a model, is designed with carefully structured questions that guide learners using a blend of simple and complex questions working together to develop conceptual understanding. The discussions engaged in by the learners lead them to recognize patterns and relationships on the provided knowledge, linking them to their prior knowledge. The questions guide learners until they invent the concept by themselves. After concept invention, the facilitator of the POGIL activity will then provide the scientifically acceptable name of the concept to the learners.

The previous paragraphs were a description of the components of the guided inquiry learning component of POGIL. In the following paragraphs, I describe the oriented process as a component of POGIL. The description of the PO (process oriented) component of POGIL completes the description of POGIL.

2.6.2 Process Oriented Education

Process education envisages the enhancement of learning by utilizing strong assessment skills for increased future performance (Pacific Crest, 2013). Learners are expected to reflect on what they learned as to what worked well and what did not work well, what they have learned, and what they need to learn. This reflection comes from both assessment and self-assessment of the learners which directs them to develop transferable work and life skills. The process- and life skills learned during POGIL develop learners for future work-related and life purposes. The process skills are also referred to as transferable skills, professional skills, workplace skills, or soft skills and emphasize the relevance of education when learners prepare to face the world (Renee, Lantz, & Ruder, 2019). According to POGIL, the process skills are communication (oral and written), teamwork, information processing, critical thinking, problem-solving, management, and assessment (self, peer, and metacognition) (Renee, Lantz, & Ruder, 2019).

Communication is defined as the exchange of information through speaking, listening, written materials and non-verbal behaviours. Both oral and written communication requires the use of appropriate language and suitable expressions in both content and grammar, which are understood by the audience. Communication both oral and written is important for learners during POGIL activities as they discuss their ideas to solve the problem. It is also important as the group present their response to the facilitator or the whole class. Written communication is important when learners submit written work for assessment to ensure that the marker clearly understands what is meant by the written information. The learners need to be well equipped with the proper language and correct concepts for the subject under discussion (Renee, et al., 2019).

Teamwork is a skill worthy of cultivating in the learners considering the need to work collectively at a local and global level. Teamwork consists of parameters like team decision-making, leadership, conflict management, resolution, planning, collaborative problem-solving, and trust-building. Besides being an asset in their future professions, these parameters also help learners succeed in their studies (Hughes & Jones, 2011; Vance, Kulturel-Konak, & Konak, 2014).

Information processing is the interpretation, evaluating and transforming of information which can be symbols, text, diagrams, plots or models, or translations or transcriptions aimed at getting to the proper meaning of concepts (Renee, Lantz, & Ruder, 2019). Learners usually have difficulties interpreting scientific concepts (Greer, 1997; Nakhleh, 1992; O'Toole & Schefter, 2002). Some studies have revealed that learners develop mental models of all the things they learn as they make their own representations of the concepts (Mamombe, Mathabathe, & Gaigher, 2020; Nelson , 1999; Novick & Nussbaum, 1985). Learners need to process the information and need to be provided with suitable strategies and resources for effective processing to occur (Renee, et al., 2019).

Critical thinking involves analysis, evaluation, and synthesis of information to reach a conclusion with supportive evidence (Renee, Lantz, & Ruder, 2019). It is an essential outcome of formal education (Fahim & Masoulch, 2012) because it includes application of skills and resources (Bailin, 2002; Lewis & Smith, 1993). The practice of critical thinking leads to the development of higher-order thinking skills (Lai, 2011). Components of critical thinking include, but are not limited to, identifying information sources, distinguishing between available evidence, evidence-based conclusions, and forming judgements based on reasons and evidence (Miri, David, & Uri, 2007; Zohar, Weinberger, & Tamir, 1994). Unlike POGIL, most formal education rarely aims at developing critical thinking skills or seek feedback as to the extent to which learners have developed critical thinking (Renee, et al., 2019).

Problem solving is the process of planning and carefully executing a strategy that finds a solution to a problem or question (Renee, et al., 2019). The dimensions of problem-solving include strategy, identification of variables, procedure, and use of formulae (Carlson & Bloom, 2005; Garrett, 1986; Taasoobshirazi & Glynn, 2009). Problem-solving requires a non-trivial process involving multi-step procedures to arrive at the appropriate answer (Renee, et al., 2019). Many instructional methods provide learners with opportunities that require problem solving, but few provide explanations that guide learners (Renee, et al., 2019).

Management, also referred to as self-regulated learning, is the ability of learners to plan, organize, and coordinate others and themselves to accomplishing a goal (Renee, et al., 2019). The dimensions of management include, but are not limited to, creativity, decision-making, planning, and organizing. Each learner needs to be educated on management skills so that they manage themselves and some may become managers of others (Renee, et al., 2019).

Assessment is the gathering of information and reflecting on previous experiences to improve future learning and performance (Renee, et al., 2019). Self-assessment and peer assessment require monitoring of learning progress and determination of learning needs (Falchikov & Boud, 1989; Walser, 2009).

Metacognition is thinking about, and being critically aware of, one’s thought processes as a thinker and learner (Renee, et al., 2019). It is composed of self-regulation, awareness of the demands of a task, understanding factors affecting one’s cognition, and problem solving (Veenman, 2012; Zohar, Weinberger, & Tamir, 1994). Assessing process skills in the classroom is often constrained by a lack of resources. The available resources are channelled into assessing broad institutional goals or assessing the general aims of the program. There is, therefore, less focus on assessing classroom progress or providing feedback to learners and instructors (Renee, et al., 2019).

POGIL activities are hinged on the learning cycle (Lawson, 1988), where learners develop process skills through information processing as they use reasoning and critical thinking to interpret and understand the provided models (Renee, et al., 2019; Karplus & Their, 1967). The directed questions during the exploration stage of the learning cycle develop critical thinking and problem-solving skills by guiding learners to consider certain parameters of a concept during the process of concept development. These questions direct learners to develop communication skills as they will have to explain their understanding to one another (Renee, et al., 2019). The use of the learning cycle promotes scientific argumentation (Kulatunga, Moog, & Lewis, 2014). POGIL activities should, however, not be too hard because learners may not progress well and may not develop the necessary process skills. The activities be too easy either, as the learners will end up doing the activities individually and compare their responses afterwards. POGIL activities, therefore, need to be at a level that promotes collaboration amongst learners, encouraging them to inquire more from the available resources and even from the facilitator (Renee, et al., 2019). Table 2.4 shows the roles assigned to each team member in POGIL and the process skills developed by assuming each role (Renee, et al., 2019).

Table 2:4

Process skills developed by use of roles in POGIL (Renee, et al., 2019)

Role	**Tasks**	**Process skills developed**
Manager	Reads questions to the group. Ensures that all members participate actively. Time keeping. Asks questions for the team.	Management, self and peer assessment, teamwork, oral communication
Presenter/ spokesperson	Presents written or oral answers for the team. Defends group answer to a problem.	Oral and written communication, critical thinking, teamwork
Recorder	Completes reflection reports or answers from group quizzes.	Teamwork and written communication.
Reflector	Reflects of group experiences or process skills.	Metacognition and assessment, communication, teamwork.
Team strategist	Reflects on how the team functioned and the contributions of team members.	Teamwork, metacognition self and peer-assessment, management.

Technician	Manages team materials (apparatus) and their use.	Management, teamwork, communication

POGIL facilitators are encouraged to make annotations on the activities so that they make follow-up questions to help learners to develop process skills. Such annotations also remind the facilitator of the questions to ask at an instance to probe learners and develop process skills (Renee, et al., 2019). The facilitators can focus on one or two process skills per lesson and make the annotations that will focus on the development of such skills (Renee, et al., 2019). The nature of instructor facilitation is particularly important for the development of process skills (Daubenmire & Bunce, 2008; Daubenmire, et al., 2015; Stanford, Moon, Towns, & Cole, 2016). When learners work collaboratively, they develop teamwork, communication, management, and other process skills, but it takes some time for the teams to cultivate team spirit (Loo, 2013). Assigning learners with roles and changing the roles after a few activities help them to develop a variety of process skills (Bailey, Minderhout, & Loertscher, 2011; Hanson, 2006; Johnson, 2011).

The instructor can facilitate the development of process skills by asking questions that promote the use of a particular skill or having group reports (Daubenmire, et al., 2015; Kulatunga & Lewis, 2013; Stanford, Moon, Towns, & Cole, 2016). The nature of group interactions increases when the instructor asks more guiding questions or requires learners to provide justification to their answers (Daubenmire & Bunce, 2008; Daubenmire, et al., 2015; Kulatunga, Moog, & Lewis, 2014; Stanford, Moon, Towns, & Cole, 2016). Learners take more time to prepare high-quality responses with sound argumentation when the instructor asks questions that elicit reasoning. Such probing questions help learners to justify their conclusions (Renee, et al., 2019). Asking learners to provide justifications for their responses assists them to think critically (Daubenmire, et al., 2015). The facilitator enhances critical thinking by asking learners in each group to explain their responses supporting their claims with reasoning or ask two teams to explain their responses with supporting evidence to convince each other. The facilitator may also ask prompting questions to guide learners in the direction they should be thinking. Observing teachers as they facilitated POGIL activities was useful in determining the extent to which they used the prompts to encourage the development of process skills. Table 2.5 shows some prompts that facilitators should use to promote and enhance the development of process skills (Renee, et al., 2019).

Table 2:5

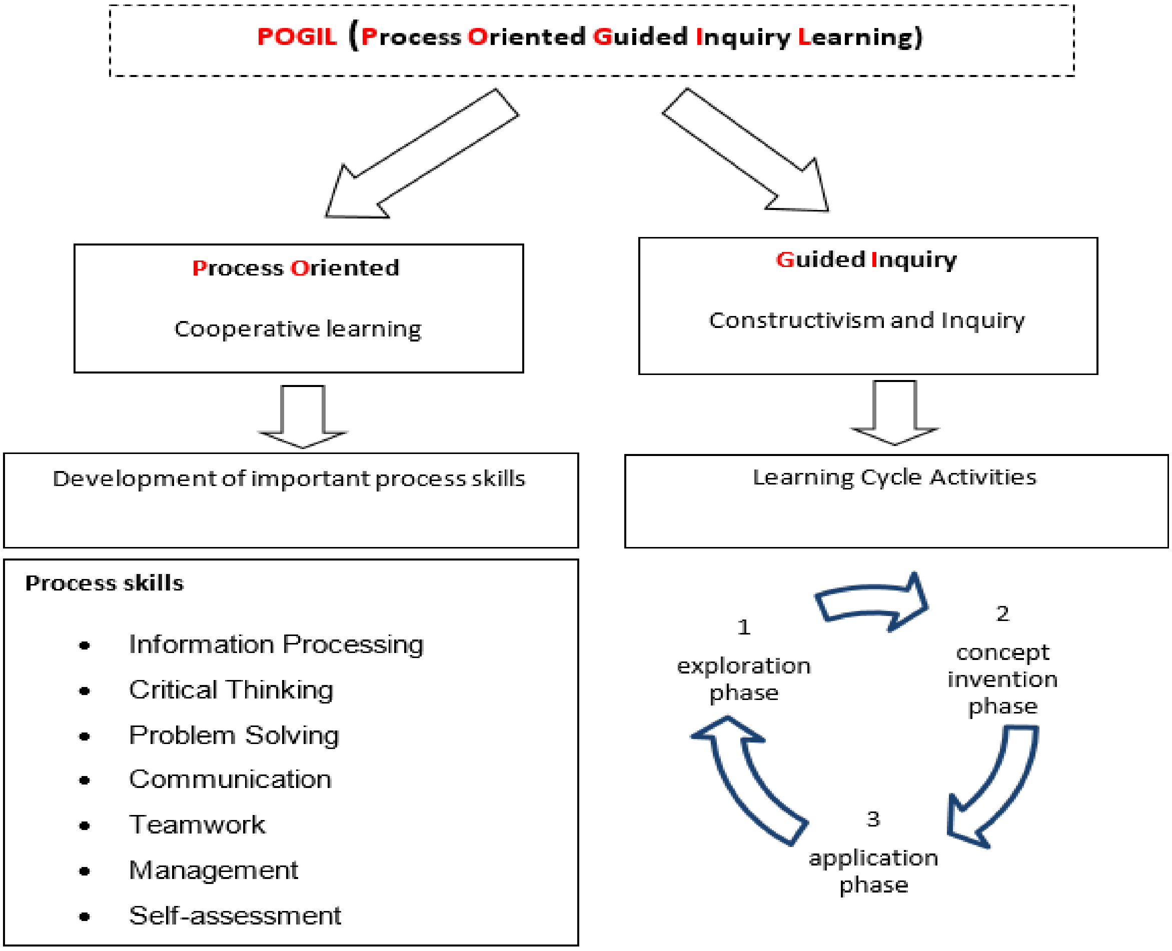
Prompts to facilitate development of process skills (Renee, et al., 2019)

Process skill	**Facilitator prompting statement**
Oral communication	Justify your answers to each other. Defend your answers with reasoning. Presenter must verbalize the answer of the team.
Written communication	Teams must complete the tasks in full sentences. Teams must write answer on the board/chart.
Management	Managers to check in with each member. Managers to pace the team sticking to the given time. Managers to get responses from each team member.
Information processing	Ask teams to identify key terms and their meanings. Teams to think about their prior knowledge applicable to the task.
Critical thinking	Teams explain their answers using claim and supporting evidence. Teams with different answers to defend their answers with reasons. Teams to critique an argument or a solution provided.
Problem-solving	Teams to explain the strategy for getting an answer. The whole class discusses differing strategies used by teams.
Teamwork	Assign roles to each member. Ask if each member agrees with the response. Allow only the manager to ask questions to the facilitator. Assign team projects and quizzes.

POGIL involves the process-oriented and guided inquiry learning components. These have been described at length in this study and work simultaneously to develop the learner. The process-oriented component develops the process skills as the learners work in groups. The presence of a qualified facilitator and well prepared POGIL worksheets guide learners through the learning cycle during the activities as they develop concepts. Cognitive processes actively occur as learners attentively participate and actively interact with the text, with each other and with the facilitator and as they develop conceptual understanding. Figure 2.3 shows a summarized picture of components of POGIL.

Figure 2:3

Characteristic components of POGIL (Simonson, 2019)



2.6.3 Advantages of POGIL

There exists a substantial library of readymade and well prepared POGIL worksheets for science, engineering, and mathematics (Moog & Spencer, 2008; Process Oriented Guided Inquiry Learning, 2010). Facilitators throughout the world need only adapt the learning material to their classroom contexts and expectations (Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). The POGIL worksheets should be well constructed so that they lead learners through learning cycles following a series of activities that guide learners to personally develop concepts. One of the advantages of POGIL as an inquiry approach is that it is not confined to one source of information. The learners can search from many information sources such as textbooks, the internet, peers, or the facilitator, which they may use to acquire knowledge (Mabusela

& Adams, 2016; Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). Well trained facilitators adapt POGIL worksheets so that learners can learn in context and, therefore, develop an in-depth understanding of the content (Mamombe, Kazeni, & de Villiers, 2016). POGIL promotes strong self-directed learners who can face real-life problems when leaving school (Kompa, 2012; Process Oriented Guided Inquiry Learning, 2010). POGIL helps learners by focusing on the development and use of high-level cognitive and metacognitive skills (Anderson & Krathwohl, 2001; Bloom, 1956; Simonson, 2019). These high-order cognitive skills form the basis of investigative skills used when searching for information, analysing, synthesizing, evaluating, creating, and organizing findings. These skills show learners' understanding of the content and not just memory recall (Bloom, 1956; McGuire & McGuire, 2015; Zohar & Dori, 2012). The cognitive and metacognitive skills are helpful for learners to become self-regulated, continue research to discover more knowledge, and for learners to be aware of what they know and what they need to know (McGuire & McGuire, 2015; Nelson , 1999; Zohar & Dori, 2012).

Inquiry, and particularly POGIL, allows for the active participation of all learners, encouraging them to have dialogue and engaging them in inductive and systematic thinking (Simonson, 2019; Alebiosu, 2005). During POGIL, learners share their ideas and exchange roles as they discuss problems giving supporting reasons. POGIL practitioners work as a team in the POGIL project to expand the teaching approach to all parts of the world. They train POGIL facilitators and guide and assist those already trained. They have a networking facility for all teachers and prospective POGIL teachers who are either interested in or already using POGIL in their classrooms (Moog & Spencer, 2008; Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). Another advantage is that learners develop concepts by themselves, thereby reaching the 'aha' moment which helps them to remember what they learnt. POGIL helps the development of process skills which are an essential goal of teaching.

2.6.4 Shortcomings and challenges of implementation

A study by Kirschner, Sweller and Clark (2006) revealed that unguided or minimally guided instruction may not be effective in eliciting learner understanding. For that reason, POGIL has a principle that a POGIL class must be facilitated by a POGIL-trained facilitator, and that a POGIL lesson cannot be allowed to proceed in the absence of a POGIL-trained facilitator (Clark, 1969; Kirschner, Sweller, & Clark, 2006; Moog & Spencer, 2008; Process Oriented Guided Inquiry Learning, 2010). The unavailability of trained teachers in Africa and many parts of the world means that they cannot implement POGIL method though they can access POGIL worksheets freely on the internet. Another constraint of POGIL is the amount of time it takes from training to the actual implementation of POGIL lessons (Kirschner, Sweller, & Clark, 2006; Kurumeh, Jimin, & Mohammed, 2012; Simonson, 2019). School curricula are structured to have weekly topics and the Department of Education provides tests at the end of each term where all the expected topics are covered. The fixed timeframe may not work for POGIL, because more time is required to complete the topics and may not meet the requirements of mandatory assessments. A further limitation is the lack of teachers with in-depth science content knowledge. During POGIL, the teacher must be able to assist learners at any learning stage of the worksheet. The teacher must guide the learners when they are lost by asking guiding questions or referring them to appropriate text (Bybee, 1997; Bybee, 2010). Lastly, another setback of POGIL teaching may be that of noisy classes as learners will be involved in a lot of discussions (Alemu & Schulze, 2012; Pascarella & Terenzin, 2005).

Many teachers are not aware of the results which demonstrate the effectiveness of POGIL (Simonson, 2019). Most teachers and lecturers, especially in Africa, do not know the POGIL method. For example, during two workshops held in 2018 in a district in Pretoria, South Africa, all twenty lecturers and twenty-five high school teachers were unaware of POGIL as a teaching approach.

Most teachers are concerned about learning a new teaching approach. Such teachers tend to resist the new method so that they keep on using the old methods. This may be due to the fear of the unknown, while some may think of POGIL as a difficult method (Process Oriented Guided Inquiry Learning, 2010). Some teachers complain that POGIL method requires too much time to cover all the content in the annual teaching plan. POGIL may also be impractical when classes have large number of learners (Simonson, 2019). In such cases it may be difficult for one teacher to control too many groups in the same class at the same time.

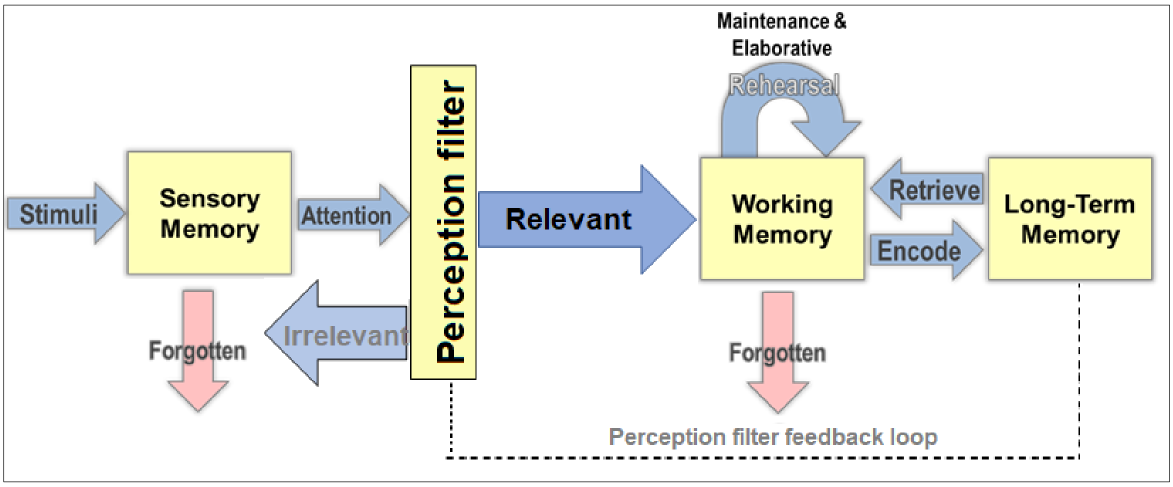
2.6.5 Information Processing Model

Bransford, Brown and Cooking (1999) discussed the importance of information processing on cognition. The information processing model is aligned to constructivist and Piagetian notions that knowledge is constructed by the learner based on experiences (Piaget, 1930; Wadworth, 1989). The model by Bransford, Brown and Cooking (1999) describes how people acquire knowledge and how they integrate it with existing knowledge to gain new understanding. Humans observe the environment using their senses of sight, hearing, feeling, smelling, or tasting. When knowledge reaches the sense organs, some of it is perceived but some knowledge may not be perceived. The knowledge that is not perceived is lost. For this reason, teachers need to communicate in the language, method and context that is understandable by the learners using suitable teaching aids (Bransford, Brown, & Cooking, 1999).

All perceived knowledge is ready for scrutiny by the perception filter. The knowledge that is perceived as irrelevant is lost and forgotten, while the knowledge perceived as relevant is sent to the working memory. In this regard, a well-prepared lesson will not have a lot of irrelevant information. Only relevant knowledge is ready for assimilation. However, before assimilating new knowledge, the related prior knowledge will be retrieved and analysed together with the new knowledge. This may lead to the new knowledge being assimilated together with the related old knowledge after proper coding. The old or new knowledge may be rejected depending on which one is perceived to be meaningful. Only meaningful information is stored in the long-term memory. Any information perceived as relevant is initially stored in the working memory while prior knowledge is recalled from the long-term memory. Possible new connections can be developed between new and prior knowledge (Bransford, Brown, & Cooking, 1999). The comparison of new and old information forms the centre of the learner’s reasoning and critical thinking. Figure 2.4 shows the information processing model (Bransford, Brown, & Cooking, 1999).

Figure 2:4

Information processing model (adapted from Bransford, et al., 1999)



The information processing model is useful for POGIL instructors and is examined through the learning cycle lens. Because humans observe the environment with their senses, some of this may be relevant and considered for storage. Other data may not be perceived as relevant and may not be stored (Bransford, Brown, & Cooking, 1999). This is partly because the brain has a limited capacity for storage (Miller, 1956). The perception filter prevents information that is not essential to the task at hand from reaching the short-term memory. This is important to avoid overloading the short-term memory with unneeded information (Bransford, Brown, & Cooking, 1999). Instructors should consider the role of the perception filter to effectively guide learners on what is relevant.

During the learning cycle activities, the questions asked will direct learners' attention to relevant information. Such questions should include the learners' prior knowledge to depart from the known point of view. When the learners retrieve information from the long-term memory, they will be able to compare it with the current information. During exploration and concept invention, appropriate information processing leads to the integration of relevant information with the long-term structures (Johnstone, 1997). Questions in the learning cycle activities are layered so that relevant ideas are explored more than once in an organized way. This repetition helps the learners to digest the information and promotes the uptake of relevant information into the long-term memory (Johnstone, 1997). In a POGIL classroom, the facilitator listens to group discussions or reads the answers of the groups to determine if they are on course. If not, the facilitator will provide additional information or ask questions to get the learners to refer to their prior knowledge and compare the additional information with the current information (Smith, Brown, Roediger, & McDaniel, 2015).

A person's prior knowledge or belief may hinder or help the interpretation of new information. Learners can be biased due to culture or religion. A person's religious belief may hinder them from accepting new information due to what they believe to be right (Smith, Brown, Roediger, & McDaniel, 2015). Sometimes prior knowledge can be incorrect or limited (misconception). Learners have observed the environment since infancy and some of this information is already stored in the long-term memory, though it may not have been examined in difficult contexts. Misconceptions are not easy to erase unless meaningful information is brought in to replace the misconception (Areepattamannil, 2012). For this reason, instructors need to be selective of the teaching methods they use during classroom activities. Teachers need to be aware of the prior knowledge of the learners to pre-empt and avoid misconceptions. To date, lists of previously identified misconceptions that are common among learners have been identified in each topic (Balushi, Ambusaidi, Al-Shuaili, & Taylor, 2012; Dahsah & Coll, 2007).

The context of a situation may also affect the way learners retrieve information from the long-term memory, including what passes through the perception filter. This is because some contexts may not be familiar to the learners (Mamombe, Kazeni, & de Villiers, 2016). POGIL teachers need to use appropriate contexts to make the information meaningful to learners.

Individuals have different abilities when it comes to retaining pertinent ideas in working memory. Some individuals capture and retain information that is not relevant (Vogel, McCullough, & Machizawa, 2005), thereby reducing the availability of relevant ideas. The capacity of working memory continues to develop into adolescence, up to around 20 years (Peverill, McLaughlin, Finn, & Sheridan, 2016). Students who do not have refined perception filters by the time they leave high school often struggle to process difficult tasks. They need special strategies to free up working memory space. POGIL activities contain strategies which can be used to free the working memory of irrelevant ideas. It is essential that relevant information required for the completion of tasks is passed through the perception filter into the working memory because individuals possess limited working memory capacity. The perception filter can be re-shaped over time due to experiences. Some new experiences can cause the perception filter to be re-moulded. The bias due to religion, misconceptions and other factors may be re-moulded through new experiences (Peverill, McLaughlin, Finn, & Sheridan, 2016).

POGIL is subject to the constraints of the perception filter and the short-term memory. As such, POGIL instructors carefully select and limit the information they provide and monitor the knowledge the learners bring to the task in real time. The processing of information done in the working memory is critical for interpreting the information, making comparisons, and rearranging information for storage in the long-term memory. Carefully crafted learning cycle activities used in POGIL help students to organize and rearrange information.

In the following paragraphs, I will describe the cognitive processing and concept development as viewed by the POGIL way of teaching.

2.6.6 Cognitive Processing

Since the nineteenth century, it is evident that inquiry was the proper method to teach science for understanding but there seemed to have been no effective change in science methodology (DeBoer, 1991; Levin & Cuban, 1993). The inquiry approach only gained ground in the twentieth century because of growing interest in experimental research in psychology and sociology. That is when human cognition was first tested (Pennar, Batsche, Knoff, & Nelson, 1993; Bruer, 1993).

Festinger (1957) described the theory of cognitive dissonance where a learner is provided with information contrary to their existing knowledge beliefs or values (Festinger, 1957). This state of dissonance is a point of conflict that is fertile ground for learning (Posner, Strike, Hewson, & Gertzog, 1982; Hewson, 1992). If the new information is appropriately related to the existing ideas, then conceptual change occurs, and the new idea is accommodated. If the new idea has no proper links with existing knowledge, then it is rejected, and the learner keeps the old conception (Posner, et al., 1982; Hewson, 1992).

During inquiry, therefore, a learner can freely explore the new information from the text, from peers and the facilitator. This may result in positive conceptual change. While during a lecture method the teacher is doing all the talking and is unaware of the cognitive conflicts in the minds of the learners. The teacher is therefore unable to provide enough supporting evidence the learners may need for effective conceptual change.

Newell and Simon (1972) studied the theory of human problem solving as it relates to memory function, goal-setting and usual representation (Newell & Simon, 1972). The study by Piaget and Inhelder (1969) and that by Wadworth (1989) demonstrated that as children learn mathematics and science, they develop personal models to explain concepts such as number properties and reasoning abilities, such as control of variables and, ratio and proportional reasoning (Piaget & Inhelder, 1969; Wadworth, 1989). Learners acquire conceptions of the world formally of informally and these conceptions undergo evolution (Driver, Guesne, & Tiberghein, 1985). The learners use personal mental evidence to represent almost every concept they have come across in the form of mental models. Such mental models may be difficult for scientists to interpret and are called “emerging ideas” (Mamombe, Mathabathe, & Gaigher, 2020) or “strange idea” (Driver, Guesne, & Tiberghein, 1985). The study by Driver, Guesne and Tiberghein (1985) resulted in many investigations in the 1980s and 1990s regarding learners’ misconceptions at all education levels (Wandersee, Mintzes, & Novak, 1994).

Constructivism has recently gained traction in education and psychology. In constructivism, knowledge and understanding must be personally constructed in the mind of the learner (Simonson, 2019). Learners construct knowledge and understanding in any classroom setting, but a well-designed instructional approach facilitates efficient and successful knowledge construction (Fosnor, 1996; Tobin, 1993).

Ausubel, Novak and Hanesian (1986) argued that ideas learned meaningfully are incorporated in the cognitive structures so that they will become memorable and reliable because they are connected to pre-existing cognitive structures (Simonson, 2019; Ausubel, Novak, & Hanesian, 1986; Ausubel, 1978). This is contrary to rote learning where there is no link between pre-existing knowledge and new knowledge. New ideas which are not connected to existing ideas are less likely recallable and are usually lost (Novak, 1977).

Vygotsky (1986) studied the sociocultural development and knowledge constructivism in what is called the Zone of Proximal Development (ZPD) (Moll, 1990; Vygotsky, 1934/1986). Vygotsky (1934/1986) suggests that learning is most effective when the task is within cognitive reach and is an obtainable goal. The facilitators must be aware of moments in the activities when learners get stuck and need help. The zone may require creative thinking and facilitators need to properly guide the learners so that the task remains within cognitive reach. Reaching the ZPD may be difficult for individual learners working in unguided activities, but with POGIL the situation is tailor-made to facilitate tasks to come within cognitive reach. This is the reason why POGIL worksheets are carefully designed to take learners from the simple familiar concepts to the more complex ones. Learner interaction and constant support from the facilitator keeps learners' attention and guides it toward concept invention and understanding. Communication between learners and the facilitator is critical for the development of understanding (Bruner & Haste, 1990; Process Oriented Guided Inquiry Learning, 2010).

2.6.7 Reasoning

Reasoning is a human's ability to logically draw inferences by use of argumentation (Merriam-Webster, 2020). It is the activity of evaluating arguments (Goel, Gold, Kapur, & Houle, 1997). It is used formally or informally for decision making, critical thinking and logically solving problems. Learners apply reasoning when they use their understanding to apply, analyse, evaluate, and create knowledge.

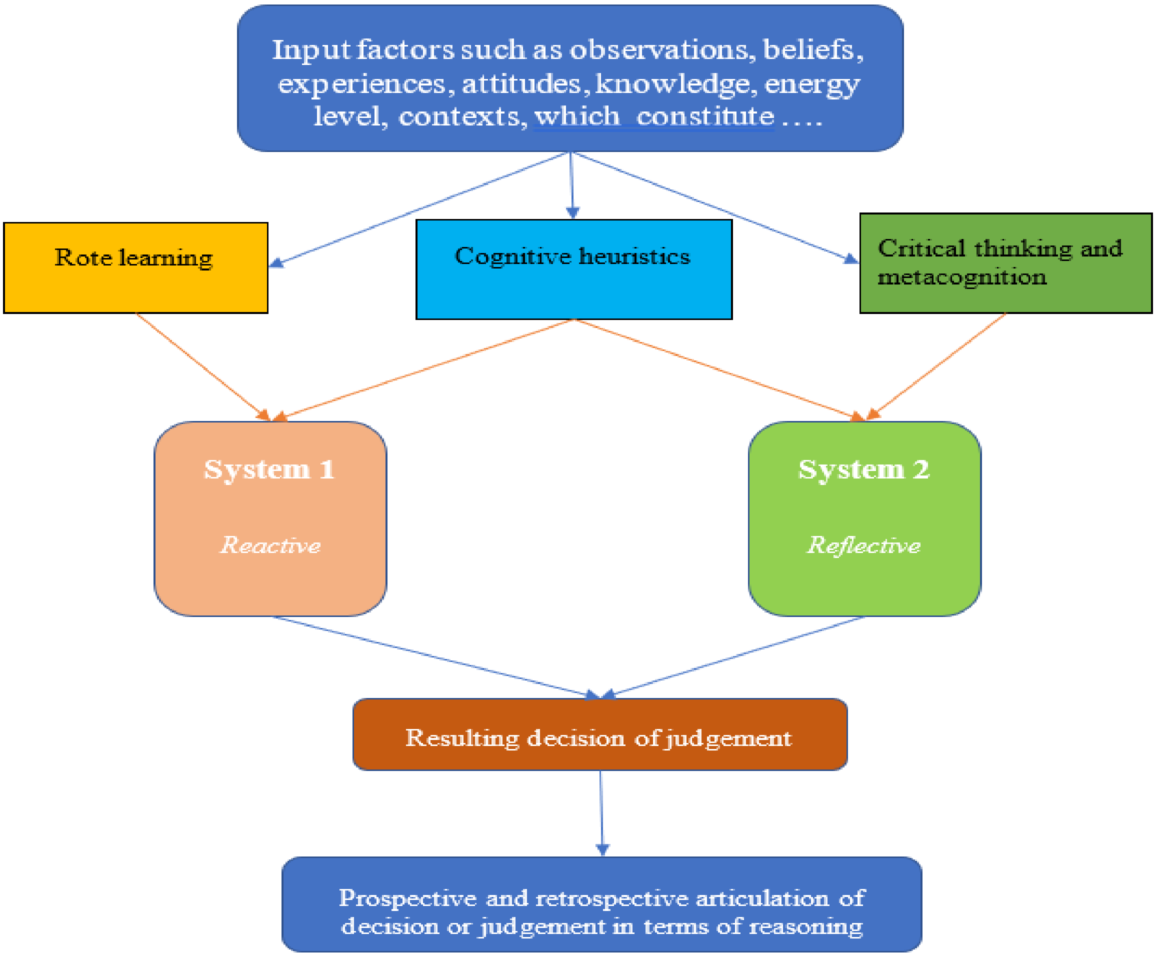
According to Facione and Facione (2008), there are two overlapping systems of reasoning that are active in human decision-making, system 1 and system 2. System 1 is based on rote learning and practice and is reactive, instinctive, quick, and holistic. System 2 is based on critical thinking and metacognition and is reflective, deliberate, analytical, and procedural (Facione & Facione, 2007; Facione & Facione, 2008).

System 1 relies heavily on heuristics and existing memories to make quick judgments in familiar situations where immediate action is required (Facione & Facione, 2007; Facione & Facione, 2008). Often, the decisions made using system 1 help to quickly avert danger. System 2 is argument-based and relies slightly on heuristics integrated with several logical arguments to make judgments in unfamiliar situations, for processing abstract concepts, and for deliberate planning and comprehensive consideration (Facione & Facione, 2008; Facione & Facione, 2007). Both systems work simultaneously, balancing each other in a way that each system works where it is best needed. People operate with both systems of reasoning, but it is possible to identify when a person is skewed to one system or the other. Both systems are used to make judgements while reasoning.

An education system aimed at improving one’s critical thinking, that is, at improving ones problem-solving and process skills to engage purposeful reflective judgment, is focused on strengthening one’s system-2 problem solving and decision making (Facione & Facione, 2008; Facione & Facione, 2007). When system 2 works optimally the decision is based on interpretation, analysis, evaluation, explanation, and self-correction (Facione & Facione, 2008; Facione & Facione, 2007). System 2 values intellectual honesty, analysis of facts, fairness, truthfulness and is without biases. Both systems make use of cognitive heuristic and each learner makes use of both systems but with different levels of intensity. Figure 2.5 shows how the two systems relate to one another and how both lead to decision-making (Facione & Facione, 2008).

Figure 2:5

The argument and heuristic analysis model by Facione & Facione, (2008)



Decision-making based on reasoning demonstrates how the answer is correct. It demonstrates the procedure of getting to the answer which is the final decision. It shows the understanding held by the decision-maker as the basis of taking up such a decision (Facione & Facione, 2007; Facione & Facione, 2008). This separates decision-making based on reasoning and decision-making based on guessing. This is the type of reasoning necessary for solving tasks that require a conceptual understanding of abstract concepts such as the ones found in chemistry.

According to Paans, Nieweg, Vermeulen, and van der Werf (2008), logical reasoning can be structured as deductive reasoning, inductive reasoning, deductive-abduction reasoning, and the common fallacies. Deductive reasoning begins with a major theory, generalization, fact, or premise that generates specific details and predictions (Paans, Nieweg, Vermeulen, & van der Werf, 2008). This is reasoning from the general to the particular and is defined as follows: if the facts in the premises are true, then the conclusion must be true (Johnson-Laird, 1999). The truth of the premises ensures the truth of the conclusion (Knauffa, Mulacka, Kassubek, Salih, & Greenleed, 2002). Inductive reasoning is a bottom-up formal method that seeks theories to explain observations. The truth of the premises does not warrant the truth of the conclusion (Knauffa, Mulacka, Kassubek, Salih, & Greenleed, 2002). Abductive reasoning is a bottom-up, less rigorous formal method that seeks theories and allowing good guesses to explain observations (Knauffa, Mulacka, Kassubek, Salih, & Greenleed, 2002).

Solving problems in a deductive way entails (a) comprehension of the propositions; (b) comprehension of the question; (c) search for information asked for in the question; and (d) construction of an answer. Comprehension of the question determines the search for the information asked and the construction of the answer (Clark, 1969). In line with Bloom's taxonomy of cognitive domain, the lowest stage of remembering corresponds to the comprehension of propositions and comprehension of the question. The search for information corresponds to the stages of understanding and analysis, applying, evaluating, and creating. All these cognitive stages require reasoning and critical thinking (Kuiper & Pesut, 2004; McGuire & McGuire, 2015).

An argument is a reason-claim combination (Arons, 1979). So, as learners perform group discussions, they make claims of a certain answer being correct and that claim is based on reasoning which they show by explanation or by calculations. A claim is a statement by which the person judges whether something is correct, while a reason is the justification of why he/she believes that the claim is true (Arons, 1979).

Arons (1979) found that arithmetic ratio reasoning is necessary for predicting numerical change, for example, the gravitational or electric forces when given new values in different scenarios, the calculation of the actual size of objects viewed under a microscope, or its use in demographic data. This same kind of reasoning is needed by learners to perform stoichiometric calculations as the learners use the ratio technique to identify the limiting reagent, to explain a shift in equilibrium, and explaining changes in the rate of reaction when some factor is altered. Learners should also be able to reason, not only quantitatively using formulae, but also on how they got the conclusive answer and from the inferences made, through qualitative explanations or demonstrations (Arons, 1979).

Much of the teaching and learning methods assume that reasoning capabilities are already developed, or that they will develop with maturity or through increased understanding of the subject matter, however, such automatic development only occurs in the upper 25% of successful learners (Arons, 1979; Jones, 2007). Research has shown that critical thinking seems to increase only if taught explicitly using learner-centred methods such as inquiry (Abrami, et al., 2008). A critical thinker must be skilled at reasoning (cognitive process) for drawing conclusions (Facione, 2009). Critical thinking instruction enhances performance and when combined with practice, critical thinking increases knowledge retention (Heijltjes, van Gog, Leppink, & Paas, 2014).

High school learners have been observed to lack problem-solving ability in stoichiometry which is essential for their performance at tertiary level (Lausin, 2020). Teachers are encouraged to impart higher-order thinking skills such as critical thinking, problem solving, rational thought, and reasoning (Cuban, 1984). Chemistry learning based on analogy positively impacts the higher-order thinking skills (Rahayu & Sutrisno, 2019). Some researchers have provided lesson plans for Grade 4 to 9 teachers so that the teachers may incorporate them in lessons to improve critical thinking among the learners (Paul, Binker, & Weil, 1990). This means critical thinking does not only focus on higher-level education, even lower-level learners need to think critically (Lewis & Smith, 1993). When the solution to a problem is not easily attainable, solving such would require reasoning (productive thinking) to identify a pattern of the parts that have been integrated using past experiences (Maier, 1933). High-order thinking skills involve reasoning or productive behaviour, while lower-order thinking skills are learned behaviour or reproductive thinking (Maier, 1933). Critical thinking requires being reasonable and reflective in thinking and focused on deciding what to believe or do (Ennis, 1987). Schools are improving in teaching the basics but not focusing on teaching about thinking (Glaser, 1983). As defined by Facione and Facione (2008), critical thinking is the process which considers available evidence, contexts, or methods to give a purposeful judgement (Facione & Facione, 2008).

Process-oriented programs aim to develop reasoning habits and learning skills to improve performance, metacognition, and self-monitoring of problem-solving learners (Bloom & Broder, 1950). POGIL activities seem to educate learners to develop critical thinking skills when they examine the questions individually and get to the interactive stage where they must give their responses accompanied by suitable reasoning or justifications (Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). POGIL is without doubt contrary to rote learning; its focus being on learners engaging in critical thinking and metacognition (Moog & Spencer, 2008; Process Oriented Guided Inquiry Learning, 2010).

2.6.8 Metacognitive Processing

Metacognition means thinking about your own thinking (McGuire & McGuire, 2015; Simonson, 2019). The learner at this level is no longer passive and depending on remembering but is now involved in the active mode of analysis, applying, and creating (Anderson & Krathwohl, 2001; Bloom, 1956). Science education becomes increasingly relevant when taught using strategies that encourage the practice of investigations along with the meta-level understanding (Zimmerman, 2007).

In practical situations, when self-regulation learning is supported, metacognition insights are developed, and this strengthens the cognitive (critical thinking) and the metacognitive (reflective thinking) (Cullipher, Sevian, & Talanquer, 2015; Kuiper & Pesut, 2004; Sevian & Talanquer, 2014). Critical thinking supports learners to make logical and unbiased decisions and leads to better learning (Facione, 2009; Helsdingen, Van Gog, & & Van Merriënboer, 2011). Critical thinking skills are important for an individual to make well-informed decisions and reasonably explain their ideas when solving problems (Thomas, 2011). Critical thinking is the intellectual work of the mind that involves thinking (Willingham, 2007). Reflective thinking is metacognition, that is, executive control and self-communication about experiences (Kuiper & Pesut, 2004). Environment-based programs demonstrated positive effects on critical thinking skills and the disposition towards critical thinking skills of Grade 9 and 12 learners (Ernst & Manroe, 2004). Science and technology taught using an inquiry-based approach demonstrated significant effects on learners' critical thinking skills in science (Duran & Dokme, 2016; Herawati, Hakim, & Nurhadi, 2020)

During POGIL activities, learners engage in the constructive stage of finding meaning in the information or questions. Each learner is aware that they will give their ideas to the group and justify their answer during the interactive stage. Therefore, they must carefully think about their own thinking so they can confidently defend their ideas with suitable reasoning in the group. Such learners can monitor their own thinking to improve their performance (Nelson , 1999; Zohar & Dori, 2012). Some of this activity is explicit, controllable, and learnable. Metacognition is a general goal with respect to critical thinking, and problem-solving skills, and as such, POGIL worksheets are designed with metacognition in mind (Simonson, 2019; Process Oriented Guided Inquiry Learning, 2010). POGIL acknowledges that knowledge is constructed in the mind of the learner, and it is an active process occurring in steps or cycles to embed new ideas into long-term cognitive structures (Simonson, 2019).

2.7 Conceptual framework

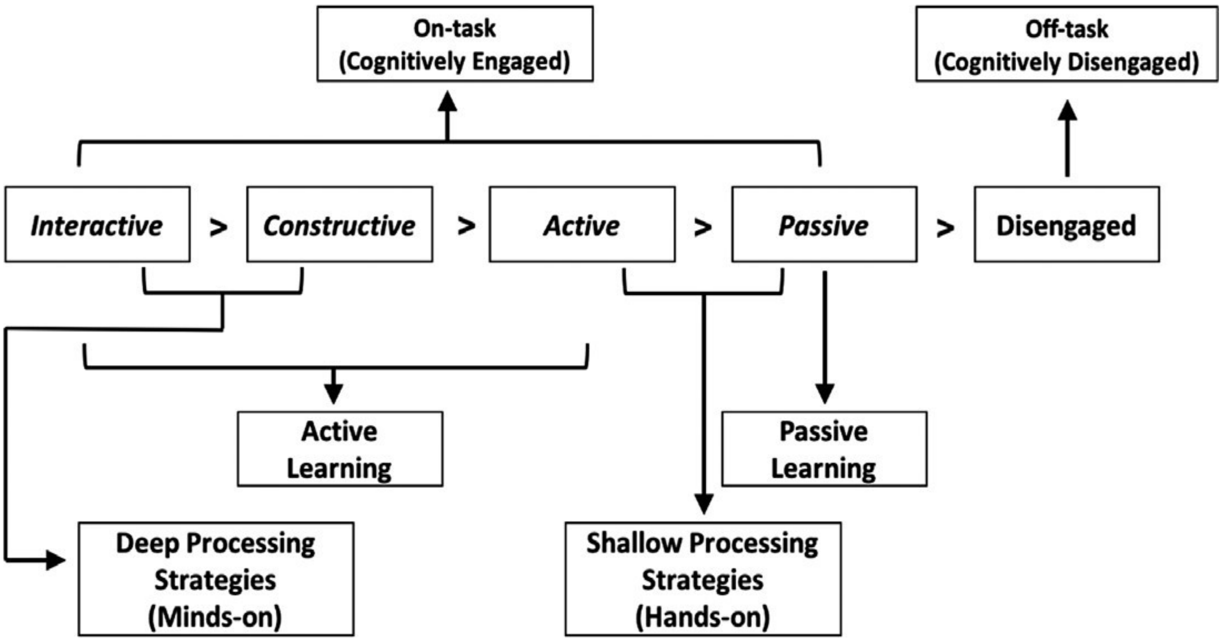
The current research is based on constructivist philosophy which holds that learning happens in the mind of the learner and involves the development of mental constructs or models (Vygotsky, 1934/1986). The conceptual framework used in this study is the Interactive, Constructive, Active, Passive framework (ICAP) (Chi, 2009; Chi, 2011).

The Interactive-Constructive-Active-Passive framework

The ICAP framework is based on the constructivist theory which acknowledges development of mental constructs by the learners (Vygotsky, 1934/1986). ICAP is used to differentiate the levels of cognitive engagement by learners during the POGIL intervention in various types of learning environments (Chi, 2011). The observable behaviours of learners define their levels of engagement, the assumption being that the behaviour of learners during an activity is related to the underlying cognitive process. The framework identifies that learners can be cognitively engaged in the given task or not. This is shown with the “on-task” as cognitively engaged and “off-task” as cognitively disengaged. The latter is not paying attention to the activity; that the learner may be daydreaming, absentminded, asleep, or unfocused. Cognitively engaged learners will be attending to the activity at any of the four different levels of engagement, these being interactive, constructive, active, or passive. The top three levels of engagement are components of active learning. The top two levels of engagement, interactive and constructive, represent minds-on, in-depth processing of information. This is where high-order thinking skills are at work. The lower two levels of cognitive engagement, the active and passive, represent hands-on shallow processing strategies (Chi, et al., 2018). Figure 2.6 shows a summary of the actions on each level of engagement as discussed on the ICAP framework (Chi, et al., 2018).

Figure 2:6

The ICAP theory of active learning (Chi, et al., 2018)



The ICAP framework used in the current study to observe the learners' engagement during the POGIL intervention imposes three main assumptions. The first assumption is that the learners' cognitive engagement can be defined by their evident behaviours and products (test scripts or group answers). The second assumption is that evident behaviours and the resulting products may imply distinguishable underlying cognitive knowledge-change processes. Assuming that knowledge can be represented as node-link structures, ICAP assumes that the four elementary processes (storing, activating, linking, and inferring) illustrate how different behaviours can elicit various combinations of these elementary processes. The third assumption is that the correspondence between evident behaviours and the underlying knowledge change processes is not perfect, but the learners' behaviours closely represent their thoughts (Chi, et al., 2018; Chi, 2011).

The following paragraphs describe the four modes/levels of engagement as illustrated in the ICAP framework and fifth level of disengagement. I shall also indicate how these levels of engagement relate to the learners' behaviours during the lesson.

1. Level I: Collaborating, or the Interactive mode/level of engagement

The collaborative/interactive level in ICAP refers to interactions between two peers (or a small group) in dialogues that result in mutual and reciprocal co-generation of ideas (Damon, 1984; Hogan, Nastasi, & Pressley, 1999). This interaction must meet two criteria: (a) the utterances of the members must be constructive (adding new ideas) and (b) each member's contribution addresses or engages the other member's contributions (co-generating). For example, speakers should build-on, elaborate, justify, explain, challenge, or question each other's ideas until they agree on a common answer.

Collaboration entails inferences from all contributors in the group. The knowledge-change processes during collaborative interactions are *store, activate, link, infer-from-own, and infer-from-other*. Interactive collaboration may result in innovative knowledge that neither partner could have generated alone, leading to enriched knowledge structures. These two criteria of collaborative learning during the interactive mode are also consistent with the construct of dialogical reasoning where each member in the team listens to and considers the views of the other members, adding or elaborating on such ideas in the process of collaborative knowledge-building (Brown & Campione, 1994; Scardamalia & Bereiter, 1996).

For the purposes of this study, the interactive level does not only imply agreed upon consensus or the development of new constructs but rather the presence of collaboration in terms of bringing ideas from different persons and putting them together and building on each other's ideas (Rochelle, 1992). Whether there is disagreement in the discussions or not, or just exploratory talk (Mercer, 1996), the important factor is learner-to-learner interactions which serves as a good start for future more productive interactions between learners and the development of valuable process skills (Chi, et al., 2018).

2. Level II: Generating, or the Constructive mode/level of engagement

During the constructive level of engagement, learners generate behaviours, or externalized ideas containing information beyond what was initially provided. The outputs of generative behaviours could be a concept map showing evidence of new ideas that go beyond the information given, where learners can find similarities and differences. The learners engage in critical questions which do not have obvious answers. Constructive behaviours include explaining, taking notes in one’s own words, posing problems, asking questions, drawing a concept map, predicting, inventing, arguing, inducing hypotheses, self-evaluating or monitoring one’s understanding, or creating a timeline. The knowledge-change processes that are cognitively associated with being constructive are that learners generate new knowledge by inferring, from activated prior knowledge, from new knowledge or the integration of old and new knowledge. Constructive processes include all four elementary processes of knowledge which are *activating, linking, inferring, and storing* the linked and inferred knowledge (Chi, et al., 2018; Chi, 2011). The constructive level is higher than the active level in terms of the elementary processes described in the previous paragraph, in that it includes *“inferring*”. During the constructive level, learners link the new concepts to the previous knowledge. This results in the activation and inclusion of previous knowledge in the current cognitive processes, thereby linking (merging and re-organizing) the old and new information. The learner goes on to explain, justify, or evaluate the concepts and come up with inferences. This leads to storage of desirable information or rejection of undesirable information, leading to more elaborate knowledge structures.

The constructive level is compatible with constructivism in that the learners “construct” their own knowledge rather than “being told” by a teacher (Piaget, 1930; Bruner, 1961; Ausubel, Novak, & Hanesian, 1986). The constructive actions in the ICAP framework include explaining, posing questions, making comparisons, elaborating one’s own thinking, or inventing.

3. Level III: Manipulating, or the Active mode/level of engagement

At the active level, learners physically manipulate or operationalize instructional materials without providing any new information. Typical activities include pointing to or gesturing, repeating, copying, or rehearsing, underlining, or choosing, *etcetera*, which all draw learners' attention to focus on what they are doing. As a result of the focused attention, prior knowledge may be activated thereby allowing information processing and subsequent knowledge integration to occur. This may lead to the new information being assimilated or embedded with this activated prior knowledge. Active engagement involves three elementary cognitive processes (storing, activating, and linking), that is why 'hands-on' activities often facilitate learning (Chi, et al., 2018; Chi, 2011). The three cognitive processes exist at this level because active engagement may link current knowledge to prior knowledge. The prior knowledge may, therefore, be activated when the learner identifies the relationships between the concepts. This may result in the storage of desirable knowledge or rejection of undesirable information.

4. Level IV: Paying attention, or the Passive mode/level of engagement

At the passive level, paying attention is the behaviour of being oriented toward and receiving information. Actions that entail paying attention include reading a text silently, watching a video, or listening to an online lecture or instructions from the teacher without undertaking any other visible activities (Chi, et al., 2018; Chi, 2011). At the passive level, the learners are not engaged in any discussions or writing down anything. The learners will, however, be engaged mentally in constructing ideas or organizing their facts or making sense of the activity at hand.

5. Level 5: Disengage level

For the purposes of my study, the disengage level was considered as a level of engagement. It was anticipated that a fifth level where learners are not focused on the given task and doing other things that are not related to the classwork would be necessary. The learners may be playing, making jokes, or any other activities apart from the work assigned to them. The learners' cognitive processes at this level are not related to the given task. The learners are engaged in other activities with various cognitive levels of engagement.

The ICAP framework is the muscle behind the POGIL classroom's powerful learning environment that leads to understanding, reasoning, and critical thinking as opposed to traditional methods. Table 2.6 below is a summarized description of the ICAP discussed in this section (Chi, et al., 2018; Chi, 2011).

Table 2:6

Learner activities and cognitive processes in the ICAP framework (Chi, 2011)

	Interactive	**Constructive**	**Active**	**Passive**	**Disengage**
Characteristics	Group discussion on the same topic, sharing ideas	Individually Producing new outputs	Doing something physically	Not doing anything	Doing other things
Learner activities	Revise errors argue, defend confront or challenge, build-on, elaborate, justify, explain, question	Explain or elaborate justify or provide reasons, construct a concept map, plan, and predict, explain, taking notes	Underline or highlight gesture or point, copy, and paste, repeating.	Looking gazing listening reading text silently, watching a video, or listening to a lecture	Playing, laughing, running around, doing other work
Cognitive processes	**Collaborative** Processes including partner's ideas	**Generative** Infer or integrate new knowledge Organize knowledge	**Manipulative** Activate prior knowledge, Assimilate, encode, store information.	**Attentive** information received for processing	**Unfocussed** Not related to given task

2.8 Chapter Summary

This chapter is a discussion of the literature related to the current study. It identified and considered the literature on stoichiometry, Bloom's taxonomy of cognitive domains, active learning, and inquiry-based learning of which POGIL is just one example. The discussion of advantages and disadvantages of POGIL as well as reasoning, cognition and metacognition were also provided. The final section looked at the conceptual framework which guided this study. The literature cited has revealed the relationship between the concepts which surround mental processes. Many researchers have sought ways to the problems faced by learners in stoichiometry. Teaching approaches, the content knowledge of the teacher, learners' understanding and critical thinking, among other areas, have been investigated to find solutions to learners' challenges. All these and other studied areas have some effect on learners' understanding, critical thinking, problem-solving and reasoning. It seems that the learners' challenges are caused by many factors which work individually or in unison.

The next chapter is a description of the research methodology followed during this study. It starts with the research paradigm and research design followed by the sampling method, and then the data collection plan. The data analysis and the aspects of trustworthiness come just before the ethical considerations which ends the chapter.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter commences with the description of the research paradigm and the research approach followed by the current study. Afterwards, I describe the sample and how sampling was done for all the participants of the current study. The data collection plan follows thereafter, and the data analysis procedure is described. Trustworthiness, crystallization, and ethical considerations conclude the chapter.

3.2 Research paradigms

The paradigm guiding this study is interpretivism. Interpretivism is the basic paradigm for qualitative research from which the critical theory and constructivism paradigms branched (Nieuwenhuis, 2011). An interpretivist researcher believes that reality consists of people's subjective experiences of the external world. This study is based on the relativist ontological view that knowledge is socially and experientially constructed (social constructivism) (Goldkuhl, 2012; Nieuwenhuis, 2011). I am of the view that learners' ideas are better captured and understood by observing them in a natural classroom context. This paradigm is underpinned by observation and interpretation. For this reason, the learners' responses in the pre-intervention test, POGIL activities and post-intervention test were analysed and interpreted to identify and characterize the reasoning and understanding of the learners.

The methodological paradigm of this study is qualitative because it appeals to me as the best way to establish some understanding. Qualitative data was obtained from the pre-intervention test (Appendix 1), POGIL activities (Appendix 12) and the post-intervention test (Appendix 3). The methodology for this study is based on pre-intervention test results, observations of learners doing POGIL activities and their post-intervention test results, and the teachers' and learners' perceptions about POGIL. These methods allowed dialogue among learners during the intervention, and dialogue with the learners and the teachers during the respective interviews, to construct meaningful insight into the learners' reasoning.

3.3 Research Approach

This research followed a qualitative approach to allow for an in-depth study of how Grade 11 learners reasoned and engaged using the POGIL approach. Qualitative data was obtained by analysing how learners reasoned while they performed mathematical calculations in the pre-intervention test and the post-intervention test. Qualitative data was also obtained from video and audio recordings of learners as they engaged and reasoned during discussions during the POGIL intervention. The interview of the learners after the post-intervention test, and that of the teachers, provided qualitative data on their respective perceptions of the POGIL way of teaching and learning.

3.4 Research design

This case study explored the effects of an intervention on learners' reasoning as they engaged with the content and demonstrated their understanding of stoichiometry, without the intention to generalize the findings (Ebersohn, Eloff, & Ferreira, 2011; Maree & Pietersen, 2011). The study also observed the participants in their usual classroom setting, while following an exploratory design involving pre-intervention testing, post-intervention testing, observations, and interviews for both the teachers and the learners. The pre- and post-intervention tests determined learners' reasoning before and after the intervention, respectively. The teachers' and learners' perceptions of POGIL were revealed during the respective interviews. Learners' reasoning was inferred from their discussions as they completed POGIL activities during the intervention. POGIL worksheets used during the intervention provided carefully planned guided inquiry learning which resulted in concept development. The worksheets lead the learners through a process of concept development combined with assistance from the facilitator. Existing POGIL worksheets were adapted to the South African context and used to guide the inquiry component of the lessons. The POGIL classes were taught by teachers previously trained in POGIL. The lessons were observed by a POGIL-trained teacher and were also video recorded.

Questions used in the pre-intervention test and the post-intervention test were developed using the design of past examination papers. Questions in the tests were open-ended just like the examination questions and the learners showed all their calculations and answers on their scripts.

The learners answered the tests following the normal expected procedure of selecting a suitable formula, substituting, and providing the answer with appropriate units. The analysis of the learners' scripts established their reasoning in identifying the unknown and known quantities, selecting appropriate formulae, applying suitable ratio, conversion of units, correctly substituting values, making the subject of the formula and calculating the answer. Reasoning was also inferred when learners linked answers from one step to the next as they did multi-step calculations.

3.5 Sampling

The sample was made up of two Grade 11 physical sciences classes taught by two different teachers at two different schools. One of the schools, identified as school A, had 22 learners who participated in this study. In school A there were 10 boys and 12 girls. The second school, school B, consisted of 26 participants. The learners in school B were 13 boys and 13 girls. The average age of learners in both classes was 16 years. There were other learners in these classes who did not give consent to participate in the current study. These learners were not considered as participants because their scripts or intervention activities could not be used for data analysis. The learners were divided into groups of four except where it was impossible to do so, in which case there were six learners per group. Each of the teachers participated during the intervention and during the interview to get their perception of the POGIL way of teaching.

All learners in the selected classes were taught stoichiometry, regardless of their participation in the study or not. This topic is part of the syllabus and they could not be excluded because the topic was not going to be taught again. The only difference was the POGIL approach, and the observation done during the intervention. However, only those learners who gave consent to participate and whose parents had also given consent had their scripts analysed and their group discussions video-recorded and analysed, while some also participated in the group interview. Learners who did not give consent were placed in separate groups to avoid their unintentional involvement in participation in the study without their permission. Such learners were treated like the rest of the learners with regards to the class activities.

The sampling procedure for schools and teachers was purposeful and convenient. Sampling of teachers was purposeful because only Grade 11 physical sciences teachers participated in the study. The sampling of teachers was purposeful in that only the teachers who willingly participated in the POGIL approach training formed part of the sample. The POGIL workshop facilitator was a retired American science teacher who is now working part-time as a POGIL trainer of teachers throughout America. During a three-day workshop, she trained 25 high school teachers as well as about 20 university lecturers on teaching using POGIL. The participants were engaged in various activities and two of the participating teachers even practically taught their peers using POGIL during the workshop. This demonstrated that the teachers understood POGIL. Most teachers indicated that they were willing to implement POGIL activities in their classes before the actual data collection. Many of these teachers used POGIL in their classes. Two of the teachers who form part of the sample of this study volunteered to participate in the current study by teaching their learners using POGIL.

The teachers were purposefully selected based on having at least 5 years' teaching experience in Grade 11 physical sciences. Such teachers were believed to have tried different teaching approaches over the years and may feel the need, or at least be more open, to try alternative teaching approaches like POGIL to benefit their learners.

The schools were conveniently sampled based on official language proficiency after consultation with the POGIL-trained subject teachers. The language command of the learners was necessary to avoid communication challenges. The focus was on both verbal and written communication so that they could be accessible through the video recording.

3.6 Data collection

The active participation of all learners in both classes during the intervention is something that I never expected and wish that in-service science or mathematics teachers would observe. This may be an eye-opener to the teachers who complain about learners' participation. The usually passive learners who worked at almost the same pace as the usually fast learners was remarkable and exceptional as they actively participated and constructively collaborated.

Some learners felt intimidated by the class and opted not to speak in the entire class. During the interventions, such learners actively participated and produced mostly correct answers to activities. Teachers may need to be aware of this behaviour by some learners which may be solved by using POGIL or other group activities.

3.6.1 Overview of the data collection procedure

The current study was conducted in six phases at two township high schools in Pretoria, South Africa, where one Grade 11 physical sciences class per school participated along with their respective teachers. The six phases of the current study included the POGIL training of high school physical sciences teachers (including the two participating teachers), the testing of learners in the pre-intervention test, observation of the learners' engagement during the POGIL intervention, the learners' views expressed during group interviews, and the learners' responses in the post-intervention test, and finally, the interview of the participating teachers.

The intervention entailed the teaching of stoichiometry to the sampled grade 11 physical sciences classes. These schools are located in the same educational district and are attended by black learners of mixed gender. The use of POGIL in this study facilitated both learners and teachers to follow a process of concept development which was assumed would likely lead to the appropriate understanding of stoichiometric concepts with minimum misconceptions. That understanding is essential to provide the required scientific and logical reasoning to engage the process skills necessary for concept development.

Essentially, the focus of the study was to observe how POGIL-trained teachers facilitated the learners' engagement during the POGIL intervention and how the teaching assisted learners' concept development and reasoning as they interacted with each other. The study also focused on how the learners engaged and reasoned after the intervention as well as their perception of the POGIL way of teaching. POGIL worksheets guided learners through carefully designed activities that helped them to analyse the available data and use their previous scientific experiences such as rules, principles, laws, and definitions of scientific concepts to come up with appropriate links between evidence and their reasoning (Brown, Furtak, Timms, Nagashima, & Wilson, 2010). Such arguments that are based on reasoning form the basis of scientific reasoning (Kuhn, 1993). The careful design of the worksheets ensured the guided-inquiry component of the intervention (Llewellyn, 2011).

The study further analysed learners' reasoning as revealed in the individual pre-intervention test and post-intervention test scripts, which included choices of formulae used in calculations, their substitutions, selection of successive formulae and steps to follow in calculations. The processes involved the use of more than one step, linking a sequence of steps with suitable ratios. Solving of the problem constitutes the steps followed by learners in problem-solving and hence their mathematical reasoning. This study adapted the Department of Education's classification of questions in tests and examinations according to levels of complexity in developing the pre-intervention test and post-intervention test (Department of Basic Education [DoBE NCS-CAPS], 2012). A level I calculation must be solved in one step, a level II question in two steps, a level III question needed solution in 3 steps and a level IV question needed solution in 4 or more steps. A step in this context means selection of one formula, substitution in the formula and finding the answer.

The pre-intervention test and post-intervention test instruments used in this study were prepared by adapting the examination type questions for Grade 11 stoichiometry. Both tests were similarly constructed and included questions at all levels of cognition. The pre-intervention test consisted of 12 questions – four level I questions, four level II questions, two level III questions and two, level IV questions. The post-intervention test consisted of 10 questions of which two were level I questions, three were level II questions, three were level III questions and two were level IV questions. More details on the test instruments are provided in sections 3.5.2.1 and 3.5.3.

The tests were reviewed and moderated by the supervisor and three high school teachers from different schools to ensure reliability and validity. More details have been provided in section 3.7.1. Data was collected from two classes at two different schools. All data collection was done at the learners' respective schools and during the weekend. This was done to avoid disturbing the normal running of the school. The two classes were initially given a 1-hour pre-intervention test three days before the intervention. The learners were taught stoichiometry the previous year in grade 10. Each learner individually answered the pre-intervention test, which was administered by the researcher in the presence of the subject teacher. This initial test revealed the learners' initial reasoning in the topic. The learners' scripts were analysed to get qualitative data on how they reasoned and arrived at solutions to the questions.

A week later, the 2-hour POGIL interventions were carried out. This started at school A, followed by school B the following weekend. During the intervention, learners collectively worked through POGIL worksheets in groups of four or six. Video recording of all the activities was done for each of the groups. Soon after the intervention, a post-intervention test was administered. Each learner individually answered the post-intervention test.

The intervention, which entailed teaching of the learners using POGIL method was done by the learners' usual teacher. These teachers were already POGIL-trained by a qualified expert and had already used the method to teach the same learners in other topics. Besides that, the researcher worked with the teachers in the preparation and execution of POGIL activities in the class. Class observations of the lessons was done in their usual classrooms. The class teachers did mixed ability grouping of learners in each class, taking care to place consenting learners in the same group so that the presenter has good language command. In school A, there were 5 groups of participants with a total of 22 learners. In school B, there were 6 groups of participants with a total of 26 learners. A total of 48 learners participated in this study.

During the lessons, all the group activities of the consenting learners were video recorded. The video focused on the written work of each group, showing all the procedures followed by the learners as they arrived at their answers. The steps taken by the learners revealed their reasoning and engagement. The researcher observed the lessons paying attention to the activities done by the learners and how each teacher managed the class. Three lessons of 40 minutes each were spent during the intervention. The first lesson covered the first two activities titled model 1 and model 2. The learners were given a 15-minute break after this session. Models 3 and 4 lasted 40 minutes each, with a 15-minute break in between. Video and audio recordings were used to collect data of the 11 participating groups' discussions while completing their POGIL activities. Seven out of 11 group discussions were considered for data analysis.

The seven groups were identified based on the clarity of their discussion and whether they worked on camera. This was because it was discovered during video analysis that some groups carried out their discussions off camera with their voices inaudible and displaying already completed worksheet to the camera. It was the learners' responsibility to video record using their cellular phones and download their videos onto laptops that were provided by the researcher. The lessons were split into four videos per group according to the number of class activities, making a total of 44 videos. The video and audio recording devices were mounted above the desk of the scribe in each group as the learners engaged in discussions without revealing the faces of the learners but only recording their written work. The learners' pre-intervention test and post-intervention test scripts were analysed to determine their reasoning before and after completion of POGIL activities, respectively. Table 3.1 summarizes the estimated duration of each data collection process, the participants and the aims which guided the collection processes.

Table 3:1

Sequence followed for data collection.

Data collection	**Estimated duration**	**Participants**	**Aim for data collection**
Pre-intervention test	1 hour	Both classes separately in their classrooms	To get initial understanding and reasoning of learners. The learners' scripts were qualitatively analysed to identify their initial reasoning.
Intervention	2 hours	POGIL teaching of both classes. In their respective classrooms. Taught by their usual teacher	To collect data on the processes of concept development, engagement, and the learners' reasoning as they arrived at solutions to various POGIL activities. Video recording per group captured all the steps taken by learners.
Lesson observation	2 hours	Observing both classes during intervention	To observe the engagement of the learners in class activities. To observe how teachers facilitated the lessons. Observe to what extent the lesson was a POGIL intervention.
Post-intervention test	1 hour	Both classes separately in their classrooms	To get the individual understanding of learners after instruction. Their post-intervention test was qualitatively analysed to get their understanding and reasoning in stoichiometry after the intervention.

Interview	10 minutes	The teacher who taught the class using POGIL	To get the opinions of the teacher on how the POGIL activities were carried out. To get information on teachers' assessment of participation, understanding, reasoning and performance of learners during the lesson.
Interview for learners	10 minutes	One group of learners who participated in the intervention	To get the opinions of the learners with regards to POGIL. The learners' views on the effectiveness of POGIL with regards to their reasoning, understanding and achievement.

3.6.2 Description of the data collection instruments

Data was collected using pre-intervention tests, post-intervention tests, an observation schedule, video recording, interview schedules for teachers and the group interviews for learners. I describe each of these instruments in the following paragraphs.

3.6.2.1 Structure of the pre-intervention test and post-intervention test design

The pre-intervention test (Appendix 1) was used to collect data about the learners' reasoning in stoichiometry before the intervention, based on their knowledge from Grade 10 where the same topic was covered. The post-intervention test (Appendix 3) was used to collect data about the learners' reasoning in stoichiometry after the intervention. Both tests were similarly designed.

The test instruments were carefully structured by adapting the past examinations questions on stoichiometry as well as the syllabus for Grade 11 physical sciences. This was done to ascertain the validity of the instrument as a tool to assess the expectations of the learning program. The questions addressed various skills expected in the examination. Most questions required that the learners use ratios and proportion method. All the questions also scaffolded around Bloom's taxonomy of cognitive domain. The simplified table 3.2 below shows the question items, the cognitive levels and the skills expected of the learner in the pre-intervention test.

Table 3:2:

Structure of question items in the pre-intervention test

Question	**Question complexity**	**Technique**	**Cognitive demand**	**Skills assessed**
1	I		Understanding	Identify correct formula. Substitute in the formula, identify the correct atomic mass
2	III	Ratio	Analyse, apply, evaluate	Calculate molecular mass, chose the correct formula, substitute appropriately. Use mole ratio, use the other formula, substitute appropriately, calculate the answer.
3a	III	Ratio	Analyse, apply, evaluate	Calculate molecular mass, chose the correct formula, substitute appropriately. Use mole ratio, use the other formula, substitute appropriately, calculate the answer.
3b	II	Ratio	Analyse, apply, evaluate	Use balanced equation of reaction and mole ratio, use the other formula, substitute appropriately, calculate the final answer.
4a	I	Recall	Remember	Remember the definition of limiting reactant
4b	IV	Ratio	Analyse, apply, create, evaluate	Calculate molecular mass, chose the correct formula, substitute appropriately. Use mole ratio from balanced chemical reaction, use the other formula, substitute appropriately, calculate the final answer.
5	IV	Ratio, comparison,	Analyse, apply, create, evaluate	Calculate molecular mass of the 3 compounds, convert cm3 to dm3, chose the correct formula, substitute appropriately. Use mole ratio on each of the 3 solutions, calculate number of moles of ions; compare the three values
6a	II	Comparison	Analyse, apply, evaluate	Count number of atoms of each element. Compare on both sides of equation. Use suitable coefficient to balance
6b	I		Analyse, apply, evaluate	Chose the correct formula, substitute appropriately, calculate the answer.
6c	I		Analyse, apply, evaluate	Chose the correct formula, substitute appropriately, calculate the answer.
6d	II	Ratio	Analyse, apply, evaluate	Use ratios to calculate number of moles
6e	II	Ratio	Analyse, apply, create evaluate,	Use ratios to calculate number of moles, chose the correct formula, substitute appropriately, calculate the answer.

Table 3.2 shows the complexity of the questions and the techniques that learners were supposed to use during the answering of the questions. Most of the questions required

mathematical knowledge such as ratios, calculation, changing subject of formula and simple substitution in the correct formula. The questions in which ratio technique was needed are questions 2, 3(a), 3(b), 4(b), 5, 6(d) and 6(e). Table 3.3 shows the questions, the cognitive levels and the skills expected of the learner in the post-intervention test.

Table 3:3

Structure of question items in the post-intervention test

Question	**Question complexity**	**Technique**	**Cognitive domains**	**Skills**
1	I		Understanding	Identify correct formula. Substitute in the formula, identify the correct atomic mass
2	III	Ratio	Analyse, apply, evaluate	Calculate molecular mass, chose the correct formula, substitute appropriately. Use mole ratio, use the other formula, substitute appropriately, calculate the final answer.
3a	III	Ratio	Analyse, apply, evaluate	Calculate molecular mass, chose the correct formula, substitute appropriately. Use mole ratio, use the other formula, substitute appropriately, calculate the final answer.
3b	II	Ratio	Analyse, apply, evaluate	Use balanced equation of reaction and mole ratio, use the other formula, substitute appropriately, calculate the final answer.
4a	I	Recall	Remember	Remember the definition of limiting reactant
4b	IV	Ratio	Analyse, apply, create, evaluate	Calculate molecular mass, chose the correct formula, substitute appropriately. Use mole ratio from balanced chemical reaction, use the other formula, substitute appropriately, calculate the final answer.
5	IV	Ratio, comparison	Analyse, apply, create, evaluate	Calculate molecular mass of the 3 compounds, convert cm3 to dm3, chose the correct formula, substitute appropriately. Use mole ratio on each of the 3 solutions, calculate number of moles of ions; compare the three values
6a	II	Comparison	Analyse, apply, evaluate	Count number of atoms of each element. Compare on both sides of equation. Use suitable coefficient to balance
6b	III		Analyse, apply, evaluate	Chose the correct formula, substitute appropriately, calculate the answer. Use ratios to calculate number of moles.
6c	II		Analyse, apply, evaluate	Use ratios to calculate number of moles Chose the correct formula, substitute appropriately, calculate the answer.

The questions in the pre-intervention test and the post-intervention test were of different levels of complexity. The classification of levels of difficulty of questions was informed by Bloom's taxonomy of cognitive domains (Section 2.2) which is also used by the Department of Basic Education to classify test items. Table 3.4 below shows the classification of questions based on the different cognitive levels used in tests according to the requirements of the department. This table was adapted and simplified for use in the current study.

Table 3:4

Classification of cognitive levels assessed in DoBE tests and examinations.

Cognitive level	**Description of cognitive level**	**Description of the question complexity level and the associated cognitive demand**
1	**Recall** - The learner can recall, remember, and restate facts and other learned information.	**Level I** question which needs recall from memory. Or a single step calculation requiring basic reasoning.
2	**Comprehension** - The learner grasps the meaning of information by interpreting and translating what has been learned	An average (**level II)** question that needs solution over maximum of 2 steps. Reasoning limited to choosing of correct formulae, substitution and calculation of answers making appropriate subject of the formula.
3	**Application** - The learner can use (or apply) knowledge and skills in other familiar situations and new situations., **Analysis** - Elements embedded in a whole are identified and the relations among the elements are recognised.	An above average (**level III**) question where solution is found through up to three steps using different formulae. Reasoning involves to choosing of correct formulae, substitution and calculation of answers making appropriate subject of the formula. Linking two or three formulae with appropriate ratios
4	**Evaluation** - The learner makes decisions based on in-depth reflection, criticism, and assessment. The learner works at the extended abstract level, **Synthesis** – the learner creates new ideas and information using the knowledge previously learned or at hand.	An above average (**level IV**) question solved through multi-steps. Reasoning involves to choosing of correct formulae, substitution and calculation of answers making appropriate subject of the formula. Linking many formulae with appropriate ratios

The pre-intervention test and post-intervention test instruments had the same aim and were classified according to the level of required competence to solve the problem. The questions were classified as recall, comprehension, application/analysis, and evaluation/synthesis, according to their increasing level of difficulty. The DoBE requires all tests and examinations to assess process skills, critical thinking, and scientific reasoning among other skills (Department of Basic Education [DoBE NCS-CAPS], 2012). These skills are embedded in the questions and appear with different levels of complexity according to the cognitive level being assessed (Department of Basic Education [DoBE NCS-CAPS], 2012).

A recall question was either a definition or a single-step simple calculation requiring basic reasoning. A comprehension question had a maximum of two steps where appropriate ratio may be necessary to link the two formulae. An application/analysis question had at least three steps linking the stages with appropriate ratios where necessary, while an evaluation/synthesis question required multi-step calculations backed by appropriate ratios.

Question 1 in both the pre-intervention test and the post-intervention test was a recall question. It required learners to calculate the mass of a substance given the number of moles by going through a one-step process of getting the correct formula, substituting appropriately, and getting the answer. The learners were expected to use the same formula $n=\frac{m}{M}$ in both the pre-intervention test as in the post-intervention test. The learners needed only to select the correct formula provided at the back of their question paper. They also needed to select and use the relative atomic mass of the substance in question from the provided periodic table. This question was a one-step calculation to get to the answer.

Question 2 was also structured similarly in both tests. It was a level III question which required learners to use multi-step procedures to get to the appropriate answer. In the pre-intervention test, the learners were supposed to calculate the relative molecular mass of CO_2 while in the post-intervention test, they were given N_2O_4. In both cases the learners were supposed to use the formula $n=\frac{m}{M}$ to calculate the number of moles. In the pre-intervention test they were supposed to use the number of moles of CO_2 to calculate the number of moles of oxygen atoms using ratios. Then the learners were required to use the formula $n = \frac{N}{NA}$ to calculate the number of oxygen atoms. Question 2 in the post-intervention test had a similar design but, in this case, learners were only required to calculate the number of moles instead of the number of atoms. Both questions involved multi-steps and needed logical reasoning and conceptual understanding on the part of applying the stoichiometric ratios.

Question 3 was similarly designed in both the pre-intervention test and the post-intervention test. The question had a balanced equation of a chemical reaction. In 3(a) the learners were given the mass of one of the reactants and told that it reacted completely. In both cases they were supposed to calculate the relative molecular mass of the reactant with the given mass, with the aid of the provided periodic table of elements. They were then supposed to use the formula n = $\frac{m}{M}$ to calculate the number of moles in the given mass. They were then supposed to use ratios to find the number of moles of Cu in the pre-intervention test and number of moles of CO_2 in the post-intervention test. In the case of the pre-intervention test, the learners were supposed to use the formula n = $\frac{m}{M}$ for the second time to calculate the mass of Cu. While in the post-intervention test, they were supposed to use the formula n = $\frac{V}{Vm}$ to calculate the volume CO_2 of used. Question 3(a) was classified as a level III question based on the multi-steps involved.

For question 3(b), learners were supposed to use the initial number of moles they calculated in question 3(a) above. In the pre-intervention test, they would use mole ratios to calculate the number of moles of H_2 used, after which they would calculate the volume of H_2 consumed by using the formula n = $\frac{V}{Vm}$ and the molar gas volume provided in the table of constants. In the post-intervention test learners would use mole ratios to calculate the number of moles of $CaCO_3$ produced. After which they would calculate the mass of $CaCO_3$ produced using the formula n = $\frac{m}{M}$. This question was classified as level II.

Question 4 had the same design in both the pre-intervention test and the post-intervention test. In both tests, the learners were given a balanced chemical equation of the reaction. In question 4(a) learners were asked to define the limiting reactant. This was a level I question where learners needed to recall the definition of a limiting reactant as the substance that is used completely and determines the amount of product. The definition was meant to guide learners to identify the limiting reactant in the second sub-question.

Question 4(b) was more cognitively demanding because it was a level IV multi-step question. In both the pre-intervention test and post-intervention test, the learners were given the masses of the two reactants. They were supposed to use the mass of each reactant and the formula n = $\frac{m}{M}$ to calculate the number of moles in the given mass. They were supposed to use proportions to find the limiting reactant, then use the moles of the limiting reactant to find the moles of substance produced using ratios before calculating the molecular mass of the product and using the formula n = $\frac{m}{M}$ to calculate the mass of the product.

Question 5 was of a similar design for both the pre-intervention test and the post-intervention test. It was demanding, being a level IV multi-step question that required critical thinking. Both questions required learners to identify a solution with the highest concentration of ions when a given mass of substance is dissolved to make a volume solution. There were three solutions in the pre-intervention test and, two solutions in the post-intervention test. In each case, the learners were supposed to calculate the relative molecular mass of the given substance. After which they were supposed to change the volume from cm^3 to dm^3 and use the formula c = $\frac{m}{MV}$ or n = $\frac{m}{M}$ and c = $\frac{n}{V}$ to calculate the concentration of the solution. The learners were supposed to use ratios to calculate the concentrations of the ions in question and then compare to find the highest concentration.

Question 6 again followed a similar design in both the pre-intervention test and the post-intervention test. The learners were given the concentration and volume of two solutions. Question 6(a) required learners to write a balanced chemical equation. Learners we supposed to use simple analytical skills (level II) to write a balanced chemical equation of reaction. Question 6(b) and 6(c) in the pre-intervention test are like question 6(b) in the post-intervention test.

In question 6(b) of the pre-intervention test, learners were required to calculate the number of moles of H_2SO_4 in the given solution. They were supposed to change the volume from cm^3 to dm^3, then use the formula c = $\frac{n}{V}$ to calculate the concentration. This is a simple two-step question that learners could have done easily. Question 6(c) in the pre-intervention test required learners to calculate the number of moles of NaOH. Both questions 6(b) and 6(c) were level II questions. Learners were supposed to follow the same procedure as in 6(b); converting volume to dm^3 and using the formula c = $\frac{n}{V}$ to calculate the concentration. For learners to answer question 6(d), they needed to use the proportion of the number of moles of H_2SO_4 in relation to the moles of NaOH on a balanced chemical equation in relation to the calculated concentrations to find the limiting reactant. Question 6(e) required learners to calculate the mass of water produced. They were supposed to identify the limiting reactant by making sense of the definition of limiting reactant, then use ratios and the balanced chemical equation of the reaction to calculate the numbers of moles of water produced. After that, they would calculate the mass of water using the formula n = $\frac{m}{M}$.

Question 6(b) in the post-intervention test was like questions 6(b), 6(c) and 6(d) in the pre-intervention test. It was, therefore, a multi-step question where learners would go through all the steps just like in 6(b) of the pre-intervention test. Learners needed to convert the volume to dm^3 and then use the formula c = $\frac{n}{V}$ to calculate the number of moles of HCl and NaOH. They would then use the proportion of mole ratio of the balanced equation of reaction to determine the excess reactant. Question 6(c) in the post-intervention test required learners to calculate the mass of the water produced. Learners were supposed to use mole ratios from a balanced chemical equation to calculate the moles of water produced. Then they would use the formula n = $\frac{m}{M}$ to calculate the mass of water produced. This question was a level II question requiring critical and analytical thinking skills to get to the answer.

3.6.2.2 The interview schedules description

a) The interviews schedule for the teachers

The interview schedule for the teachers (Appendix 13) was open-ended to allow the interviewee an opportunity to air their views openly. The questions ranged from easy to complex ones. The teachers were interviewed in their office soon after the intervention to gauge their experiences with POGIL before and during the intervention. This included asking them about the advantages and disadvantages of POGIL based on their personal experience with the teaching approach. The teachers were also questioned on the perceptions of learners towards POGIL and the understanding, reasoning, and general performance because of using POGIL. The teachers also commented on the manner in which learners worked with regards to teamwork, communication, management, problem-solving, and general participation. In addition, they were asked whether they considered using POGIL in their classes going forward. They also commented on the concerns they had regarding POGIL.

The interviews lasted just below ten minutes, and a copy of the interview schedule for teachers is available in Appendix 13. Throughout the interview, the teachers were asked to describe their perceptions in relation to the POGIL method, the learners' attention and participation, and the expected outcomes. There were no pre-existing codes for the interview since the teachers were expected to air their own views openly. This appealed to me as an appropriate way to get in-depth data from the teachers.

b) The interview schedule for the learners

The interview schedule for the learners (see Appendix 14) was also open-ended. This helped to avoid yes/no answers and allowed the learners to express themselves freely and provide rich information. The learners were asked to describe their understanding of POGIL as it was important to find out if they had already used POGIL in their previous lessons. They were also asked how they thought POGIL might have influenced their understanding, performance, reasoning, and interest in science. The learners were then asked if they wished to use POGIL in other science topics, and if they expected that the POGIL method would help them to achieve their goals in terms of career choices in the future. The interview lasted less than ten minutes. The questions in this interview also progressed from easy to complex. The questions sought the learners' perceptions of the POGIL method, their understanding of stoichiometry as a result of the POGIL method, and their expected achievement in science if they continue using POGIL. The open-ended interview appealed to me as a method of getting rich data when participants express themselves openly.

3.6.2.3 Description of the lesson observation schedule

The lesson observation schedule was open-ended (Appendix 21). The observation schedule aimed to observe the actions of the learners during the lessons and that of the teachers as they taught. As for the learners, the observation schedule focused on the excitement, cooperation, and communication in the group and with the teacher, as well as participation. For the teachers, the observation looked at the teachers' ability to teach using POGIL. The teachers were observed on their awareness of the needs of the learners during the lessons, their roles in facilitating the lessons, their response in terms of excitement and communication with learners. The observation of teachers and learners was necessary to determine if the intervention met the requirements of POGIL or otherwise.

3.6.2.4 The description of the POGIL lesson plans

The POGIL lessons (Appendix 12) were developed by adapting existing POGIL worksheets from the bank of worksheets on the POGIL website. The worksheets were adapted in terms of language and the contexts of the scenarios. A complete activity in POGIL is called a 'model' and for the purposes of this study, four models were used. All the models started with a diagram or scenario which assisted learners in developing mental models of the concept they are studying. These models were structured based on the learning cycle described in Section 2.6.1. During the learning cycle (Lawson, 1988), learning occurs from exploration, invention to application of concepts.

Model 1 was easy, with simple real-life examples which learners were familiar with and able to comprehend easily. The examples were designed to remind learners of what they already know that relates to the new concept. Model 2 was the application of concepts learnt in model 1. That application was again related to the concept limiting reactant. Model 3 referred to the actual chemistry concepts. Similar to model 1 and 2, this model was designed to progress from easy to more challenging. The model aims to develop the concept of 'limiting reactants' in the real context of chemistry by having a lot of activities for concept invention. Model 4 started with some examples of concept invention and moving to concept application. At this stage, examination-type questions were provided starting from the easy to the more challenging. At this stage, the learners were applying the concept in real chemistry situation.

3.7 Data analysis

This section describes the data analysis process. Thematic analysis of themes used in the current study are described by linking them to the conceptual framework of the study. Description of themes was done in describing how themes were developed and used in data collection using the pre-intervention tests, post-intervention tests, an observation schedule, video recording, interview schedules for teachers and the group interviews for learners.

3.7.1 Thematic analysis

Thematic analysis is the method that identifies and analyses the patterns in the data (Kirschner, Sweller, & Clark, 2006). Thematic analysis reveals how data was analysed and the assumptions used during data analysis. Inductive thematic analysis was used in this study in coding data from lesson observations and the interviews of both the teachers and the group interview of the learners. Deductive thematic analysis was used to analyse qualitative data collected using the pre-intervention test and the post-intervention test, and learners' activities in the intervention.

During inductive thematic analysis, themes are allowed to emerge from the data (Patton, 2002; Fereday & Muir-Cochrane, 2006; Thomas, 2006; Nieuwenhuis, 2011). In this study, the semantic type of inductive approach was used to analyse interviews and lesson observations. In the semantic approach, themes are identified superficially without looking at anything beyond what is said or done (Kirschner, Sweller, & Clark, 2006). The semantic approach was used to avoid making subjective judgements of what the learner or teacher said or did. The semantic approach enhanced inter-coder reliability when the second person codes the same interview transcripts or what happened during lessons.

During deductive thematic analysis, pre-existing themes are used to code the events as they occurred (Patton, 2002; Fereday & Muir-Cochrane, 2006; Thomas, 2006; Nieuwenhuis, 2011). In the pre-intervention test and the post-intervention test, codes were designed based on the level of complexity of the question. Each answer was coded according to how the answer was written in relation to the codes as described in Section 3.6. For the intervention learners' activities were coded based on their actions in relation to the ICAP framework. Themes are imposed on the data and the observed results are analysed (Patton, 2002; Fereday & Muir-Cochrane, 2006; Thomas, 2006; Nieuwenhuis, 2011)

The coding of all data was done with the aid of *ATLAS.ti* software for qualitative data analysis. This made coding much easier, and the files are still available for further reference. My supervisor coded the same results using the same semantic thematic approach to ascertain reliability of the coding system. After discussing the two sets of results it was agreed that there were no significant differences.

Learners' work in the pre-intervention test and the post-intervention test was coded according to the level of difficulty of the question and the extent to which the learner answered the question. The answers were classified as novice, elementary, intermediate, competent, or advanced with increasing level of complexity. Where a response was not given, it was coded as a novice idea. An answer was coded as elementary when correct definitions or a single step calculation had minor errors. The intermediate code was used for balancing equation of reaction or appropriately performing a two-step calculation. A competent code was used for three-step calculations where minor errors occurred. The advanced code was used for multi-step calculations where no error occurred (see Table 3.6).

The learners' activities during the intervention were coded following the ICAPD framework which stand for the Interactive, Constructive, Active, Passive and Disengaged. The ICAPD framework was used to identify the engagement and reasoning of the learners during their discussions. More detail on the ICAPD is given in Section 2.7.

The interviews for teachers and learners were coded according to their responses to the questions. The observations of the lessons were coded according to the checklist

(Appendix 21) of the activities done by the learners and the teachers during the intervention.

3.7.2 Data analysis of learners' activities during the intervention

Data collected during the POGIL lessons was analysed following the ICAP framework (Chi, 2011; Chi, et al., 2018; Chi, 2009) discussed in chapter 2. Learners' activities during the lessons were video recorded by focusing on the work written down and recording the learners' discussions. The faces of the learners were intentionally not recorded for ethical reasons. The ICAP framework described in Section 2.7 is composed of the interactive, constructive, active, and passive as shown by the actions of the learners. These observable behaviours show the level of engagement of the learners. During each level of engagement, learners display certain actions which reflect that level of engagement. During the data analysis such actions were coded to identify the levels of engagement during the intervention and assess the extent of the inquiry component of the intervention. Figure 2.7 briefly describes the actions on each level of engagement as used in the current study (Chi, et al., 2018).

For the purposes of the study, the POGIL intervention which was video recorded was coded following the guidelines of the ICAP framework to ascertain the active learning therein. Table 3.5 shows the codes that were used and the corresponding activities that reflected the components of the ICAP framework. I have considered adding "disengaged" to classify the moment when learners were off task. So that the ICAP framework may look modified to ICAPD. These codes were loaded into ATLAS.ti, software for qualitative data analysis and coded accordingly.

Table 3:5

Codes used in video analysis (Chi, et al., 2018)

	I	**C**	**A**	**P**	**D**
Code group	**Interactive**	**Constructive**	**Active**	**Passive**	**Disengaged**
Codes	Argue, justify, elaborate, explain, agreement	Explain, elaborate, reason, predict, brainstorm	Underline, highlight, copy, repeat, match	Look-on, gaze, read, listen, observe	Off-task, sleeping, playing, searching other things

3.7.3 Data analysis of the pre-intervention test and the post-intervention test

The requirements of the department of basic education of South Africa focuses on four levels of difficulty. These levels are based on Bloom's taxonomy of cognitive domain (Section 2.2). The current study relied on the classification of questions by the Department of Basic Education. The coding of the learners' responses was also based on the classification level of questions (see Tables 3.3 and 3.4). Other tools for problem-solving techniques were looked at.

The study by Selvaratnam and Fraser (1982) was identified as being close but not close enough to use as the basis of the marking guidelines. All learners' work was classified as novice, elementary, intermediate, competent, or advanced (Table 3.6) depending on the extent of reasoning the learner demonstrated.

Responses were classified as novice when a learner did not show a formula, or there was no response or there was a formula without substitution, or something was wrong with the definition. The Department of Education's assessment guidelines states that marks are allocated to formula, substitution, and answer; one mark for each. However, no mark is allocated to a formula if no substitution was done. A learner who gives the correct formula without substitution was not awarded any mark.

The elementary response was awarded to a correct definition or single-step identification of correct formula followed by appropriate substitution and correct answer. A response could be classified as elementary for a level I, level II, level III, or level IV question. For the definition, only memory recall was needed to get this award. Only a correct definition was awarded as an elementary response. If there was anything wrong with the definition, then it was assigned as novice. Similarly, the Department of Education awards full marks for a correct definition and no mark if anything on the definition is incorrect.

A response was classified as intermediate when there was a maximum of two steps followed and the answer was correct. An appropriate ratio may be used to link up the two formulae in a level II, level III, or level IV question. An answer was identified as competent when at least three steps were correctly followed, and the stages were linked with appropriate ratios where necessary. At least three formulae were used in a competent response to a level III or level IV question. A response was classified as advanced when multi-step calculations to a level IV question were done and all the related mathematical calculations, such as ratio, were properly recorded and correct.

A response to a level I question can either be elementary if the one step is correct or novice if nothing is correct, while a response to a level II question can be intermediate if two steps are correct, elementary if one step is correct or novice if nothing is correct. A response to a level III question can be competent if three steps are correct, intermediate if two steps are correct, elementary if one step is correct or novice when nothing is correct. Furthermore, a response to a level IV question can be advanced when everything is correct, competent if three steps are correct, intermediate if two steps are correct, elementary if one step is correct or novice if nothing is correct. Table 3.6 shows a summary of the classification of the learners' responses.

Table 3:6

Codes used in analysis of pre-intervention test and post-intervention test.

Response level	**Bloom's taxonomy**	**Description**
Novice idea	-	No response provided. No formula chosen or no substitution done. No recall of definition.
Elementary	I	Recall of definition. Or single-step calculation. Reasoning involves selecting appropriate formula, appropriate substitution, and getting correct answer.
Intermediate	II	Solution of a question through a maximum of two steps. Reasoning involves selection of appropriate formulae, correct substitution done in the correct formula. Correct use of relevant ratios to link the formulae. Answer to a maximum of two-step question is correct.
Competent	III	Solution is found through a maximum of three steps. Reasoning involves selecting correct formulae, substitutions, linking by use of ratio.
Advanced	IV	Reasoning is involved in the selection and use of more than three formulae. Appropriate substitution and solving is done by linking the formulae with appropriate ratios.

In the Selvaratnam and Frazer (1982) model, the first stage does not fit with how the Department of Basic Education recommends the assessment of learners' work. Identification of the unknown and known quantities is not examinable according to the

DBE. The second stage of selecting the formula correspond with the elementary response. Therefore, stages 1 and 2 will have been the elementary level. The third level of deriving the formula is not examinable according to the department's guidelines. The learners are only supposed to substitute in the formula as it is, to be awarded marks for substitution. The fifth stage is also not examined by the Department of Basic Education.

According to Selvaratnam and Frazer's (1982) model for problem-solving, the stages indicate the reasoning taken by a learner in the process of solving the problem. The identification of the known and the unknown quantities is a basic step required for problem-solving. A learner may not be able to solve a problem before they can identify the known and the unknown variables from the available data. The learner would have reasoned that "*this* information is what I have, and *that* is what I do not have". Sometimes the learner goes further, reasoning that the quantities given are not in the appropriate units and may have to change those quantities to the appropriate units using the suitable ratio. This again is reasoning implied in the identification of the known and the unknown quantities. Table 3.7 shows the stages in the problem-solving model by Selvaratnam and Frazer (1982).

Table 3:7

Stages in the Selvaratnam and Frazer (1982) problem-solving model

Stage	Learner's activities
1. Clarify and define problem	Learner identifies the unknown and the known. Identifies additional information required.
2. Select the formula	Identifies physical quantities available in the given data. Establish relationship between known and unknown quantities.
3. Derive the key formula for the calculation	Breaks down the question into sub questions. Relate each data using formulae. Clarifies relationships and all necessary information.
4. Collect data and calculate	Solve the problem numerically using the formulae. Check the units.
5. Review and learn from the solution	Check if problem was correctly solved. Check if the answer is correct.

In the second stage, which is the selection of the formula or formulae, the learner must check on the provided formula sheet to get the appropriate formula to use. The Department of Basic Education provides a formulae sheet attached to the examination paper. In the process, the learner must use reason to determine which formula to use. The learner matches the available quantities to the given formulae to get a suitable formula to solve the problem. This is the analysis and application stage where the learner selects a formula that will appropriately work to solve the problem.

The third stage of the model is the breakdown of the question into sub-questions. This applies in the case of multi-step calculations where the learner must select all the formulae that they will use in succession. They also must reason on the sequence of steps to follow up to the final answer. They must reason on how to link all the formulae from one step to another either by using an answer from the previous step or by linking it with an appropriate ratio. The third stage corresponds to the evaluation and synthesis in Bloom’s taxonomy.

The classification of different levels of questions by the DoBE does not spell out some of the steps indicated in the problem-solving models. The Department emphasizes the formula, substitution, and answer. Problem-solving is, however, implied in the levels of the questions. A similar problem-solving model by Ashmore, Frazer, and Casey (1979) was observed in the literature. Both models of problem-solving end with evaluation, which is implied when a learner has finished calculating. The learner analyses the final answer if it makes sense and if they have successfully solved the problem (Ashmore, Frazer, & Casey, 1979; Selvaratnam & Frazer, 1982).

3.8 Trustworthiness

Trustworthiness refers to the credibility, transferability, dependability, and confirmability of a research study (Guba & Lincoln, 1994; Nieuwenhuis, 2011). It aims to persuade the audience and self that the findings are worth taking into consideration. The trustworthiness of a study demonstrates the truth value of a study, on how it can be applied in other scenarios. It establishes the extent of the consistency of its procedures and the neutrality of its findings (Nieuwenhuis, 2011; Shenton, 2004).

In this study, trustworthiness was established by triangulating data obtained through the pre-intervention test, post-intervention test, intervention, lesson observations, and the interviews to establish the links between the different sources of data. The reasoning of the learners during the intervention and the post-intervention test, as well as their perceptions in the interview, were used to establish the consistency of the findings after the intervention. The pre-intervention test results and the interview for the learners was used to establish the initial reasoning the learners had before the intervention. Trustworthiness was also ascertained by having an independent coder use the same coding scheme to code the tests and the intervention data to identify reasoning and engagement, respectively.

Some elements of trustworthiness of this study are discussed in the following paragraphs.

3.8.1 Credibility

According to Lincoln and Guba (1985), the confidence in the truth delivered on the intended findings spells out the credibility of a study. In this study, previous examination type questions were adapted in the construction of the pre-intervention test and post-intervention test. The tests were carefully designed with reference to the curriculum expectations for Grade 11 stoichiometry (Department of Basic Education [DoBE NCS-CAPS], 2012). Taking cognizance of such parameters ensured that the learners were able to tackle normal examination questions in the same topic (Department of Basic Education [DoBE] Report, 2019). Hence, the tests measured what they were intended to measure according to the Department of Basic Education’s expectations. The test instruments were assessed by an experienced chemistry lecturer in the science education field at a university, as well as four experienced high school teachers to ascertain the extent to which they would enable credible data collection. The four teachers and the lecturer provided feedback on the ability of the instruments in assessing the reasoning of learners in their calculations. A pilot study was done to test the pre-intervention test and post-intervention tests at one school to 24 learners not participating in the main study. This was done to ascertain if the test assessed what it intended to while ensuring that the language was pitched at the level of the target sample. The instruments were, therefore, deemed trustworthy for the intended use (Nieuwenhuis, 2011).

The POGIL intervention worksheets were adapted from POGIL worksheets available on the POGIL website (Moog, 2020). These worksheets have been used successfully in many countries and schools over a period of time and are deemed credible for use in the current study.

3.8.2 Dependability of the data collection instruments

Dependability has to do with whether the results of a study are consistent with the data collected (Lincoln & Guba, 1985). This measure can be increased by investigator triangulation. All written work for the pre-intervention test and post-intervention test and video recording of the lessons were loaded into *ATLAS.ti* for qualitative data analysis coding and categorizing. One of my supervisors used the same coding scheme to code the tests and the video, as well as the transcribed interviews of both learners and teachers. A discussion was done with the researcher on how he had coded in comparison with how the supervisor had coded. This provided investigator triangulation (Patton, 2002) by providing credible and multiple ways of observing data. This increased the credibility of the coding scheme and the process used, reducing primary investigator bias (Anderson & Krathwohl, 2001; Thomas, 2006).

3.9 Crystallization

Crystallization uses various data collection techniques to allow the emergence of the findings. The different data collection techniques represent the multiple dimensions of a crystal which enables the credibility of the findings and improves trustworthiness of the findings (Nieuwenhuis, 2011). In the current study, the pre-intervention test and the post-intervention tests provided data about the learners' reasoning before and after the intervention, respectively. The data from the intervention provided information about how the learners engaged and reasoned in completing the POGIL worksheet. This data provided information about how learners reasoned in performing calculations. The data therefore supported what was found in the post-intervention test.

The interview of the learners enquired about their views on reasoning before and after the intervention. The responses of the learners in the interviews provided data that complemented data from the pre-intervention test, post-intervention test, and the video recording. The interview of the teachers also provided information on how they assessed the reasoning of the learners before and after the intervention. All the data collection techniques worked in unison to provide information about learners' reasoning in stoichiometry.

3.10 Ethical considerations

Before going for fieldwork, the researcher obtained permission from the University of Pretoria to conduct research (Appendix 19). The next stage was seeking permission from the Department of Basic Education (Appendix 20). Following this, I requested permission from two high schools to carry out research with at least one physical sciences teacher per school (Appendix 8). Consent was sought from two POGIL-trained physical sciences teachers at these two schools (Appendix 9). The parents and learners in the identified classes were requested to voluntarily give consent of their participation in the study before the research commenced (Appendix 10). All the learners in the two Grade 11 physical sciences classes were taught regardless of giving consent, but the interviews and analysis of results was only done with the learners who had given consent (Appendix 11). All data collection in the form of observations and field notes during POGIL lessons, pre-intervention tests and post-intervention tests and interviews for learners and for POGIL teachers was done outside normal teaching time. This was done so that data could be collected over a short period of time, to avoid the possibility of learners forgetting what they learned if it occurred over a long period of time.

All participants' identities were protected by using pseudonyms when collecting data and reporting the findings of the study. The videos taken were only used for analysis purposes and shall not be distributed or used in any other situations outside the consent of the participants. The video recorders were set up above the scribe such that only the work done by the group was recorded and not the faces of the learners. This helped to ensure anonymity. The researcher undertook to submit all the data collected to the university after analysis as it would remain the property of the university, which would keep it in safe storage for a set period.

3.11 Chapter Summary

During this study, various instruments were used to collect data before, during and after the intervention. ATLAS.ti’s version 8 software programme was used for careful coding and categorizing. The pre-intervention test provided information on the learners’ initial reasoning in solving stoichiometry. The intervention provided information about how learners engaged and reasoned while completing POGIL worksheets. The post-intervention test provided information of the learners’ reasoning after the intervention, and the interviews of both the teachers and the learners provided information about their perceptions of the POGIL method and how the teachers felt about the learners’ reasoning. The next chapter focusses on the results obtained using the various methods of data collection described in chapter 3.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter focuses on the presentation and discussion of the data collected using the various instruments of data collection discussed in chapter three. I started by firstly presenting the results and discussion of the pre-intervention test. This is followed by the results from the post-intervention test. A brief comparison of the pre-intervention test and the post-intervention test results then follows. This is followed by the discussion of the pre-intervention test and post-intervention test results on the ratio technique. The discussion of the pre-intervention test and post-intervention test results follows thereafter. Next, the data collected during the intervention are presented followed by a discussion thereof. The presentation of results ends with the report on the interviews of both the teachers and the learners.

4.2 Results from the pre-intervention test

4.2.1 Results obtained for each item in the pre-intervention test

In the following paragraphs, I give examples of results obtained for each item in the pre-intervention test. I briefly explain how each response was classified according to the learners' reasoning level. The classification of the responses was guided by the cognitive levels prescribed by the DoBE (see Tables 3.2 and 3.3) regarding the codes assigned to each question (see Table 3.6). This coding was also developed taking into consideration the level of complexity of each question in the test (see Tables 3.2 and 3.3 showing the levels of complexity of the questions in the pre-intervention test and post-intervention test, respectively).

4.2.1.1 Question 1

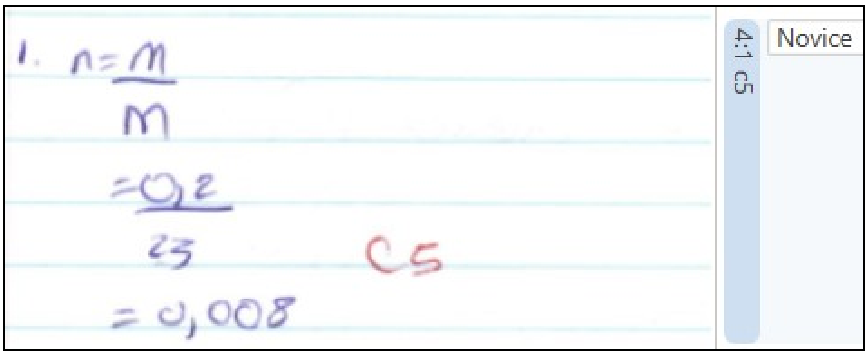
Learners' execution of this level I question in the pre-intervention test was poorly done. The question required learners to identify a suitable formula from the provided formula sheet. This single-step calculation required learners to have the knowledge of the formula needed and use the appropriate substitution to calculate the answer. Most learners did not do well as they made various errors such as wrong substitution, wrong formulae, not responding and wrong calculations, among others.

Novice response to question 1

Some learners who demonstrated novice responses used a correct formula and a wrong substitution to get a wrong answer. The learners demonstrated novice ideas regarding of the use of the formula and the meaning of each symbol in the formula. Such work was classified as novice response since this was a level I question with a single step. Figure 4.1 shows an example of a novice response in the pre-intervention test to question 1.

Figure 4:1

Novice response to question 1



1. $n = \frac{m}{M}$

$= \frac{0,2}{23}$

$= 0,008$

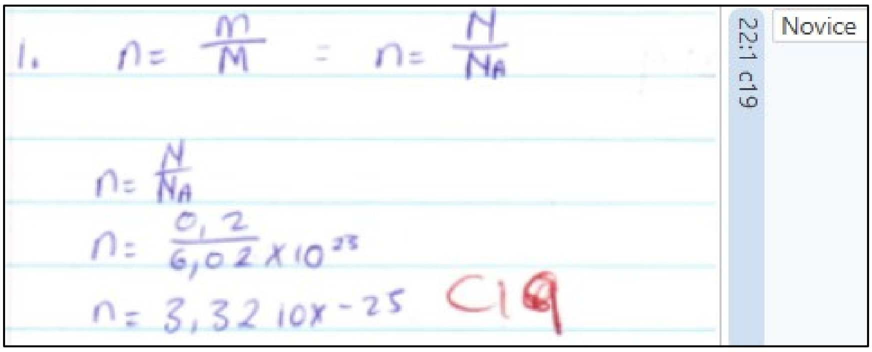
C5

Another Novice response to question 1

Some learners attempted to do the calculations using a wrong formula. As a result, their answers ended up being incorrect. An example of such a novice response to question 1 is shown in figure 4.2.

Figure 4:2

Novice response to question 1



1. $n = \frac{m}{M}$ = $n = \frac{N}{N_A}$

$n = \frac{N}{N_A}$

$n = \frac{0,2}{6,02 \times 10^{23}}$

$n = 3,32\ 10x{-25}$ C19

22:1 c19

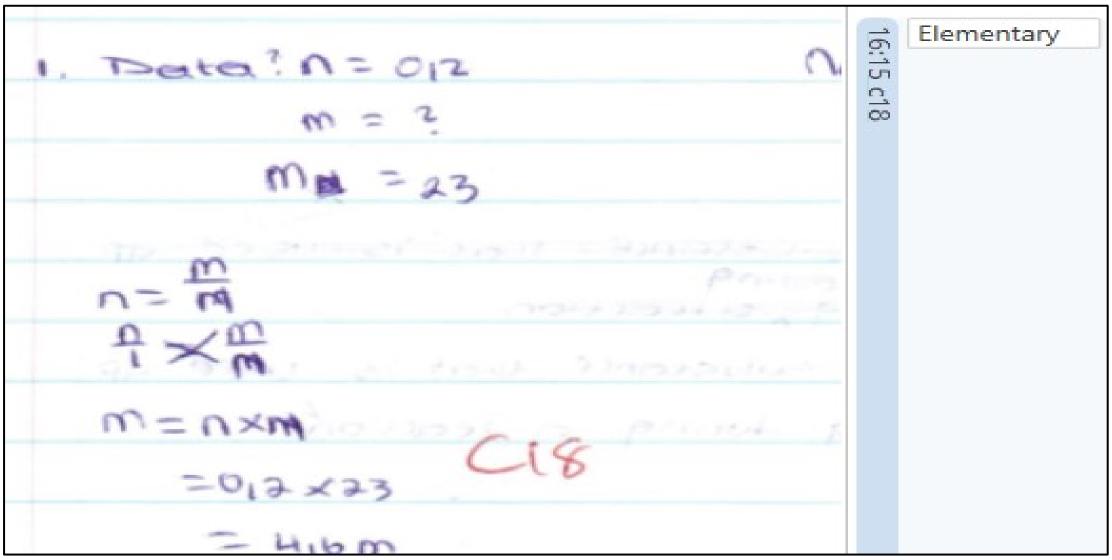
Novice

Elementary response to question 1

Some learners used the correct formula and correct substitution got the correct answer. The learner used an incorrect unit, but that fault was overlooked during the assessment. Such responses were classified as elementary. Figure 4.3 shows an example of an elementary response to question 1.

Figure 4:3

Elementary responses to question 1.



1. Data: $n = 0,2$

$m = ?$

$M = 23$

n

$n = \frac{m}{M}$

$\frac{n}{1} \times \frac{m}{M}$

$m = n \times M$

$= 0,2 \times 23$

$= 4,6\ m$

C18

16:15 c18

Elementary

4.2.1.2 Question 2

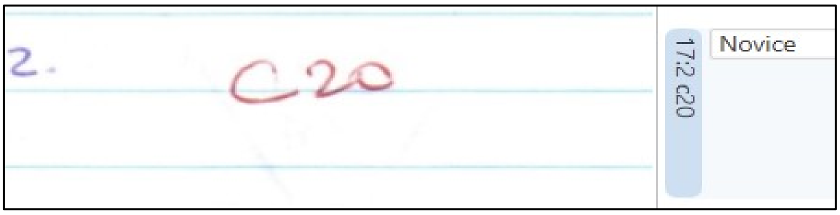
Question 2 was a level III question which needed three-step calculation. The question required analysis, evaluation, synthesis, and application on top of the basic cognitive domains of knowledge and understanding.

Novice response to question 2

Some of the learners who had novice ideas of solving the question left blanks as shown in Figure 4.4 below.

Figure 4:4

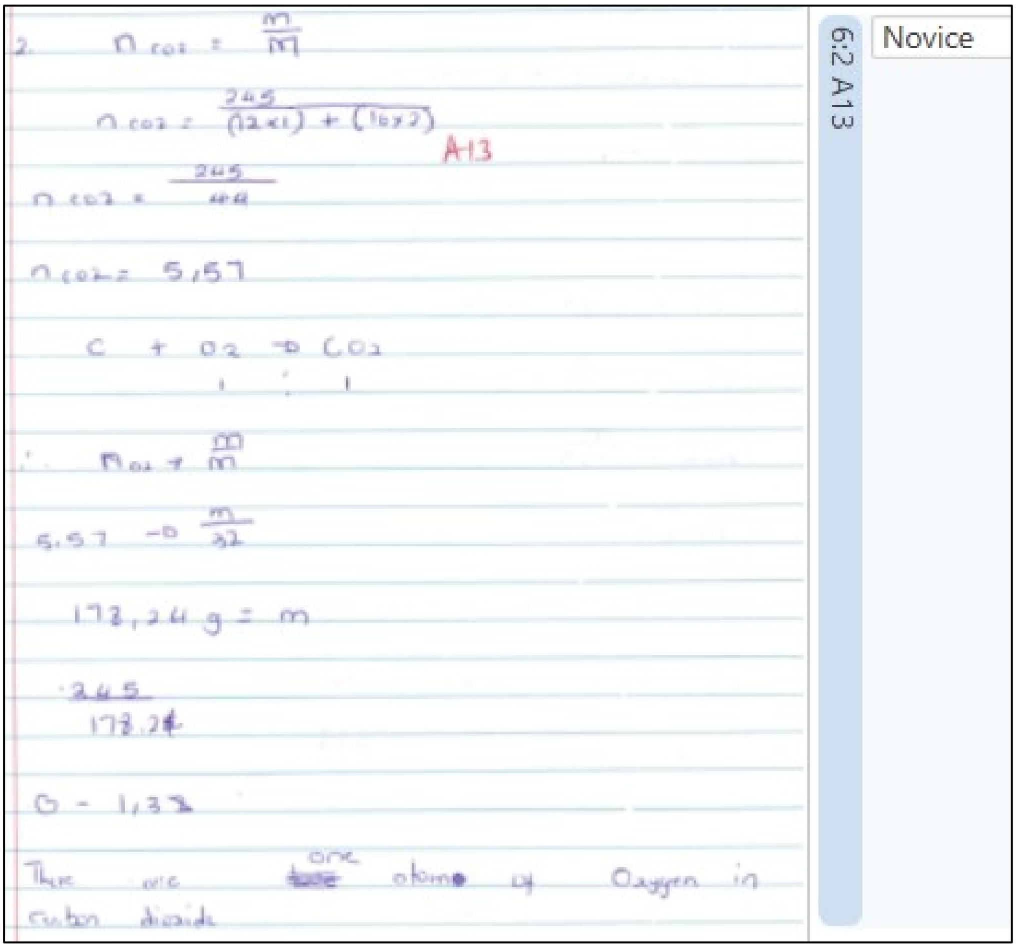
Novice response to question 2



Yet, some learners did wrong substitution on the correct formula. Such learners ended up getting the answer wrong because of incorrect substitution, as shown in Figure 4.5.

Figure 4:5

Novice response to question 2



2. $n_{CO_2} = \frac{m}{M}$

$n_{CO_2} = \frac{245}{(12\times1)+(16\times2)}$

A13

$n_{CO_2} = \frac{245}{44}$

$n_{CO_2} = 5,57$

$C + O_2 \rightarrow CO_2$

1 : 1

$\therefore n_{O_2} = \frac{m}{M}$

$5,57 \rightarrow \frac{m}{32}$

178,24 g = m

$\frac{245}{178,24}$

O - 1,37

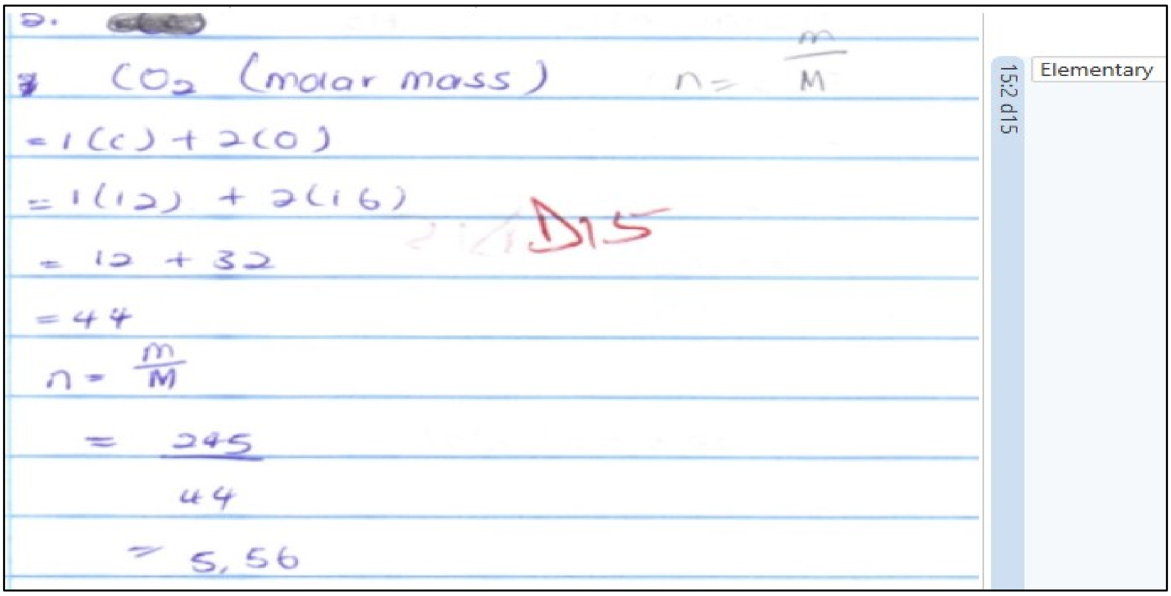
There are ~~[illegible]~~ one atoms of Oxygen in carbon dioxide

Elementary response to question 2

Some learners with elementary knowledge could do only one step in this three-step problem. For example, some learners calculated the relative molecular mass of the compound but failed to use it further. Figure 4.6 is an example of an elementary response to question 2.

Figure 4:6

Elementary response to question 2



2. [redacted]

CO_2 (molar mass) $n = \frac{m}{M}$

$= 1(C) + 2(O)$

$= 1(12) + 2(16)$ D15

$= 12 + 32$

$= 44$

$n = \frac{m}{M}$

$= \frac{245}{44}$

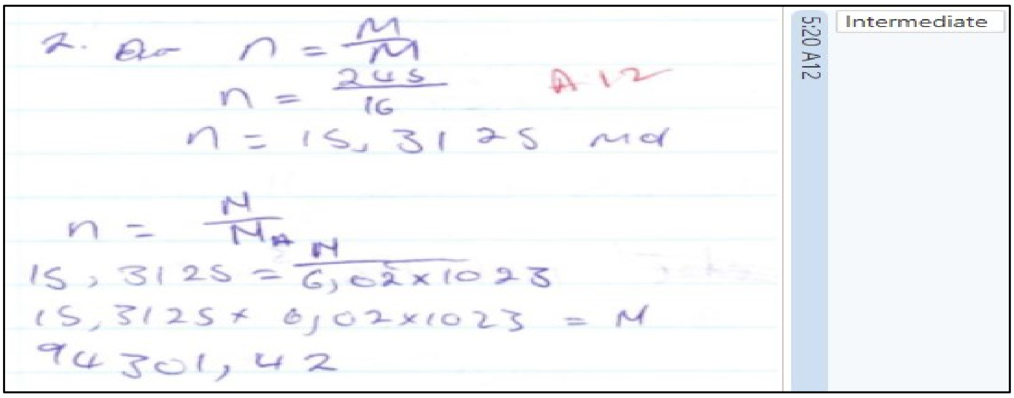
$= 5,56$

Intermediate response to question 2

Some learners with intermediate knowledge calculated the relative molecular mass and chose the correct formula and did the first calculation and the second calculation correctly. Since the learner managed to do two steps, the work was coded as intermediate. Figure 4.7 is an example of an intermediate response to question 2.

Figure 4:7

Intermediate response to question 2



2. Ar $n = \frac{M}{M}$

$n = \frac{245}{16}$ A12

$n = 15,3125$ mol

$n = \frac{N}{N_A}$

$15,3125 = \frac{N}{6,02 \times 10^{23}}$

$15,3125 \times 6,02 \times 10^{23} = N$

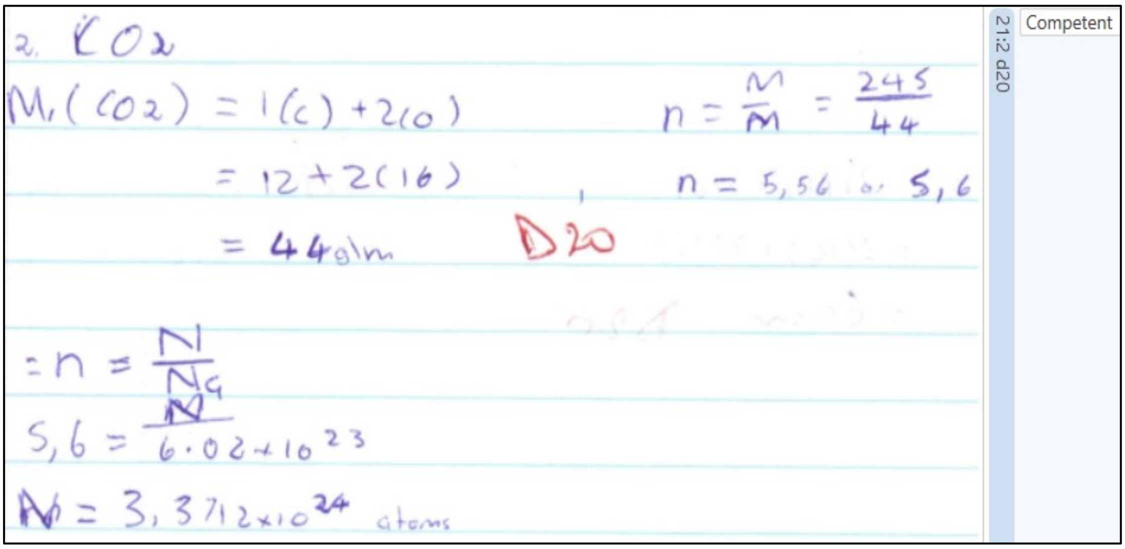
$94301,42$

Competent response to question 2

Some learners demonstrated competence in question 2 by performing all the steps required to get the answer. An example of such response was when the learner used a correct relative molecular formula, and all three steps were appropriately done. Figure 4.8 is an example of a competent response to question 2.

Figure 4:8

Competent response to question 2



2. CO_2

$M_r(CO_2) = 1(c) + 2(o)$

$= 12 + 2(16)$

$= 44$ g/m

$n = \frac{m}{M} = \frac{245}{44}$

$n = 5{,}56$ or $5{,}6$

D20

$\therefore n = \frac{N}{N_A}$

$5{,}6 = \frac{N}{6{\cdot}02 \times 10^{23}}$

$N = 3{,}3712 \times 10^{24}$ atoms

4.2.1.3 Question 3a

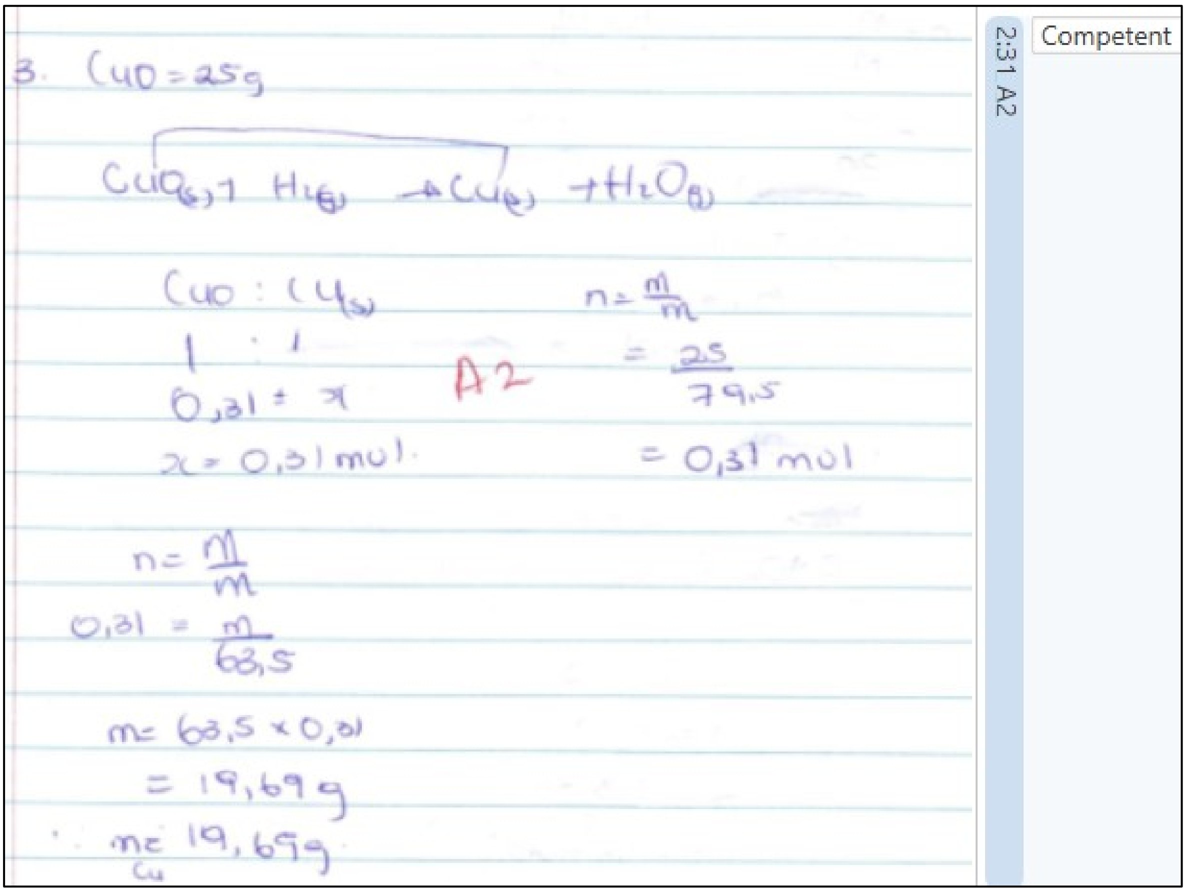
Question 3a was a level III question in the pre-intervention test. It required a three-step calculation. This question produced the highest number of learners with competent knowledge.

Competent response to question 3a

A learner with the competency to answer this question used the correct formula and calculated the number of moles of CaO appropriately, then used the ratio technique to calculate the equivalent number of moles of CO_2. Thereafter, the learner used the appropriate formula to calculate the volume of CO_2. The learner did not make any mistakes. The work was, therefore, classified as competent because the response needed three steps in a level III question. An example of a competent response to question 3a is shown in Figure 4.9.

Figure 4:9

Competent response to question 3a



3. $CuO = 25g$

$CuO_{(s)} + H_{(g)} \rightarrow Cu_{(s)} + H_2O_{(l)}$

$CuO : Cu_{(s)}$ $\quad n = \frac{m}{M}$

$1 : 1$ $\quad = \frac{25}{79,5}$

$0,31 = x$ $\quad$ A2

$x = 0,31\ mol.$ $\quad = 0,31\ mol$

$n = \frac{m}{M}$

$0,31 = \frac{m}{63,5}$

$m = 63,5 \times 0,31$

$= 19,69\ g$

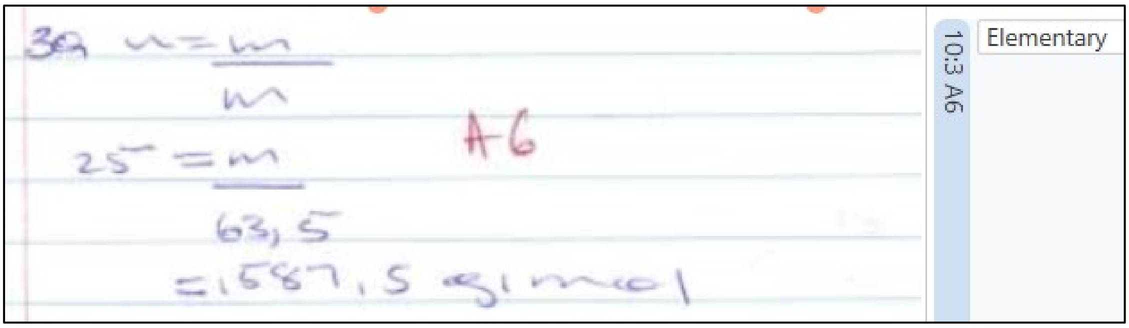
$\therefore m_{Cu} = 19,69g$

Elementary response to question 3a

The learners with elementary knowledge managed to do one-step calculations. The formula was correct, and so was substitution. But the learner failed to proceed past the first step. An example of an elementary response to question 3a is shown in figure 4.10.

Figure 4:10

Elementary response to question 3a



3a $n = \frac{m}{M}$

$25 = \frac{m}{63,5}$

$= 1587,5$ g/mol

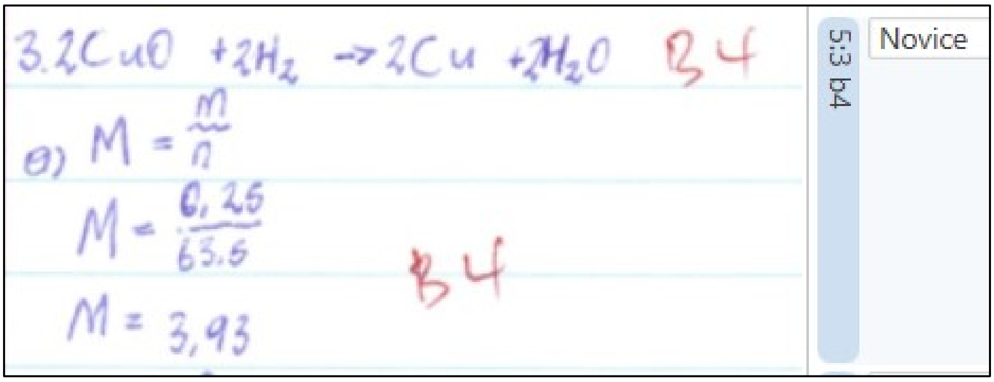
A6

Novice response to question 3a

Most learners in the sample had 'novice ideas' of how to answer the question. Some of the learners used wrong formula and incorrect substitution to get wrong answers. An example of such a novice response to question 3a is shown in figure 4.11.

Figure 4:11

Novice response to question 3a



3. $2CuO + 2H_2 \rightarrow 2Cu + 2H_2O$ B4

a) $M = \frac{m}{n}$

$M = \frac{0,25}{63.5}$

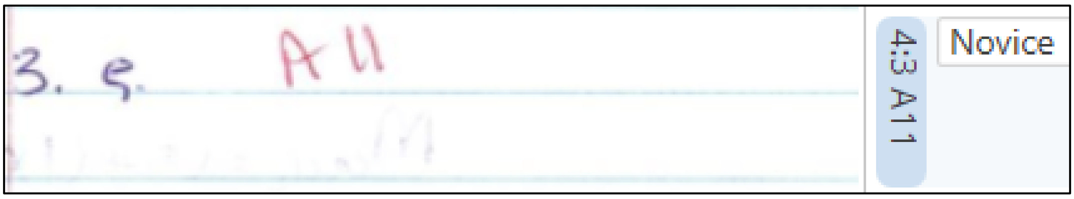
$M = 3,93$

B4

Other learners with novice ideas towards solving questions left blank spaces without further attempts to solve the question. The assumption here is that such learners did not have a clue where to start solving the problem. Figure 4.12 shows another novice response to question 3a.

Figure 4:12

Novice response to question 3a



3. a. A11

4:3 A11

Novice

4.2.1.4 Question 3b

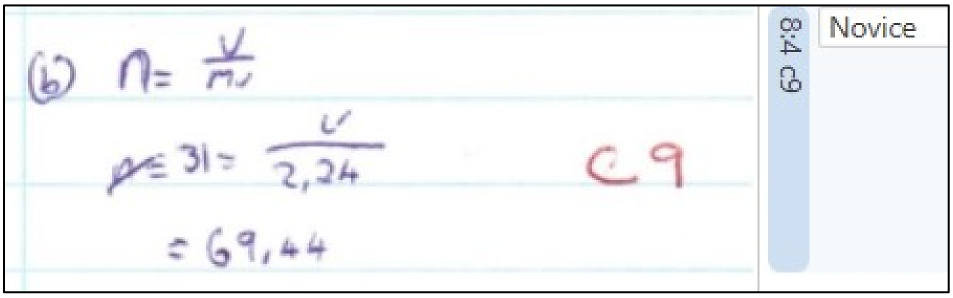
This was a level II question in which learners were supposed to use the mole ratio of CuO and H_2 on the balanced equation of reaction to find the equivalent number of moles of H_2. Then the learners were required to use the formula n = $\frac{V}{Vm}$ to find the volume of H_2 produced.

Novice response to question 3b

Some learners with ‘novice responses’ to using the mole ratio used an incorrect formula in the calculation. Figure 4.13 shows an example of a novice response to question 3b.

Figure 4:13

Novice response to question 3b



(b) $n = \frac{V}{mv}$

$n = 31 = \frac{v}{2,24}$

$= 69,44$

c9

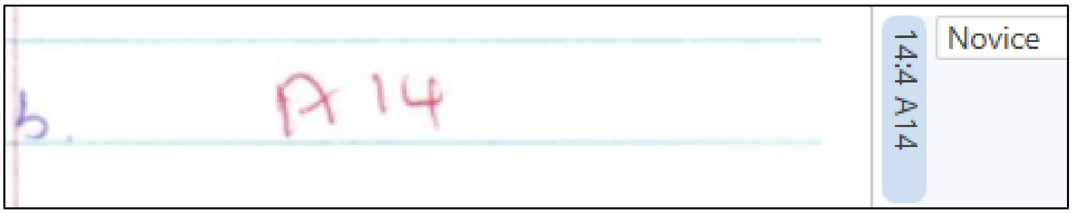
8:4 c9

Novice

Most of the learners showed that they had novice ideas of how to answer the question by leaving it blank. An example of a novice response where learners left blanks is shown in figure 4.14.

Figure 4:14

Novice response to question 3b



b. A 14

14:4 A14

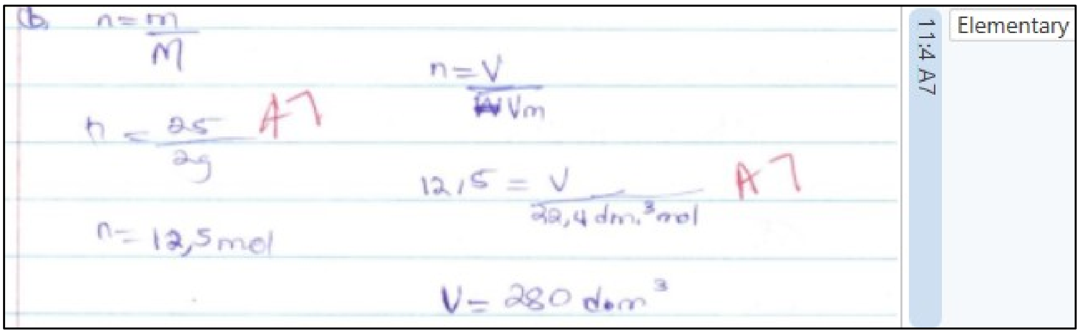
Novice

Elementary response to question 3b

Some learners with elementary knowledge used the correct formula but did wrong substitution. The number of moles is incorrect, but they appropriately used the value in the calculation to get an inappropriate answer. Example of elementary response to question 3b is shown in figure 4.15.

Figure 4:15

Elementary response to question 3b



(b) $n = \frac{m}{M}$

$n = \frac{25}{2g}$ A7

$n = 12,5 \text{ mol}$

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

$12,5 = \frac{V}{22,4 \text{ dm}^3\text{mol}}$ A7

$V = 280 \text{ dm}^3$

11:4 A7

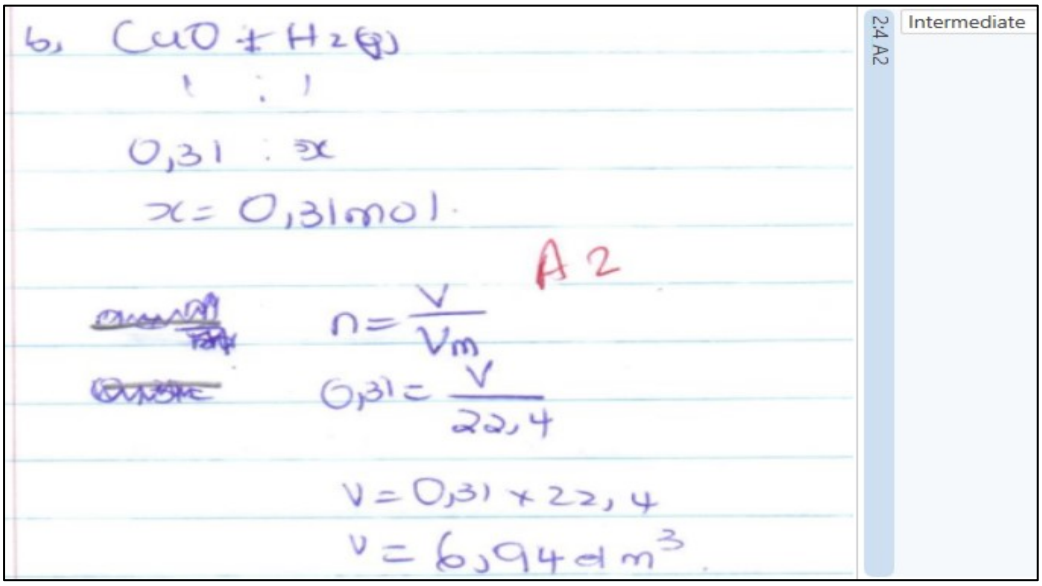
Elementary

Intermediate response to question 3b

Other learners had intermediate knowledge and used the correct ratio and formula and got the appropriate answer to the question. The learner did correct conversion of units to cubic decimetres and used correct formula, substituted appropriately, and got the appropriate answer. Figure 4.16 shows intermediate response to question 3b.

Figure 4:16

Intermediate response to question 3b



b, $CuO + H_2(g)$

$1 : 1$

$0,31 : x$

$x = 0,31 mol.$

A 2

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

$0,31 = \frac{V}{22,4}$

$V = 0,31 \times 22,4$

$V = 6,94 dm^3.$

2:4 A2

Intermediate

4.2.1.5 Question 4a

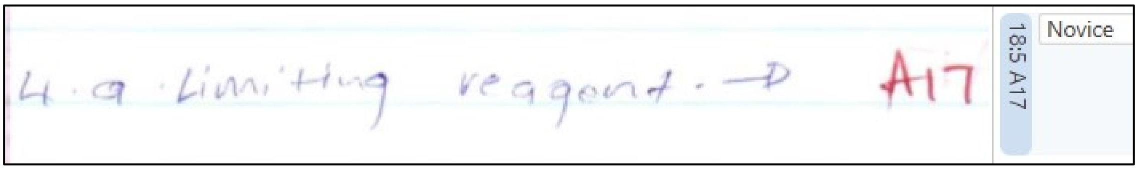
This was a level I question that required learners to recall and state the definition of limiting reactant. Most of the learners failed to state the correct definition of limiting reactant.

Novice response to question 4a

Some of these learners left blanks showing that they did not have an idea of how to solve the problem. Example of novice response to question 4a is shown in figure 4.17.

Figure 4:17

Novice response to question 4a



4.a Limitting reagent. →

A17

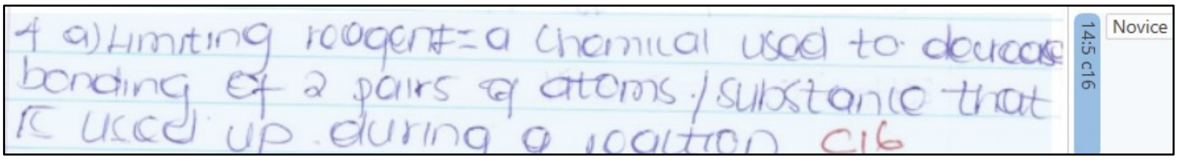
18:5 A17

Novice

Other learners had completely wrong definitions of limiting reactant such as the one shown in figure 4.18.

Figure 4:18

Novice response to question 4a



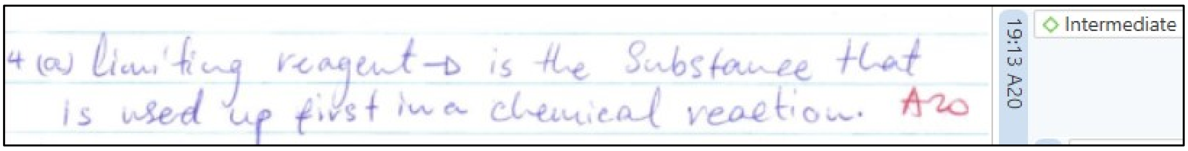
4 a) Limiting reagent = a chemical used to doucas bonding of 2 pairs of atoms / substance that is used up during a reaction C16

Elementary response to question 4a

Very few learners however appropriately stated the definition of a limiting reactant. Such work was classified as elementary knowledge since only recall was needed to answer the question completely. Example of elementary response in question 4a is shown in figure 4.19.

Figure 4:19

Elementary response to question 4a



4 (a) limiting reagent → is the substance that is used up first in a chemical reaction. A20

4.2.1.6 Question 4b

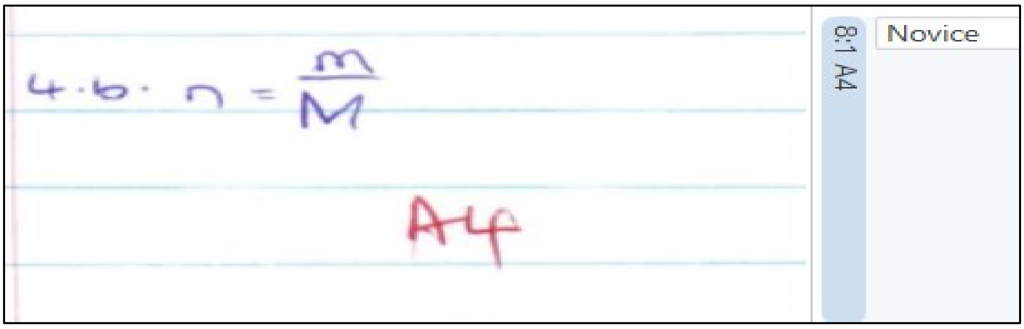
This was a level IV question where learners were supposed to solve the problem using a multi-step calculation. The learners were supposed to calculate the number of moles of NO and O_2. After that, they were supposed to use the mole ratio as shown from a balanced chemical equation to calculate the equivalent number of moles required to react with the calculated moles. This would have led them to identify the limiting reactant. Then they were supposed to use the number of moles of the limiting reactant to calculate the equivalent number of moles of NO_2. They were then expected to use the correct formula to calculate the mass of NO_2 produced. Most of the learners in the sample demonstrated novice ideas in attempting to answer this question.

Novice response to question 4b

Some of these learners failed to calculate the molecular mass to begin with. They did not proceed with calculation. Figure 4.20 shows a novice response to question 4b.

Figure 4:20

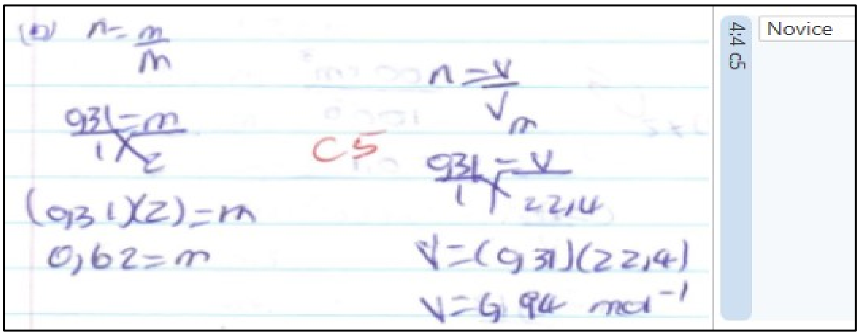
Novice response to question 4b



Other learners failed to use appropriate formula or failed to use the formula appropriately. An example of such novice response is shown in figure 4.21.

Figure 4:21

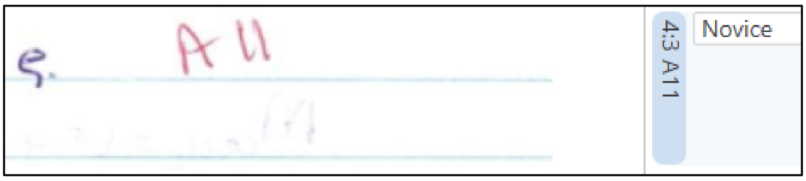
Novice response to question 4b



Some learners left the question completely blank. They did not attempt to respond and therefore their work was classified as a novice idea. Figure 4.22 shows an example of such novice response to question 4b.

Figure 4:22

Novice response to question 4b



5. A11

4:3 A11

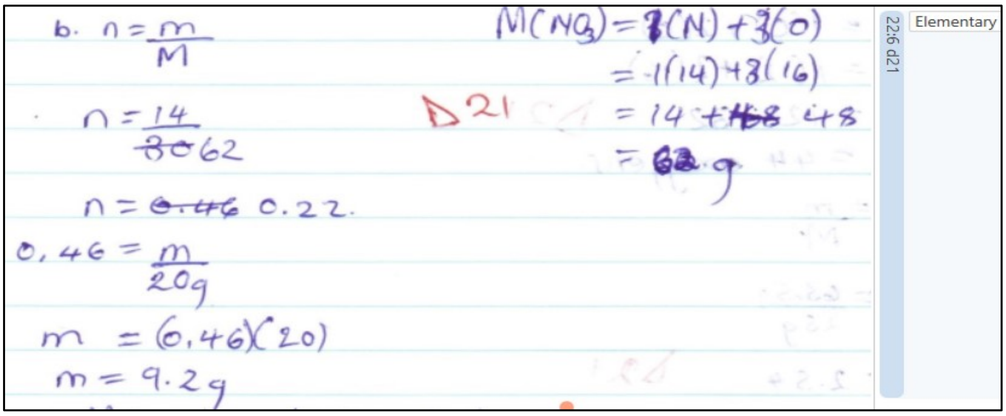
Novice

Elementary response to question 4b

Learners with elementary knowledge managed to calculate relative molecular mass but failed to proceed to the use the next formula. An example of an elementary response to question 4b is shown in figure 4.23.

Figure 4:23

Elementary response to question 4b



b. $n = \frac{m}{M}$

$n = \frac{14}{\cancel{80}\,62}$

$n = \cancel{0.46}\ 0.22.$

$0,46 = \frac{m}{20g}$

$m = (0,46)(20)$

$m = 9.2g$

$M(NO_3) = \cancel{3}1(N) + 3(O)$

$= 1(14) + 3(16)$

$= 14 + \cancel{168}\ 48$

$= 62\,g$

D21

22:6 d21

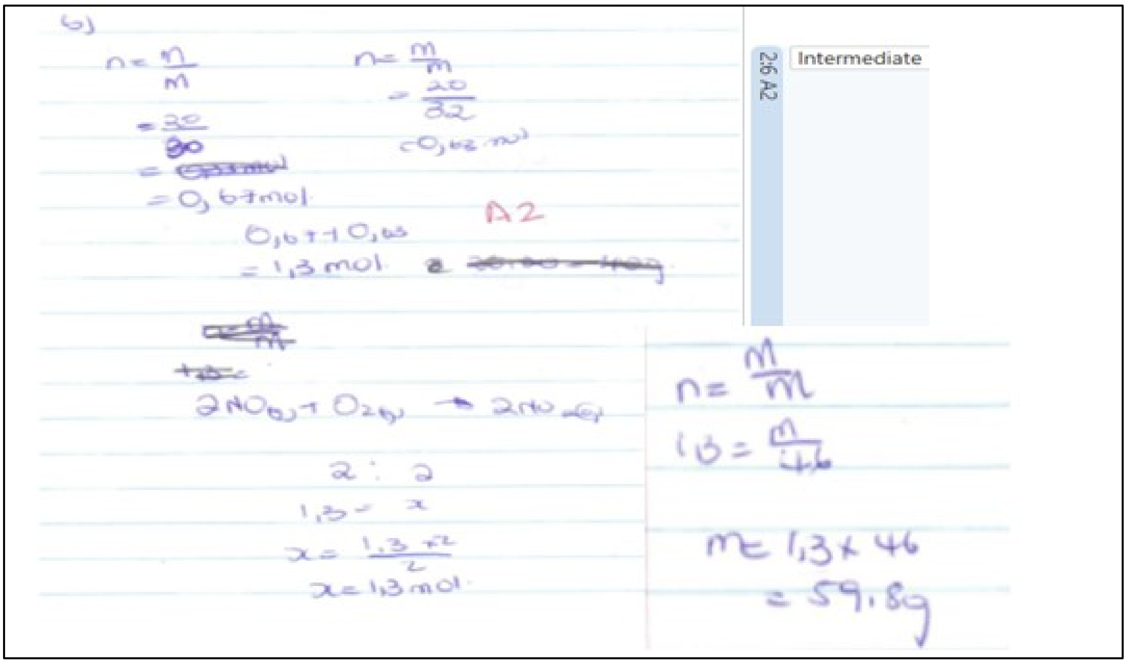
Elementary

Intermediate response to question 4b

Other learners with intermediate knowledge appropriately calculated the relative molecular mass. They used the first formula and appropriately calculated both number of moles. The learners however, added up the number of moles instead of identifying the limiting reactant using those calculated moles. The learners used the total number of moles to calculate the mass produced. The mass is incorrect because of where the learner added the number of moles. An example of an intermediate response to question 4b is shown in figure 4.24.

Figure 4:24

Intermediate response to question 4b



b)

$n = \frac{m}{M}$

$= \frac{20}{30}$

$= 0,67 mol$

$n = \frac{m}{M}$

$= \frac{20}{32}$

$= 0,62 mol$

$0,67 + 0,63$

$= 1,3 mol$

A2

$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$

$2 : 2$

$1,3 = x$

$x = \frac{1,3 \times 2}{2}$

$x = 1,3 mol$

$n = \frac{m}{M}$

$1,3 = \frac{m}{46}$

$m = 1,3 \times 46$

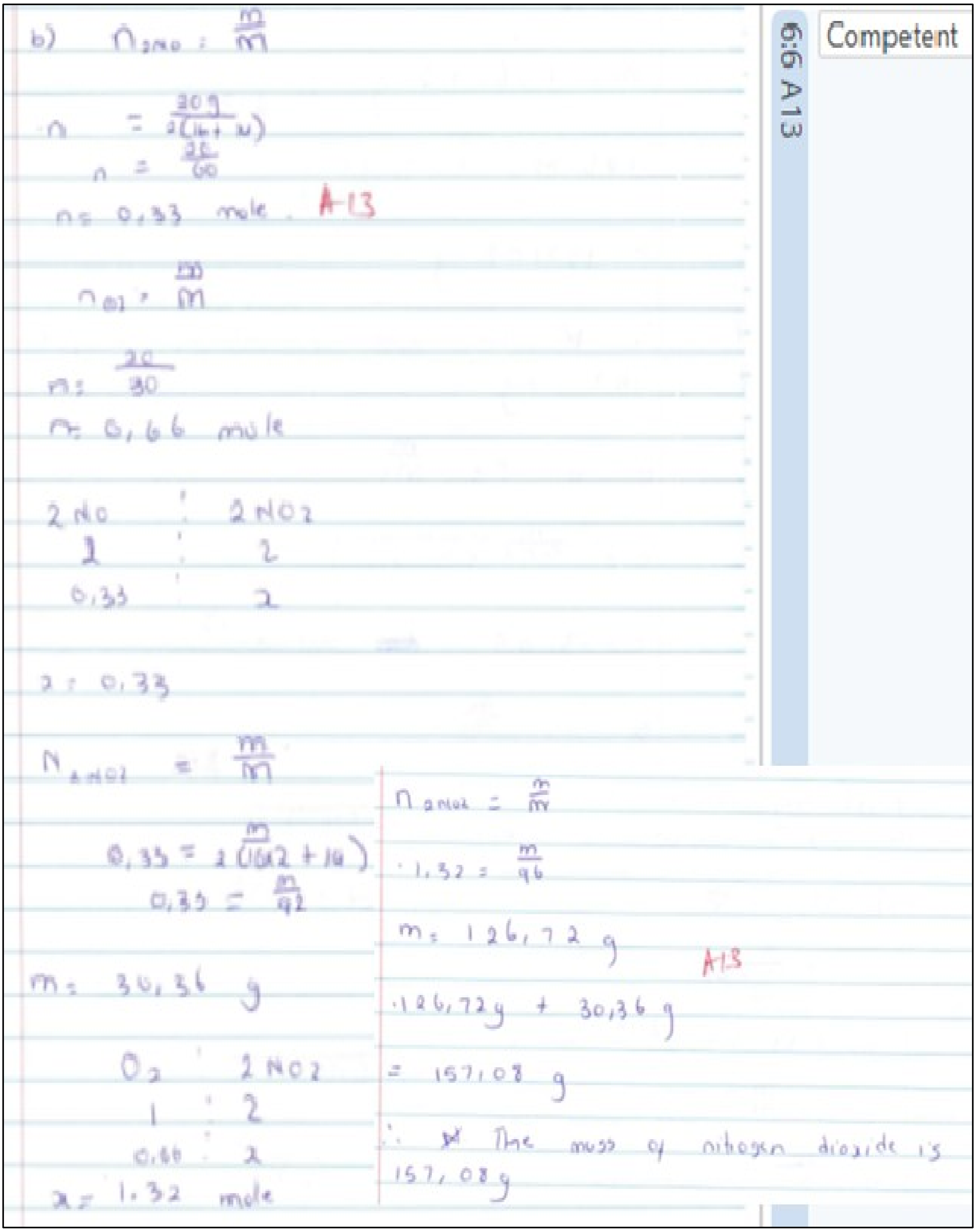
$= 59,8g$

Competent response to question 4b

From the sample there was only 1 competent response. The learner did all the other steps appropriately. The only mistake made by the learner was the wrong relative molecular mass used in the first part of the calculation. The competent response done by the learner is shown in figure 4.25.

Figure 4:25

Competent response to question 4b



b) $n_{2NO} = \frac{m}{M}$

$n = \frac{30g}{2(16+14)}$

$n = \frac{20}{60}$

n = 0,33 mole . A13

$n_{O_2} = \frac{m}{M}$

$n = \frac{20}{30}$

n = 0,66 mole

2 NO : 2 NO_2
1 : 2
0,33 : x

x = 0,33

$N_{2NO_2} = \frac{m}{M}$

$0,33 = \frac{m}{2(16\times2+14)}$

$0,33 = \frac{m}{92}$

m = 30,36 g

O_2 : 2 NO_2
1 : 2
0,66 : x

x = 1.32 mole

$n_{2NO_2} = \frac{m}{M}$

$1,32 = \frac{m}{96}$

m = 126,72 g A13

126,72 g + 30,36 g

= 157,08 g

∴ ~~x~~ The mass of nitrogen dioxide is 157,08 g

6:6 A13

Competent

4.2.1.7 Question 5

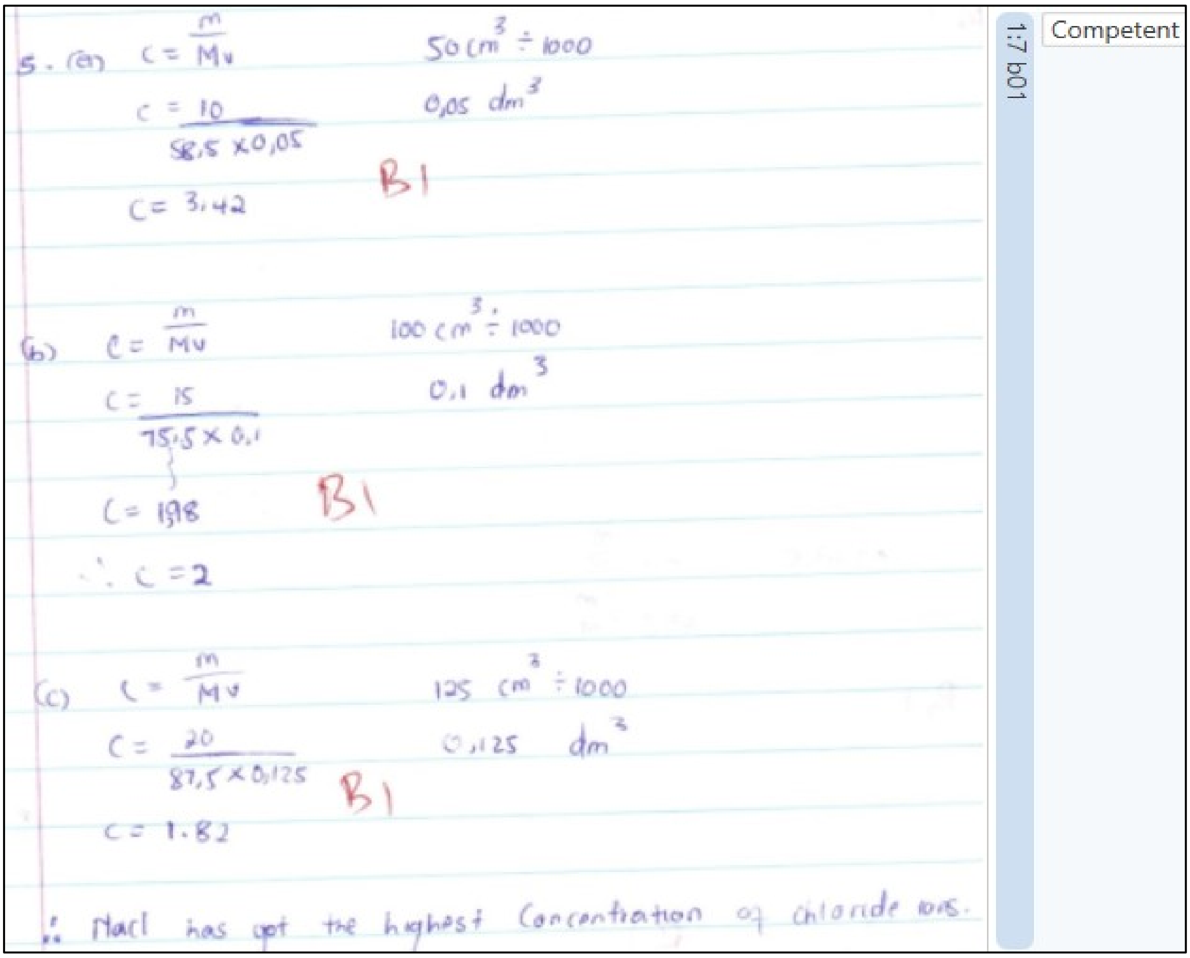
This was a level IV question which required multi-step calculations. There was no learner in the sample who demonstrated advanced knowledge of answering this question.

Competent response to question 5

There were competent learners who had minor errors. These learners appropriately converted the units to cubic decimetres and used the correct formula to appropriately calculate the concentration of each substance. They, however, did not calculate the concentration of the ions as required by the question. Their answer is, therefore, incomplete. Figure 4.26 is an example of a competent response to question 5.

Figure 4:26

Competent response to question 5



5. (a) $c = \frac{m}{Mv}$ $50\ cm^3 \div 1000$

$c = \frac{10}{58,5 \times 0,05}$ $0,05\ dm^3$

$c = 3,42$ B1

(b) $c = \frac{m}{Mv}$ $100\ cm^3 \div 1000$

$c = \frac{15}{75,5 \times 0,1}$ $0,1\ dm^3$

$c = 1,98$ B1

$\therefore c = 2$

(c) $c = \frac{m}{Mv}$ $125\ cm^3 \div 1000$

$c = \frac{20}{87,5 \times 0,125}$ $0,125\ dm^3$ B1

$c = 1.82$

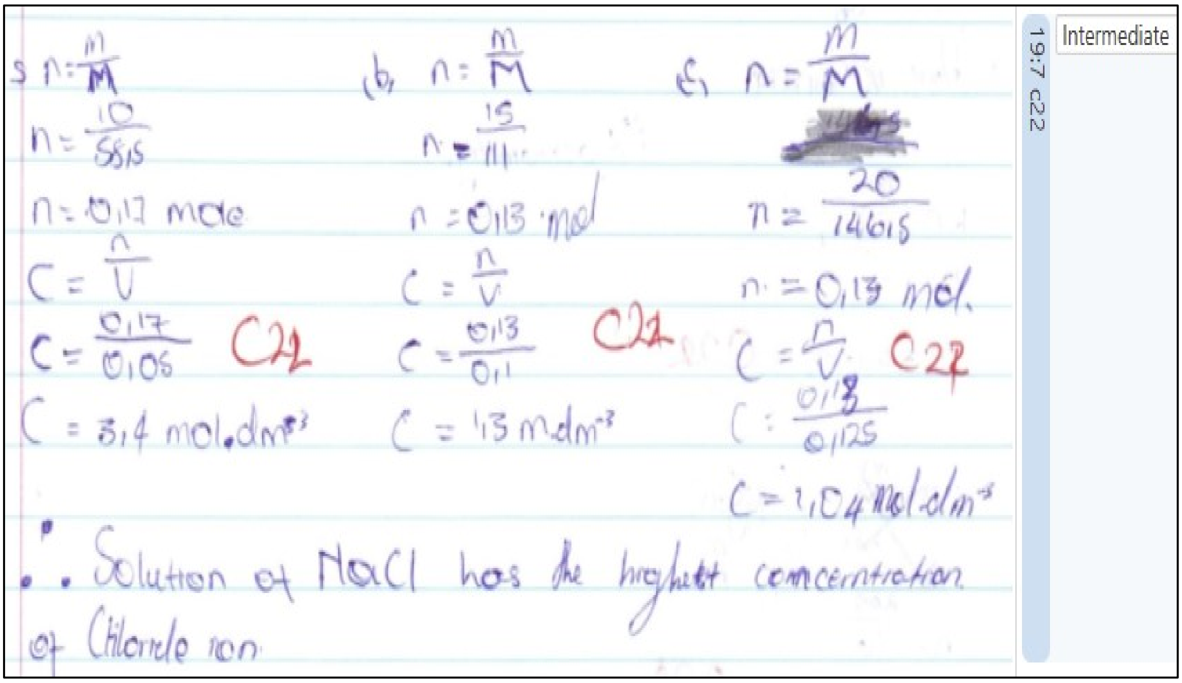
$\therefore$ Nacl has got the highest Concentration of chloride ions.

Intermediate response to question 5

The sample had 14 learners showing intermediate knowledge in answering question 5. For example, learners appropriately calculated the number of moles for each substance and the concentration for each. However, they did not proceed to calculate the concentration of moles by using ratios. As such, the learner did not complete the calculation. An example of an intermediate response to question 5 is shown in figure 4.27.

Figure 4:27

Intermediate response to question 5



5 $n = \frac{m}{M}$

$n = \frac{10}{58,5}$

$n = 0,17$ mole

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

$C = \frac{0,17}{0,05}$ C22

$C = 3,4$ mol.dm^{-3}

(b) $n = \frac{m}{M}$

$n = \frac{15}{111}$

$n = 0,13$ mol

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

$C = \frac{0,13}{0,1}$ C22

$C = 1,3$ m.dm^{-3}

(c) $n = \frac{m}{M}$

$n = \frac{20}{146,5}$

$n = 0,13$ mol.

$C = \frac{n}{V}$ C22

$C = \frac{0,13}{0,125}$

$C = 1,04$ mol.dm^{-3}

∴ Solution of NaCl has the highest concentration of Chloride ion

19:7 c22

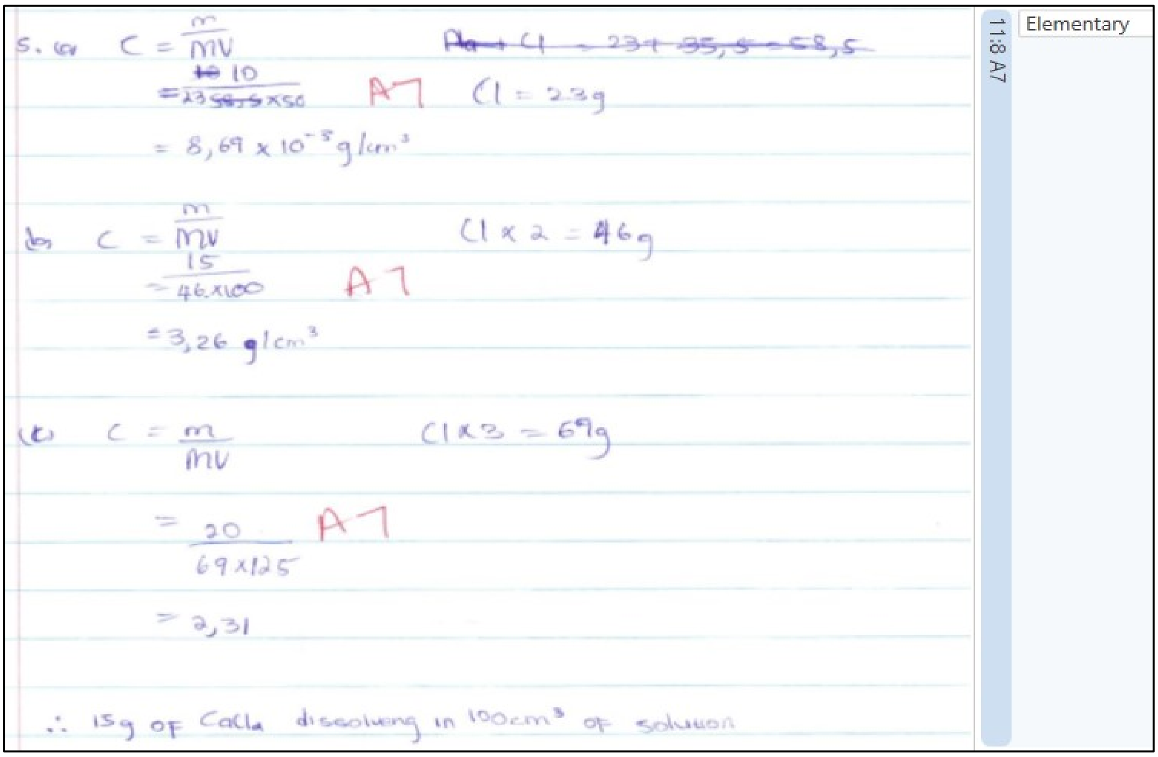
Intermediate

Elementary response to question 5

Another 14 learners in the sample had elementary knowledge to answer question 5. They could not calculate the relative molecular mass but used the correct formula to calculate the number of moles. An example of an elementary response to question 5 is shown in figure 4.28.

Figure 4:28

Elementary response to question 5



5. (a) $C = \frac{m}{MV}$ ~~Na + Cl = 23 + 35,5 = 58,5~~

$= \frac{\cancel{10}\ 10}{23\ \cancel{58,5} \times 50}$ A7 Cl = 23g

$= 8,69 \times 10^{-5}$ g/cm³

(b) $C = \frac{m}{MV}$ Cl × 2 = 46g

$= \frac{15}{46 \times 100}$ A7

$= 3,26$ g/cm³

(c) $C = \frac{m}{MV}$ Cl × 3 = 69g

$= \frac{20}{69 \times 125}$ A7

$= 2,31$

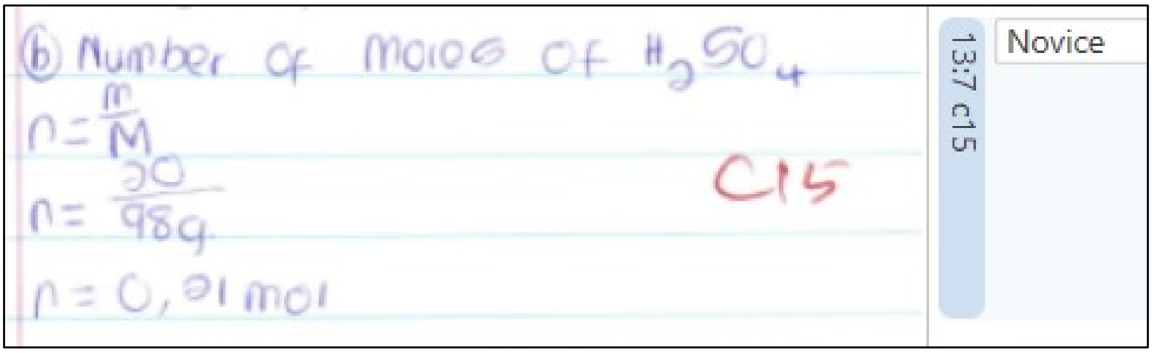
∴ 15g of $CaCl_2$ dissolving in 100cm³ of solution

Novice response to question 5

Most of the learners had novice ideas in attempting to answer question 5. The calculation done to the response below has nothing to do with what was expected in the question. The formula does not work to respond to this question. An example of a novice response to question 5 is shown in figure 4.29.

Figure 4:29

Novice response to question 5



(b) Number of moles of H_2SO_4

$n = \frac{m}{M}$

$n = \frac{20}{98g}$ C15

$n = 0,21$ mol

4.2.1.8 Question 6a

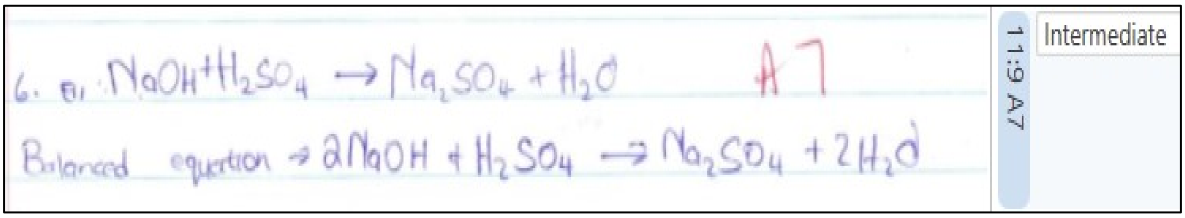
Question 6a was a level II question that required learners to balance an equation of a chemical reaction. Only a few learners in the sample demonstrated intermediate knowledge to balance the equation of a chemical reaction.

Intermediate response to question 6a

The learners with intermediate knowledge made sure that the number of atoms on the left balances their number on the right. An example of intermediate response to question 6a is shown in figure 4.30.

Figure 4:30

Intermediate response to question 6a



6. a. $NaOH + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$ A7

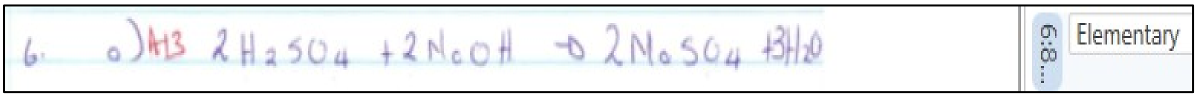
Balanced equation → $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

Elementary response to question 6a

In the sample, a few learners had elementary knowledge to balance the equation of the reaction. The elementary learners knew the formula of the reactants and products but failed to balance the numbers of atoms. This learner had the correct idea of the formulae of reactants and products. The learner, however, made a slight mistake on the formula of sodium sulphate. He/she tried to balance but did not do it well, possibly because of the wrong formula of sodium sulphate. Figure 4.31 shows an example of an elementary response to question 6a.

Figure 4:31

Elementary response to question 6a



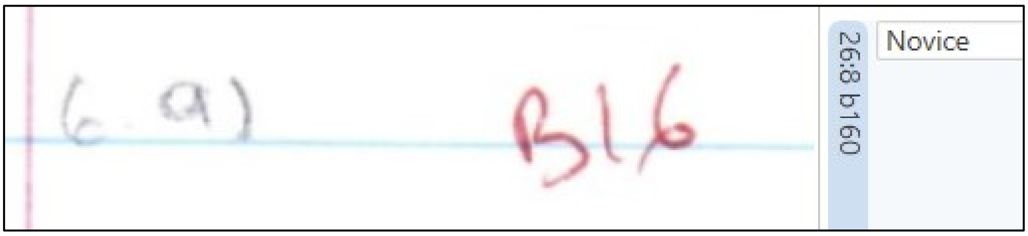
6. a) A13 $2H_2SO_4 + 2NaOH \rightarrow 2NaSO_4 + 3H_2O$

Novice response to question 6a

Most learners in the sample demonstrated novice ideas of how to balance an equation of reaction. Some of them did not know the formula of the products or left blank spaces or never attempted to answer. Figure 4.32 shows and example of novice response to question 6a.

Figure 4:32

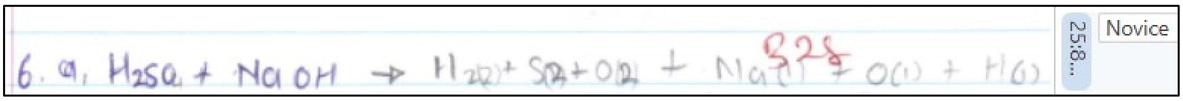
Novice response to question 6a



Still, some learners with novice ideas for answering question 6a made varied attempts to solve the question but failed. In the example below, the learner did not know the formula of the products of the reaction. Figure 4.33 shows another example of a novice response to question 6a.

Figure 4:33

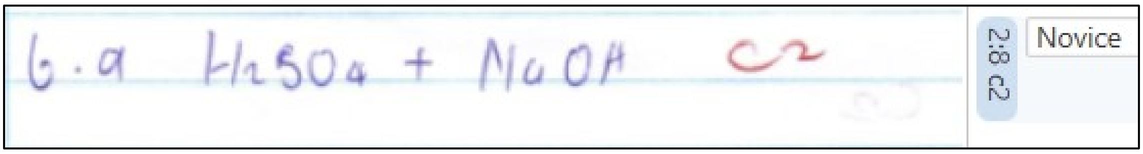
Another Novice response to question 6a



Other learners with novice ideas for answering question 6a managed to write only the formula of the reactants but no products. Such learners may have thought that they already wrote a balanced equation of reaction by so doing. Further investigation is required to ascertain the meaning of the answer indicated to figure 4.34.

Figure 4:34

Novice response to question 6a



6.a $H_2SO_4 + NaOH$ c2

4.2.1.9 Question 6b

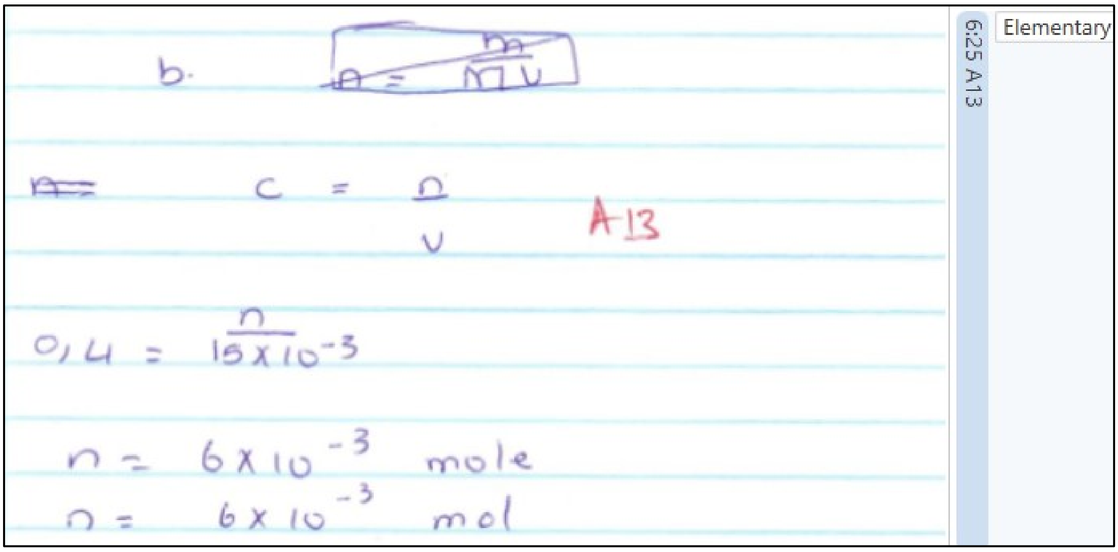
This was a level I question which required learners to convert cubic centimetres to decimetres and then use one formula c = $\frac{n}{V}$ to substitute and find the answer. Very few learners in the sample demonstrated intermediate knowledge to answer the question appropriately.

Elementary response to question 6b

An example of work done by such learners is shown in figure 4.35. The learner used the correct formula, correct conversion of units to cubic decimetres, correct substitution and got the appropriate answer.

Figure 4:35

Elementary response to question 6b



b. $\boxed{n = \frac{m}{MV}}$

$c = \frac{n}{V}$ A13

$0{,}4 = \frac{n}{15 \times 10^{-3}}$

$n = 6 \times 10^{-3}$ mole

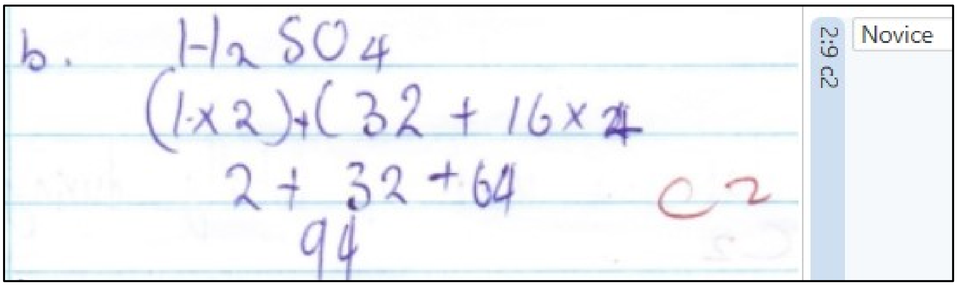
$n = 6 \times 10^{-3}$ mol

Novice response to question 6b

A total of 76 learners had novice ideas for answering this question. Such learners tried to calculate the relative molecular mass of sulphuric acid but failed to get the appropriate answer. Figure 4.36 is an example of a novice response to question 6b.

Figure 4:36

Novice response to question 6b



b. H_2SO_4
$(1 \times 2)+(32 + 16 \times 4$
$2 + 32 + 64$
94

c2

4.2.1.10 Question 6c

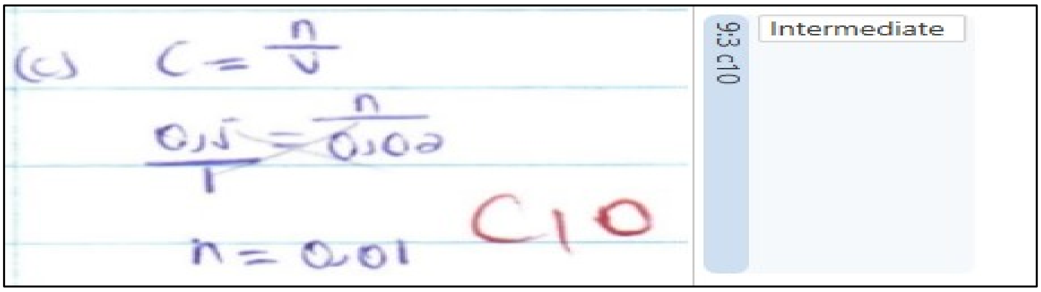
Just like question 6b, this was a level I question which required learners to convert cubic centimetres to cubic decimetres and then use one formula $c = \frac{n}{V}$ to substitute and find the answer.

Elementary response to question 6c

A few learners demonstrated elementary knowledge to answer the question appropriately. The learner whose work is shown in figure 4.37 converted the volume to cubic decimetres and appropriately used the formula to calculate the number of moles.

Figure 4:37

Elementary response in question 6c



(c) $C = \frac{n}{V}$

$\frac{0,5}{1} = \frac{n}{0,02}$

$n = 0,01$

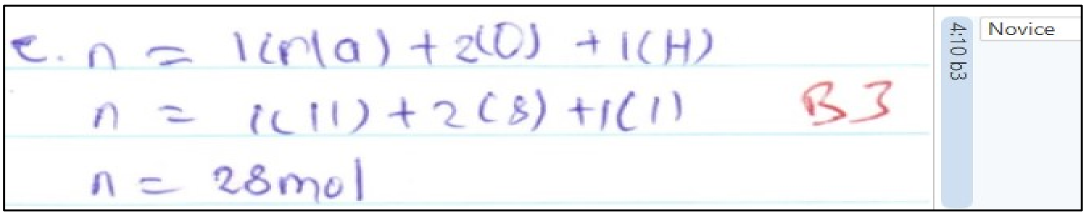
C10

Novice response in question 6c

Most of the learners demonstrated novice ideas to answer question 6c. The learner in the example below seems to be adding the atomic numbers and what results, the learner determines to be the number of moles. Figure 4.38 is an example of a novice response to question 6c.

Figure 4:38

Novice response to question 6c



c. $n = 1(Na) + 2(O) + 1(H)$

$n = 1(11) + 2(8) + 1(1)$

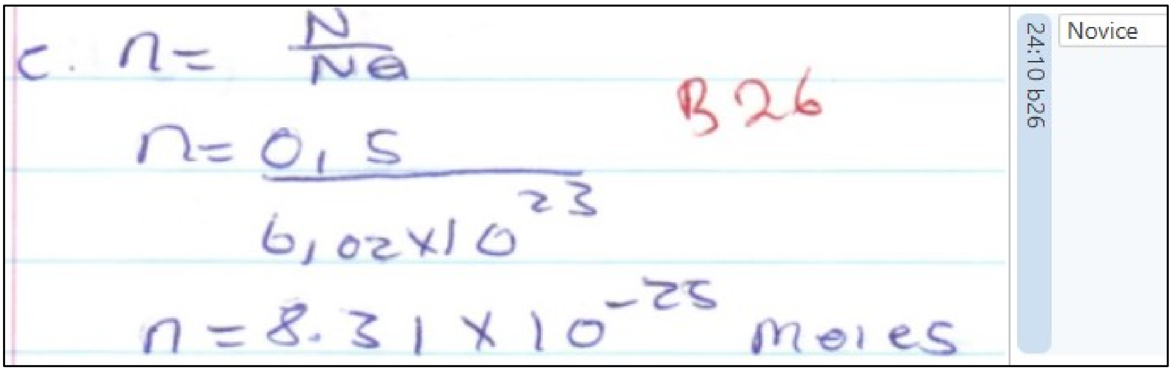
$n = 28mol$

B3

Other learners with novice ideas used wrong formulae and wrong substitutions to calculate the number of moles. Figure 4.39 shows another example of novice response to question 6c.

Figure 4:39

Novice response to question 6c



c. $n = \frac{N}{Na}$

B26

$n = \frac{0,5}{6,02 \times 10^{23}}$

$n = 8.31 \times 10^{-25}$ moles

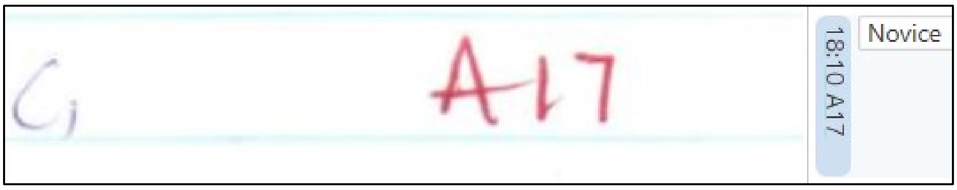
24:10 b26

Novice

Still other learners with novice ideas left empty blanks on this question. Another example of a novice response by leaving a blank space is shown in figure 4.40.

Figure 4:40

Novice response to question 6c



C,

A17

18:10 A17

Novice

4.2.1.11 Question 6d

This was a level II question in which the concept of ratio was required to appropriately identify the excess substance. No learner demonstrated intermediate knowledge to answer this question. A few learners demonstrated elementary knowledge to answer question 6d.

Elementary response to question 6d

A few learners demonstrated elementary knowledge. Such learners failed to use ratios properly. The learner wrote only the appropriate answer without showing the calculation. It is not clear whether the learner guessed the answer or had correct idea to answer the question. An example of an elementary response in question 6d is in figure 4.41.

Figure 4:41

Elementary response to question 6d

d. H_2SO_4 was in excess B11

Novice response to question 6d

Most of the learners demonstrated novice ideas in answering question 6d. This was mainly because of the failure to use the ratio technique. An example of a novice response to question 6d is shown in figure 4.42 below. The learner in the example showed no calculation and the answer was wrong. It is also not clear whether the learners had used ratios or not. If the learner used incorrect ratios, then they were also scored novice.

Figure 4:42

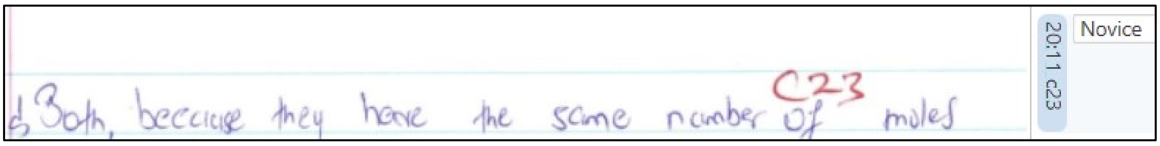
Novice response to question 6d

d. NaoH B26

Other learners, as in the example in figure 4.43, incorrectly responded that both substances had the same number of moles.

Figure 4:43

Novice response to question 6d



d, Both, because they have the same number of moles

C23

20:11 c23

4.2.1.12 Question 6e

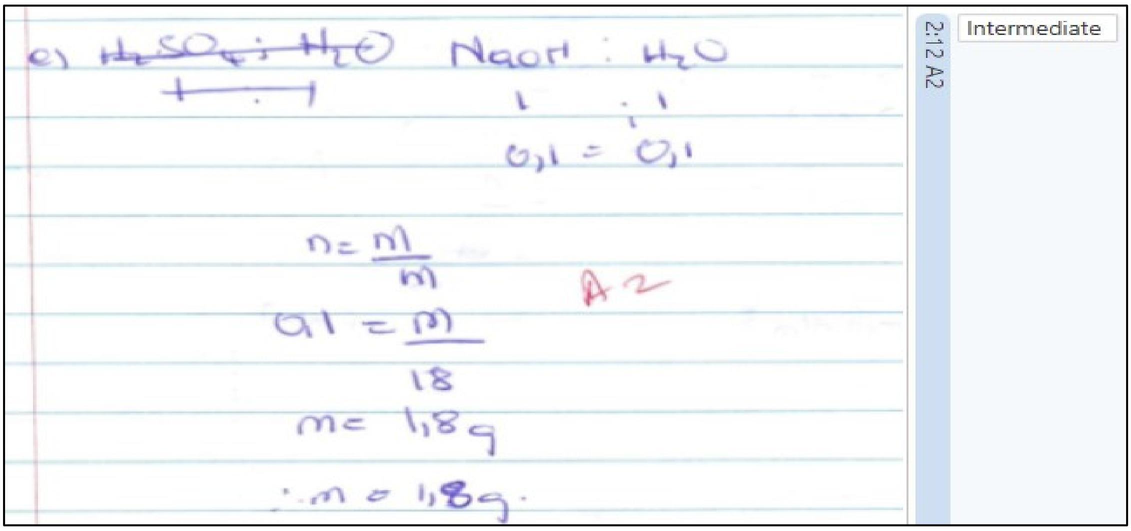
This was a level II question which included ratio analysis. The learners were supposed to use the ratio technique with the number of moles of the limiting reactant to find the number of moles of H_2O produced. Then they had to use the formula n = $\frac{m}{M}$ to find the mass of water produced. There were two steps needed to solve the question. Only three learners demonstrated intermediate knowledge when answering the question.

Intermediate response to question 6e

An example of a learner with intermediate response to question 6e used the wrong ratio and used an incorrect number of moles. However, the learner used the correct formula, did the correct substitution but got the wrong answer because they had correctly used the previous answer in the current question. The work was classified as intermediate since all the steps were correctly done. Figure 4.44 shows an example of intermediate response to question 6e.

Figure 4:44

Intermediate response to question 6e



e) ~~$H_2SO_4 : H_2O$~~

~~1 : 1~~

$NaOH : H_2O$

$1 : 1$

$0,1 = 0,1$

$n = \frac{m}{M}$

$0,1 = \frac{m}{18}$

$m = 1,8g$

$\therefore m = 1,8g.$

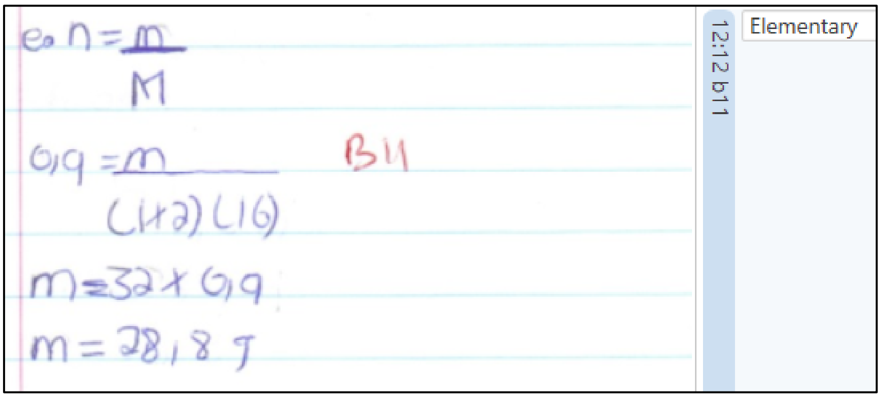
A2

Elementary response to question 6e

A learner showing elementary knowledge to answer the question used the correct substitution on the correct formula. An example of an elementary response to question 6e is shown in figure 4.45.

Figure 4:45

Elementary response to question 6e



e. $n = \frac{m}{M}$

$0,9 = \frac{m}{(1\times2)(16)}$

B11

$m = 32 \times 0,9$

$m = 28,8$ g

Novice response to question 6e

Some learners left question 6e unanswered. This work was classified as a novice response. An example of such novice response is shown in figure 4.46.

Figure 4:46

Novice response to question 6e

e. A13

4.2.2 Results of the pre-intervention test data per participating school

The learners in both schools had comparable conceptual understanding and reasoning of stoichiometry in the pre-intervention test. The results from the coding for both classes in pre-intervention test suggest that most learners had novice ideas about stoichiometry.

4.2.2.1 School A pre-intervention test results

Analysis of the results of the pre-intervention test in school A indicate that there were no advanced responses in the pre-intervention test in the topic stoichiometry. Only 3,0% of responses in this class showed competent knowledge of the topic. 8,0% of the responses showed intermediate knowledge and 31,4% demonstrated elementary knowledge of stoichiometry. Most of the learners amounting to 57,6% of learners had novice idea of the topic. The results suggest that the ideas of learners in this class are mostly novice. More detail about the analysis of the pre-intervention test results at school A is shown on the table 4.1.

Table 4:1

Pre-intervention test School A question analysis

Question	Advanced	Competent	Intermediate	Elementary	Novice
1	0	0	0	18	4
2	0	2	2	2	16
3(a)	0	2	2	3	15
3(b)	0	0	2	6	14
4(a)	0	0	0	9	13
4(b)	0	1	2	4	15

5	0	3	5	4	10
6(a)	0	0	6	6	10
6(b)	0	0	0	13	9
6(c)	0	0	0	9	13
6(d)	0	0	1	6	15
6(e)	0	0	1	3	18
Total	**0**	**8**	**21**	**83**	**152**
Percentage	**0.0%**	**3.0%**	**8.0%**	**31.4%**	**57.6%**

4.2.2.2 School B pre-intervention test results

Analysis of the results of the pre-intervention test in school B indicate that none of the learners had advanced knowledge of stoichiometry, and there were 0,6% who demonstrated competent knowledge of the topic. A low 1% of the learners demonstrated intermediate knowledge while 17% showed elementary knowledge of stoichiometry. As much as 81,4% of learners in this class demonstrated novice ideas of the topic. The results show that in school B, most learners had novice ideas about the topic stoichiometry. More details of the pre-intervention test results in school B are shown on the table 4.2.

Table 4:2

Pre-intervention test School B question analysis

Question	Advanced	Competent	Intermediate	Elementary	Novice
1	0	0	0	17	9
2	0	0	0	5	21
3(a)	0	1	0	6	19
3(b)	0	0	1	3	22
4(a)	0	0	0	3	23
4(b)	0	0	1	3	22
5	0	1	1	5	19
6(a)	0	0	0	1	25
6(b)	0	0	0	2	24
6(c)	0	0	0	4	22
6(d)	0	0	0	2	24
6(e)	0	0	0	2	24
Total	**0**	**2**	**3**	**53**	**254**

Percentage	**0.0%**	**0.6%**	**1.0%**	**17.0%**	**81.4%**

4.2.2.3 Combined pre-intervention test results for both schools

The results from both classes suggest that the initial knowledge of the learners before the intervention was comparable. No learner in the sample demonstrated advanced knowledge of stoichiometry. The responses demonstrating competent knowledge amounted to 1,7%, while 4,2% demonstrated intermediate knowledge. The elementary responses constituted 23,6% while the novice ideas appeared in 70,5% of the responses. Table 4.3 shows more details of the pre-intervention test results of both school A and B.

Table 4:3

Pre-intervention test School A and B question analysis

Question	Advanced	Competent	Intermediate	Elementary	Novice
1	0	0	0	35	13
2	0	2	2	7	37
3(a)	0	3	2	9	34
3(b)	0	0	3	9	36
4(a)	0	0	0	12	36
4(b)	0	1	3	7	37
5	0	4	6	9	29
6(a)	0	0	6	7	35
6(b)	0	0	0	15	33
6(c)	0	0	0	13	35
6(d)	0	0	1	8	39
6(e)	0	0	1	5	42
Total	**0**	**10**	**24**	**136**	**406**
Percentage	**0.0%**	**1.7%**	**4.2%**	**23.6%**	**70.5%**

4.2.3 Summary of the pre-intervention test results

The learners were taught stoichiometry the previous year in Grade 10. All the calculations should have been familiar except for the concept ‘limiting reactant’. Most of the learners demonstrated novice ideas of stoichiometry. In very few cases did the learners demonstrate elementary knowledge associated with only single-step calculations. This suggests that the learners' reasoning before the intervention was extremely poor. The learners demonstrated that they had difficulties in solving high-order complex questions. Their understanding seemed to have been low-order thinking. This was surprising since they were taught the same topic before and used the same formulae. They could not select a suitable formula from the provided list of formulae. It appears as if most of the learners had forgotten most concepts.

4.3 Results from the post-intervention test

4.3.1 Results obtained for each item in the post-intervention test

In the following sections, I give analysis of responses to each question according to the cognitive levels displayed by the learners as inferred from their test responses. I provide an example of a learner response per question in the test and show how it was coded as either novice, elementary, intermediate, competent, or advanced.

4.3.1.1 Question 1

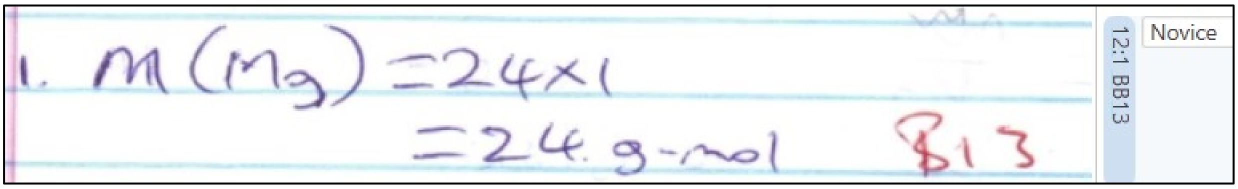
This was a level I question. Learners were supposed to find the correct formula, substitute appropriately, and get the correct answer. This was a single-step calculation.

Novice response to question 1

The learner responded by only calculating the atomic mass of magnesium, which need not have been calculated. The learner did nothing else. So, the learner had a novice idea of how to answer the question. Figure 4.47 shows an example of a novice response to question 1.

Figure 4:47

Novice response to question 1



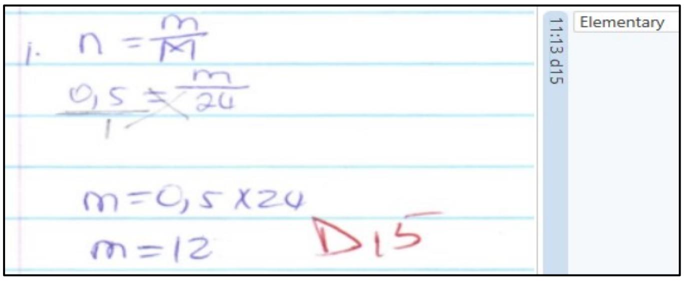
1. $m(Mg) = 24 \times 1$
$= 24$ g-mol B13

Elementary response to question 1

The learner used the correct formula, did the correct substitution, and got the appropriate answer. They did not write the units, but it was acceptable that they found the mass of the substance. Figure 4.48 shows an elementary response to question 1 in the post-intervention test.

Figure 4:48

Elementary response to question 1



1. $n = \frac{m}{M}$

$\frac{0,5}{1} = \frac{m}{24}$

$m = 0,5 \times 24$

$m = 12$ D15

4.3.1.2 Question 2

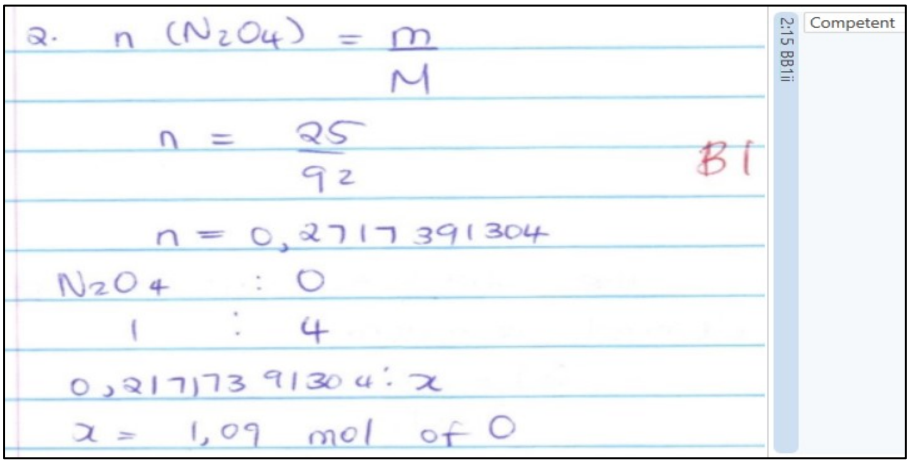
This was a level III question. It required the learners to calculate the relative molecular mass of N_2O_4 and the use the formula n = $\frac{m}{M}$. The learners were then supposed to find the number of moles of the N_2O_4. They then had to use the mole ratio of atoms in the compound to find the number moles of oxygen atoms.

Competent response to question 2

The learner used the correct formula and calculated the correct number of moles of N_2O_4. The learner proceeded to appropriately use ratio to calculate the equivalent number of moles of O atoms. This work was classified as competent because the learner correctly followed all the steps in this level III question. Figure 4.49 shows an advanced response to question 2.

Figure 4:49

Competent response in question 2



2. $n(N_2O_4) = \frac{m}{M}$

$n = \frac{25}{92}$ B1

$n = 0,2717391304$

N_2O_4 : O

1 : 4

$0,21717391304 : x$

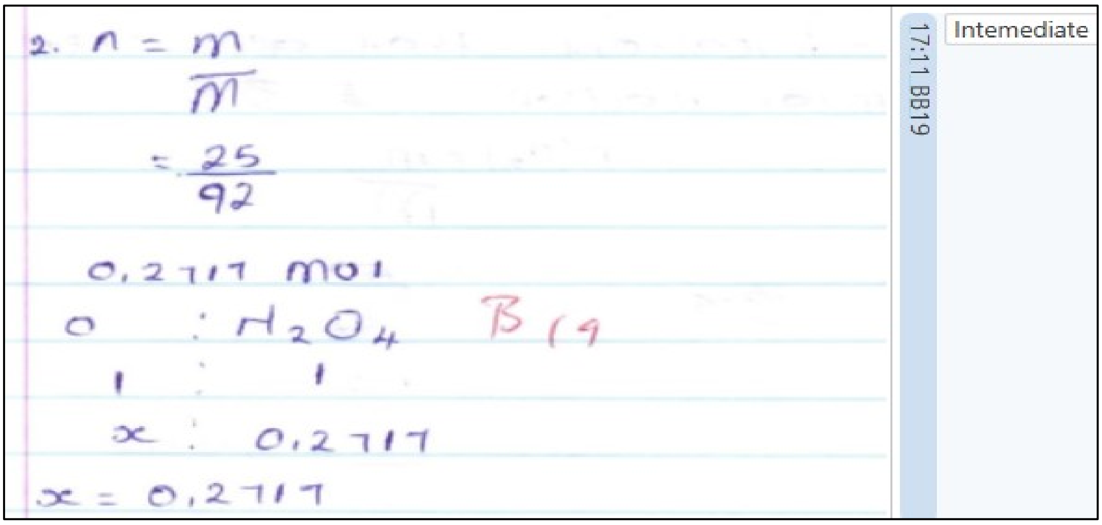
$x = 1,09$ mol of O

Intermediate response to question 2

The learner with intermediate knowledge on question 2 used the correct formula and correct substitution to calculate the correct number of moles of N_2O_4. They however, used a wrong ratio to calculate the equivalent number of moles of O atoms. As a result, their answer is wrong. This work was classified as intermediate because the learner demonstrated correct knowledge but made a small mistake after performing at least two steps. An example of an intermediate response to question 2 is shown in figure 4.50.

Figure 4:50

Intermediate response to question 2



2. $n = \frac{m}{M}$

$= \frac{25}{92}$

0,2717 mol

$O : H_2O_4$ B (4

$1 : 1$

$x : 0,2717$

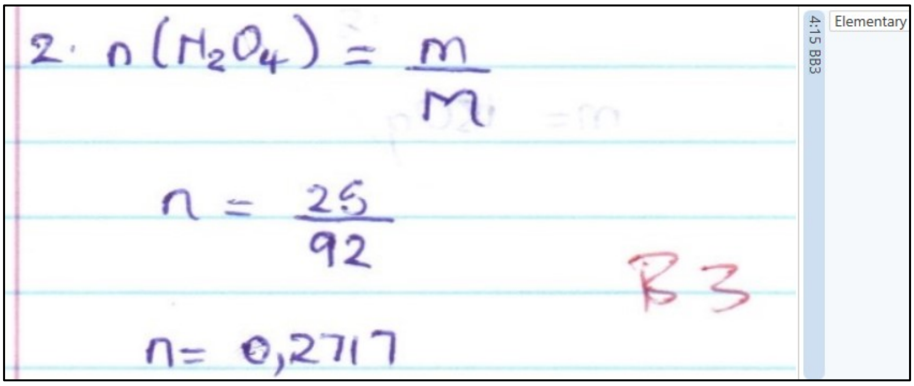
$x = 0,2717$

Elementary response to question 2

The learner in this case managed to use the correct formula to calculate the correct number of moles of N_2O_4, but just ended there and never proceeded with the calculation. Such work was classified as elementary because it appears the learner did not have an idea how to proceed with the calculation. Figure 4.51 shows an example of an elementary response to question 2.

Figure 4:51

Elementary response to question 2



2. $n(H_2O_4) = \frac{m}{M}$

$n = \frac{25}{92}$ B3

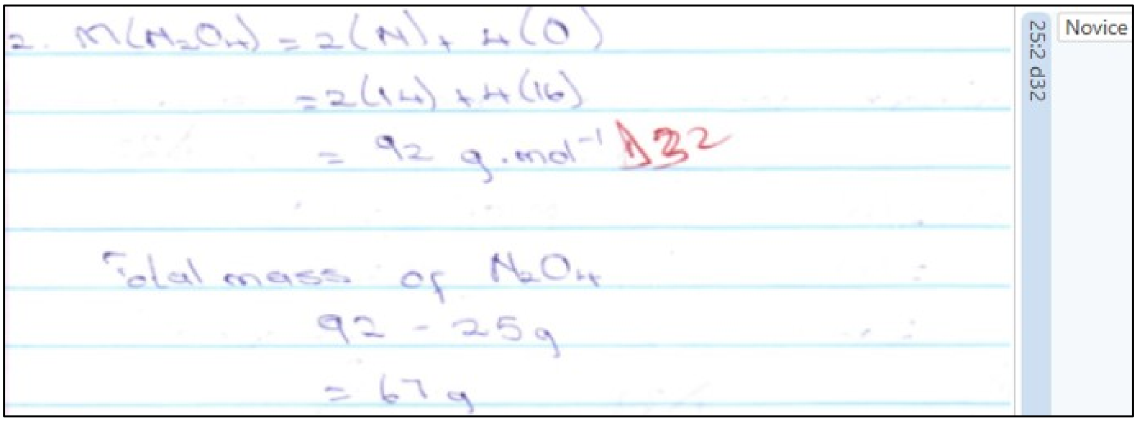
$n = 0,2717$

Novice response in question 2

Learners showed novice knowledge in this question when they subtracted the masses of the two substances but failed to use it in the equation. The work was classified as a novice idea because the learner failed to do any single correct calculation. Figure 4.52 is an example of a novice response to question 2.

Figure 4:52

Novice response to question 2



2. $M(N_2O_4) = 2(N) + 4(O)$
$= 2(14) + 4(16)$
$= 92\ g.mol^{-1}$ D32

Total mass of N_2O_4
$92 - 25g$
$= 67\ g$

4.3.1.3 Question 3a

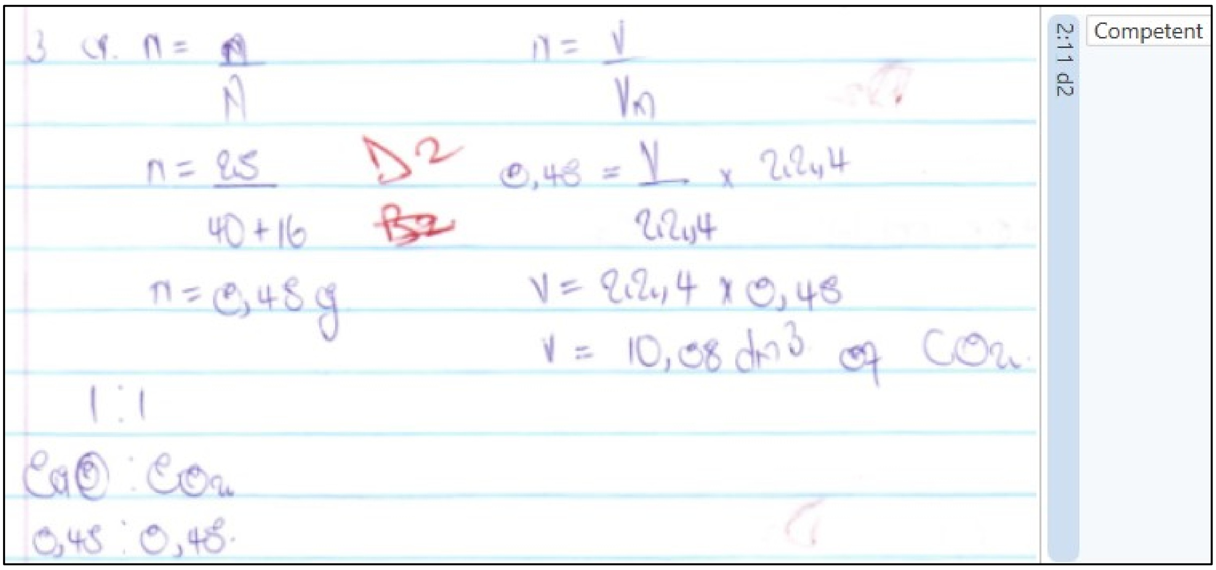
This was a level III question which had to be solved following three-step calculations. The learners were supposed to use the formula n = $\frac{m}{M}$ to find the number of moles of CaO. They were then supposed to use the mole ratio of CaO: CO_2 of 1: 1 to find the equivalent number of moles of CO_2. Then they were supposed to use the formula n = $\frac{V}{Vm}$ to calculate the volume of CO_2 produced.

Competent response to question 3a

The learner with competent knowledge to answer this question used the correct formula and calculated the number of moles of CaO appropriately. They then used the ratio technique appropriately to calculate the equivalent number of moles of CO_2, after which the learner used the formula to appropriately calculate the volume of CO_2. The learner did not make any mistakes. As such, the work was classified as competent because it was a response to a level III question. Figure 4.53 shows an example of a competent response to question 3a.

Figure 4:53

Competent response to question 3a



3 a. $n = \frac{m}{M}$ $n = \frac{V}{V_m}$

$n = \frac{25}{40+16}$ D2 B2 $0,48 = \frac{V}{22,4} \times 22,4$

$n = 0,48$ g $V = 22,4 \times 0,48$

$V = 10,08$ dm^3 of CO_2

1 : 1

$CaO : CO_2$

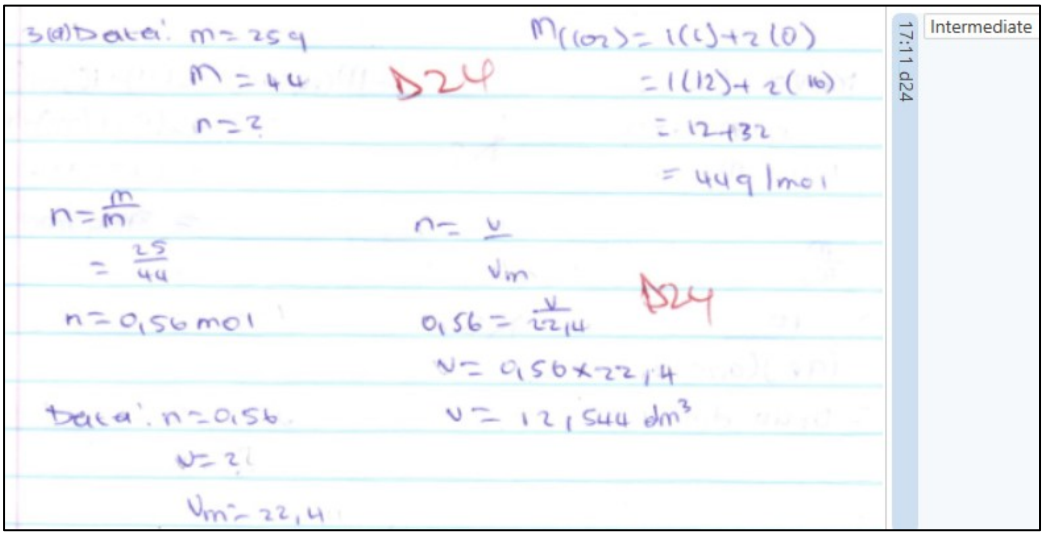
0,48 : 0,48

Intermediate response in question 3a

The learner with an intermediate response in question 3a used the correct formula but did a wrong substitution of the relative molecular mass. The number of moles of CaO which they found was therefore incorrect. But they appropriately used it to calculate the number of moles of CO_2 and then the volume of CO_2. The response is classified as intermediate because the learner managed to correctly use two steps in the calculation though the value used was initially wrongly calculated. An example of an intermediate response to question 3a is shown in figure 4.54.

Figure 4:54

Intermediate response to question 3a



3(a) Data: $m = 25g$

$M = 44$

$n = ?$

$M(CO_2) = 1(C) + 2(O)$

$= 1(12) + 2(16)$

$= 12 + 32$

$= 44 g/mol$

$n = \frac{m}{M}$

$= \frac{25}{44}$

$n = 0,56 mol$

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

$0,56 = \frac{V}{22,4}$

$V = 0,56 \times 22,4$

$V = 12,544 dm^3$

Data: $n = 0,56$

$V = ?$

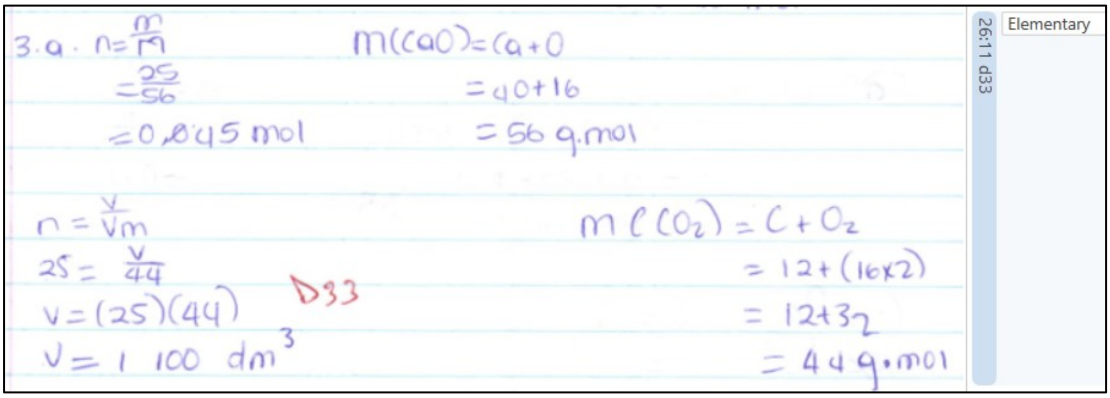
$V_m = 22,4$

Elementary response to question 3a

The learner with elementary knowledge calculated the correct relative molecular mass and the correct number of moles of CaO. The learner however, failed to use the formula to calculate the volume of CO_2. The answer was, therefore, coded as elementary because the learner correctly did a one-step calculation. An example of an elementary response to question 3a is shown in figure 4.55.

Figure 4:55

Elementary response to question 3a



3.a. $n = \frac{m}{M}$

$= \frac{25}{56}$

$= 0,845 mol$

$M(CaO) = Ca + O$

$= 40 + 16$

$= 56 g.mol$

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

$25 = \frac{V}{44}$

$V = (25)(44)$

$V = 1\ 100\ dm^3$

$M(CO_2) = C + O_2$

$= 12 + (16 \times 2)$

$= 12 + 32$

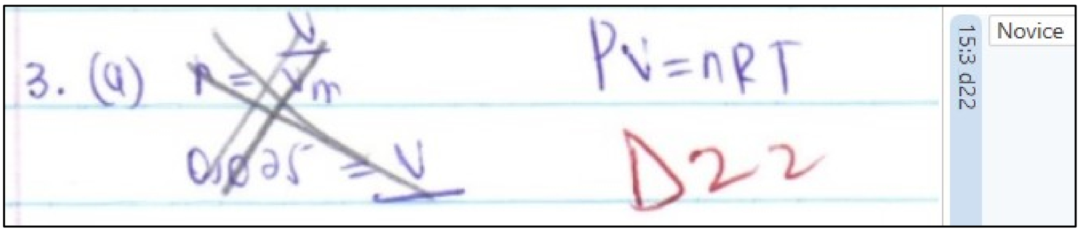
$= 44 g.mol$

Novice response in question 3a

The learner with a novice idea tried to use the wrong formula but never managed to substitute. The learner's answer was coded as a novice idea because they used a formula not related to the question. An example of a novice response to question 3a is shown in figure 4.56.

Figure 4:56

Novice idea to answer question 3a.



4.3.1.4 Question 3b

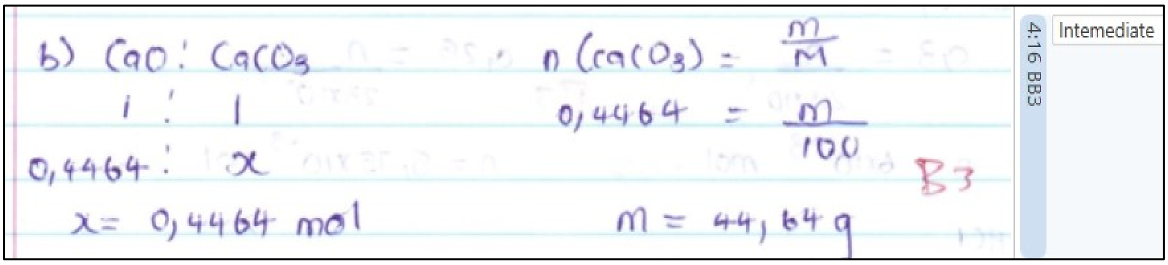
This was a level II question. Learners were required to use the mole ratio of CaO: $CaCO_3$ which was 1:1 to calculate the equivalent number of moles of $CaCO_3$. The learners then were supposed to use the formula $n = \frac{m}{M}$ to calculate the mass of $CaCO_3$ produced.

Intermediate response to question 3b

The learner with an intermediate response used the correct ratio and calculated the equivalent number of moles of $CaCO_3$. They then appropriately used the formula to calculate the mass of $CaCO_3$ produced. The learner did not make any mistake in this level II question, and hence their work was classified as intermediate. An example of an intermediate response to question 3b is shown in figure 4.57.

Figure 4:57

Intermediate response to question 3b



b) CaO : $CaCO_3$

1 : 1

0,4464 : x

x = 0,4464 mol

$n(CaCO_3) = \frac{m}{M}$

$0,4464 = \frac{m}{100}$

m = 44,64 g

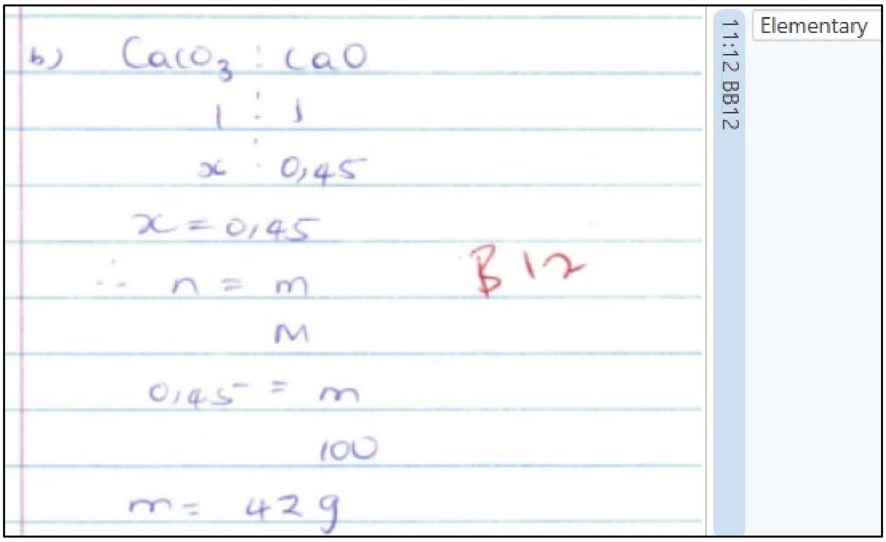
B3

Elementary response to question 3b

This elementary response in question 3b shows the learner using the correct ratio to calculate the equivalent number of moles of $CaCO_3$. The learner then used the correct formula to calculate the mass of $CaCO_3$. The response was classified as elementary because the learner only managed to do one complete and correct step in calculation. An example of an elementary response to this question is shown in figure 4.58.

Figure 4:58

Elementary response to question 3b



b) $CaCO_3$: CaO

1 : 1

x : 0,45

x = 0,45

$\therefore n = \frac{m}{M}$

$0,45 = \frac{m}{100}$

m = 42 g

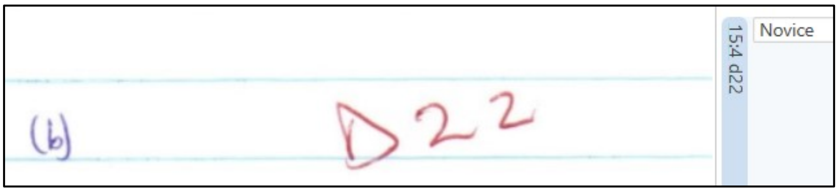
B12

Novice response to question 3b

The learner with novice ideas did not attempt to answer but left a blank space. It was assumed that they did not know what to do. An example of a novice response to this question is shown in figure 4.59.

Figure 4:59

Novice idea response to question 3b



(b) D22

4.3.1.5 Question 4a

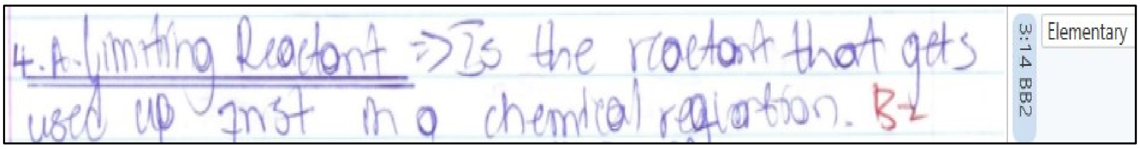
This was a level I question where learners were required to define the term ‘limiting reactant’. It only wanted learners to state what they remembered about limiting reactant.

Elementary response to question 3b

The learner gave a correct definition of limiting reactant. The work was classified as elementary because the learner had all the key words needed in the definition. An example of elementary response to this question is shown in figure 4.60.

Figure 4:60

Elementary response in question 4a



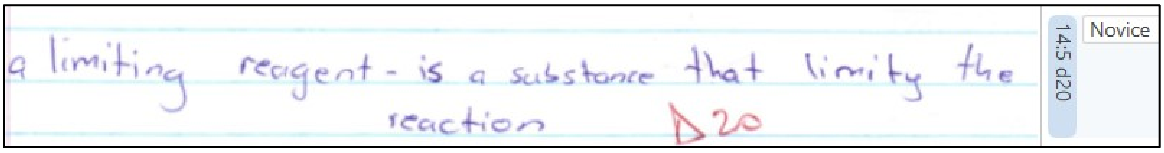
4. A. Limiting Reactant => Is the reactant that gets used up first in a chemical reaction.

Novice response in question 4a

A learner with novice ideas to this question failed to define a limiting reactant. Some learners just said something meaningless or left a blank space. An example of novice response to this question is shown in figure 4.61.

Figure 4:61

Novice response to question 4a



a limiting reagent - is a substance that limity the reaction D20

14:5 d20

Novice

4.3.1.6 Question 4b

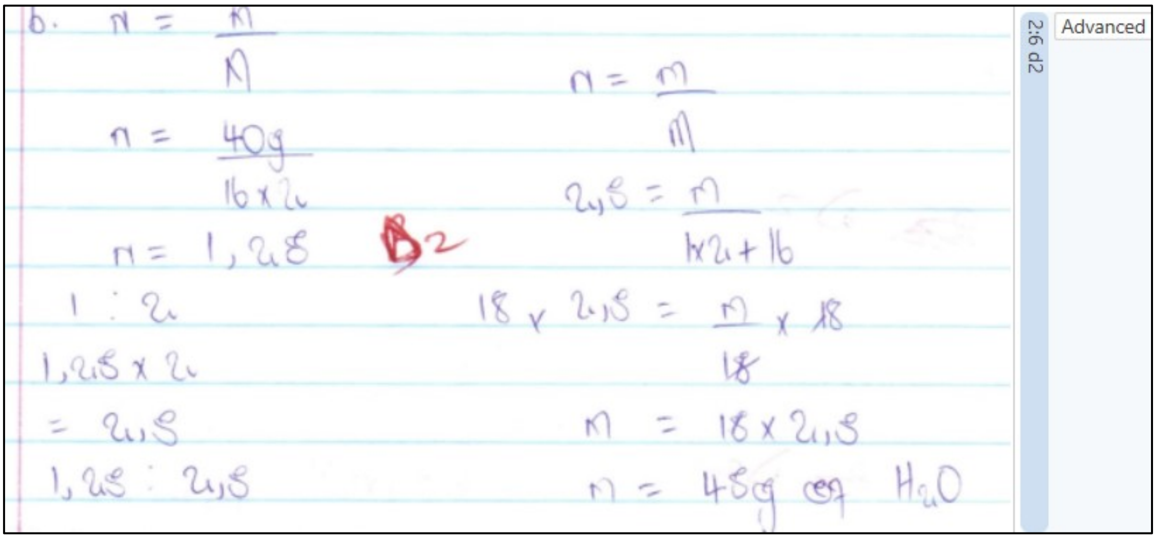
This was a level IV question solved through multi-step calculations. The learners were supposed to calculate the number of moles of oxygen and those of hydrogen. They were then supposed to use the mole ratio from a balanced equation of reaction to identify the limiting reactant. Afterwards they were supposed to use the number of moles of the limiting reactant to calculate the mass of water produced.

Advanced response in question 4b

A learner with advanced knowledge of solving question 4b used the correct formula, correct substitution, and appropriate answer for the first step which was the number of moles of O_2. The learner then used the correct ratio of 1:2 to find the equivalent number of moles of water according to the balanced chemical equation. The learner then appropriately selected the second formula, substituted appropriately, and got the appropriate answer of the mass of water. The learner did not make any mistake in the whole calculation. The learner however skipped the stage of calculating the number of moles of H_2 and therefore did not compare the number of moles of H_2 and O_2 to find the limiting reactant. The learner however, used the correct number of moles of limiting reactant. We therefore assumed that the learner may have done a separate calculation and determined the limiting reactant. An example of advanced response to this question is shown in figure 4.62.

Figure 4:62

Advanced response to question 4b



b. $n = \frac{m}{M}$

$n = \frac{40g}{16 \times 2}$

$n = 1,28$ B2

$1 : 2$

$1,28 \times 2$

$= 2,5$

$1,28 : 2,5$

$n = \frac{m}{M}$

$2,5 = \frac{m}{1 \times 2 + 16}$

$18 \times 2,5 = \frac{m}{18} \times 18$

$m = 18 \times 2,5$

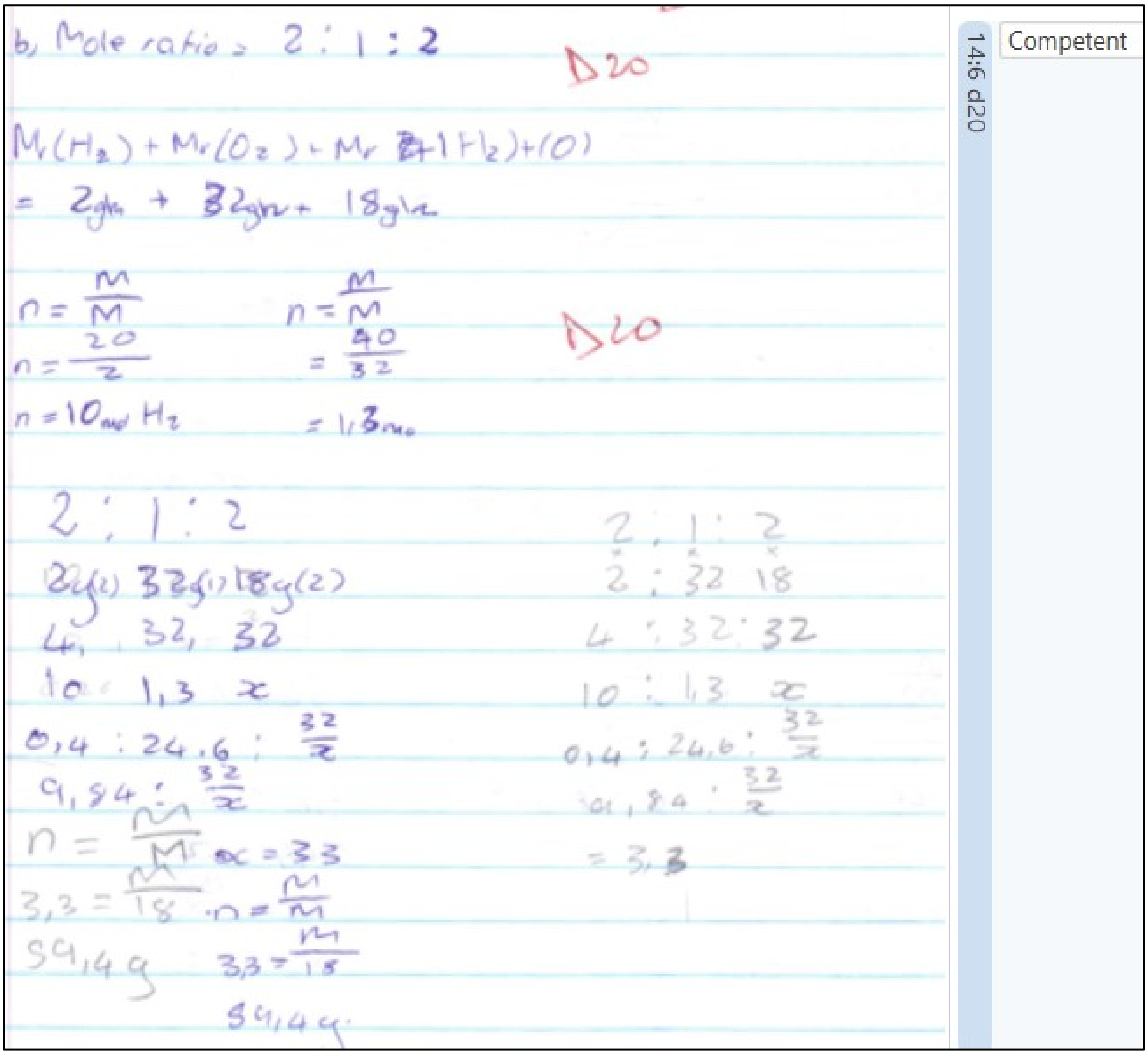
$m = 45g$ of H_2O

Competent response in question 4b

A competent learner used the correct formula and correct substitution and got the appropriate answer for the first step. This learner correctly calculated the number of moles of H_2. The learner however, used an incorrect ratio to calculate the equivalent number of moles of H_2O. But the learner chose the correct formula, did the correct substitution, and got the appropriate answer after positive marking. The learner's work was classified as competent based on the fact they only made one mistake when using ratio. An example of competent response to this question is shown in figure 4.63.

Figure 4:63

Competent response to question 4b



b, Mole ratio = 2 : 1 : 2

$M_r(H_2) + M_r(O_2) - M_r$ ~~2~~$+1H_2)+(O)$

= 2g/m + 32g/m + 18g/m

$n = \frac{m}{M}$ $n = \frac{m}{M}$

$n = \frac{20}{2}$ $= \frac{40}{32}$

n = 10mol H_2 = 1,3mo

2 : 1 : 2

2g(2) 32g(1) 18g(2)

4, 32, 32

10 1,3 x

0,4 : 24,6 : $\frac{32}{x}$

9,84 : $\frac{32}{x}$

$n = \frac{m}{M}$ x = 3,3

$3,3 = \frac{m}{18}$ $n = \frac{m}{M}$

59,4 g $3,3 = \frac{m}{18}$

59,4 g

2 : 1 : 2

2 : 32 18

4 : 32 : 32

10 : 1,3 x

0,4 : 24,6 : $\frac{32}{x}$

9,84 : $\frac{32}{x}$

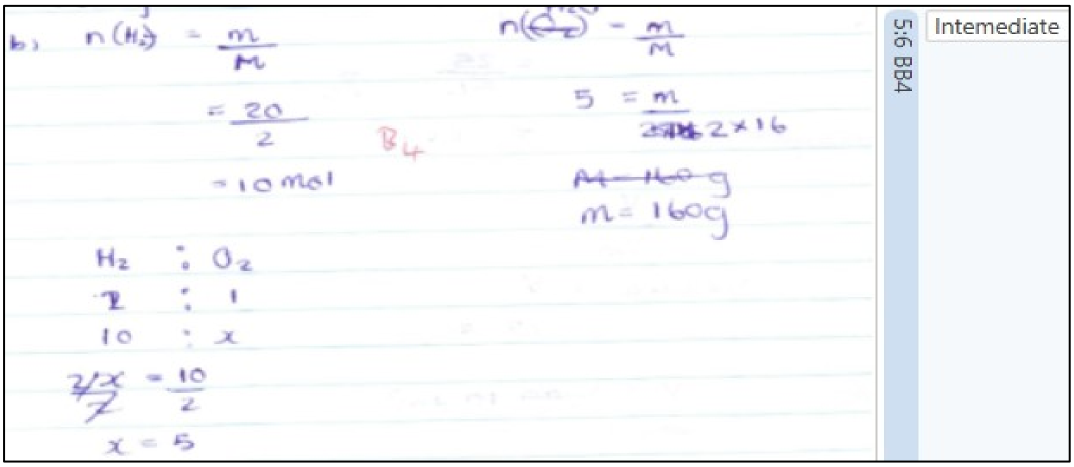
= 3,3

Intermediate response to question 4b

The learner in this example used the correct formula, appropriately substituted, and got the correct number of moles of H_2. The learner, however, did not calculate the number of moles of O_2. They did not identify the correct limiting reactant, which was O_2. The learner used the number of moles of H_2 which was the excess reactant but used the correct ratio to find the equivalent number of moles of H_2O. The final answer for the mass of H_2O was correct by positive marking. The work was classified as intermediate because the learner made a conceptual error of using the excess reactant in further calculation and did not calculate the number of moles of the limiting reactant. An example of intermediate response to this question is shown in figure 4.64.

Figure 4:64

Intermediate response to question 4b



b) $n(H_2) = \frac{m}{M}$

$= \frac{20}{2}$

$= 10$ mol

B4

$H_2 : O_2$

$2 : 1$

$10 : x$

$\frac{\cancel{2}x}{\cancel{2}} = \frac{10}{2}$

$x = 5$

$n(O_2) = \frac{m}{M}$

$5 = \frac{m}{2\times16}$

~~M = 160 g~~

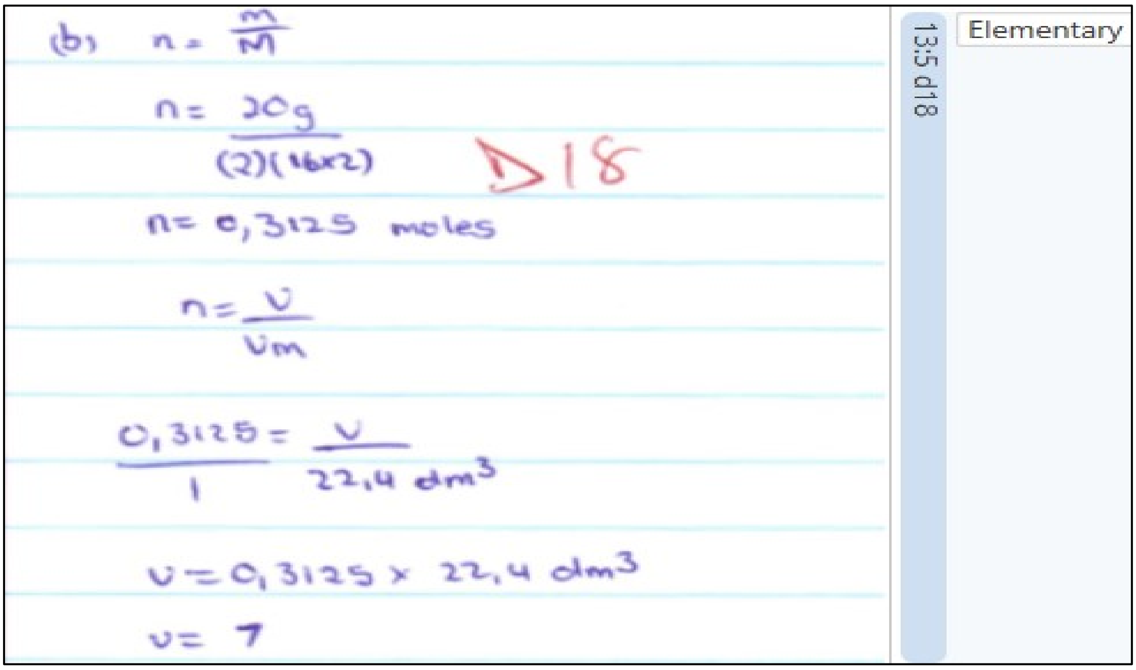
m = 160g

Elementary response to question 4b

The learner used the correct formula with the wrong substitution. The learner then used a wrong formula but did correct substitution to get the inappropriate answer. The work was classified as elementary, showing that the learner had an idea of how to respond to the question. An example of elementary response to this question is shown in figure 4.65.

Figure 4:65

Elementary response to question 4b



(b) $n = \frac{m}{M}$

$n = \frac{20g}{(2)(16x2)}$

D18

$n = 0,3125$ moles

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

$\frac{0,3125}{1} = \frac{V}{22,4\ dm^3}$

$V = 0,3125 \times 22,4\ dm^3$

$V = 7$

13:5 d18

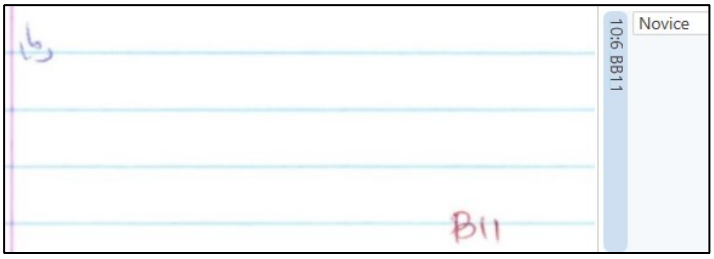
Elementary

Novice response to question 4b

This learner left the question unanswered, meaning they did not have an idea of how to answer it. The response was therefore classified as a novice idea. An example of a novice response to this question 4b is shown in figure 4.66.

Figure 4:66

Novice response in question 4b



(b)

B11

10:6 BB11

Novice

4.3.1.7 Question 5

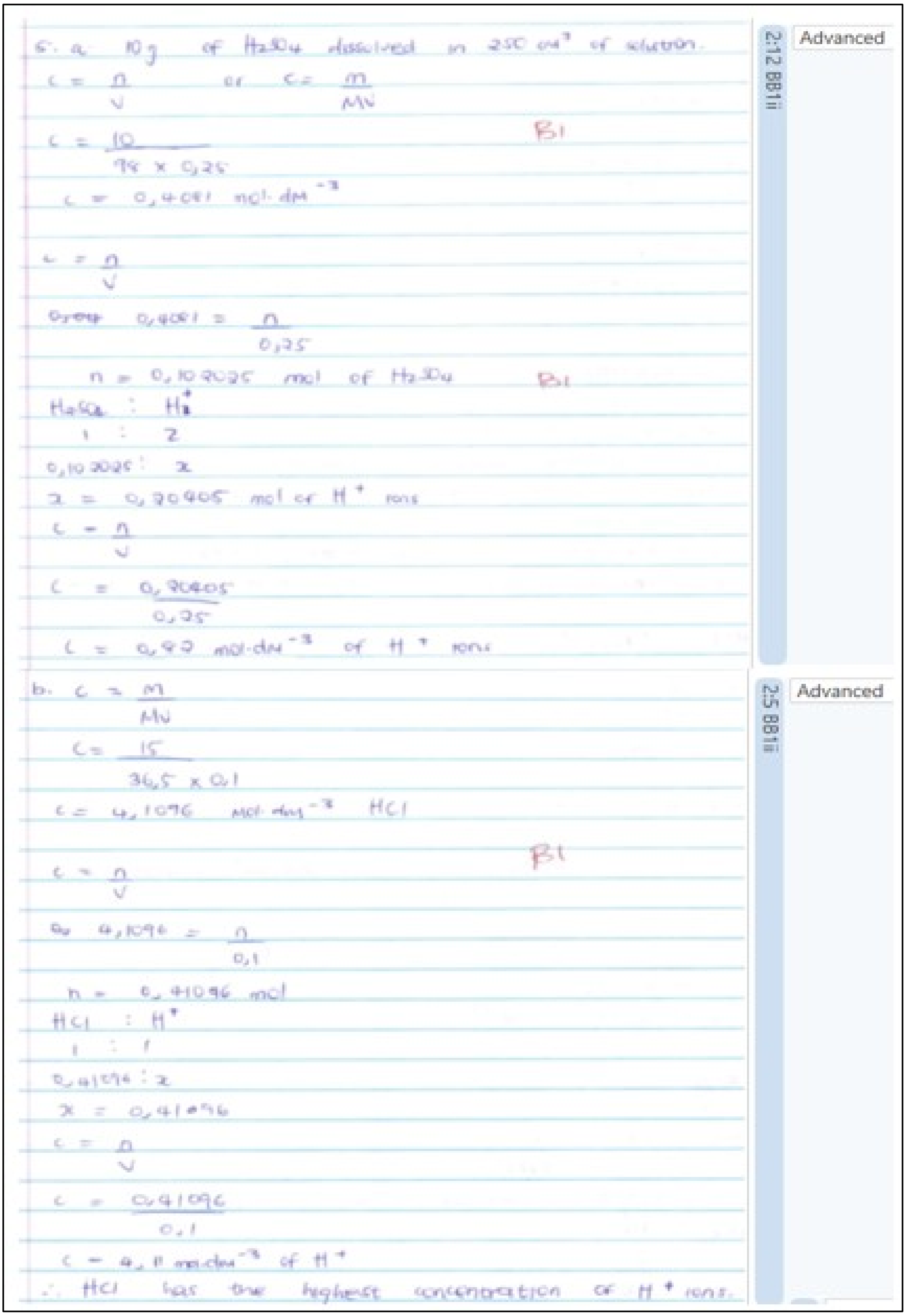
This question was a level IV question which required multi-step calculations of the concentrations of two substances and that of their respective ions. The ratio technique was necessary in this calculation. After this, the learners compared the concentrations.

Advanced response in question 5

The learner used the correct formula and correct substitution to calculate the concentrations of both substances. After that, the learner got lost but recovered to calculate the concentration of the ions of each substance by appropriately using the ratio technique. The learner appropriately compared the concentrations of the ions. The learner’s response was advanced since all the answers were correct. An example of advanced response to question 5 is shown in figure 4.67.

Figure 4:67

Advanced response to question 5



5. a. 10 g of H_2SO_4 dissolved in 250 cm^3 of solution.

$c = \frac{n}{V}$ or $c = \frac{m}{Mv}$

$c = \frac{10}{98 \times 0,25}$ B1

$c = 0,4081 \ mol \cdot dm^{-3}$

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

~~0,408~~ $0,4081 = \frac{n}{0,25}$

$n = 0,102025$ mol of H_2SO_4 B1

$H_2SO_4 : H^+$

1 : 2

0,102025 : x

x = 0,20405 mol of H^+ ions

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

$c = \frac{0,20405}{0,25}$

$c = 0,82 \ mol \cdot dm^{-3}$ of H^+ ions

b. $c = \frac{m}{Mv}$

$c = \frac{15}{36,5 \times 0,1}$

$c = 4,1096 \ mol \cdot dm^{-3}$ HCl

B1

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

$4,1096 = \frac{n}{0,1}$

$n = 0,41096$ mol

$HCl : H^+$

1 : 1

0,41096 : x

x = 0,41096

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

$c = \frac{0,41096}{0,1}$

$c = 4,11 \ mol \cdot dm^{-3}$ of H^+

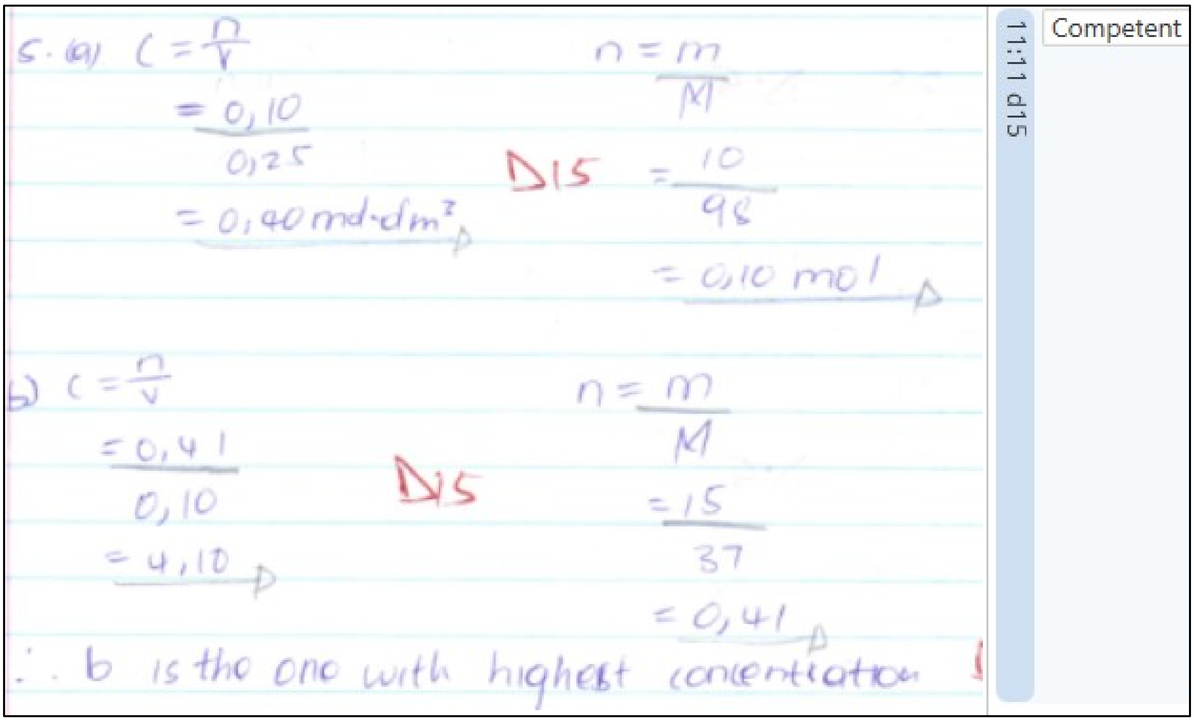
∴ HCl has the highest concentration of H^+ ions.

Competent response to question 5

This learner chose the correct formula, substituted appropriately and got the correct concentration by first finding the number of moles. The learner did the calculations for the concentrations for both substances. The learner did not calculate the concentration of the H^+ ions as required by the question, but the learner's final answer was correct. The learner's response was therefore classified as competent because of not calculating the concentration of ions. An example of a competent response to this question is shown in figure 4.68.

Figure 4:68

Competent response to question 5



5. (a) $c = \frac{n}{V}$

$= \frac{0,10}{0,25}$

$= 0,40\ mol\cdot dm^{3}$

$n = \frac{m}{M}$

$= \frac{10}{98}$

$= 0,10\ mol$

D15

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

$= \frac{0,41}{0,10}$

$= 4,10$

$n = \frac{m}{M}$

$= \frac{15}{37}$

$= 0,41$

D15

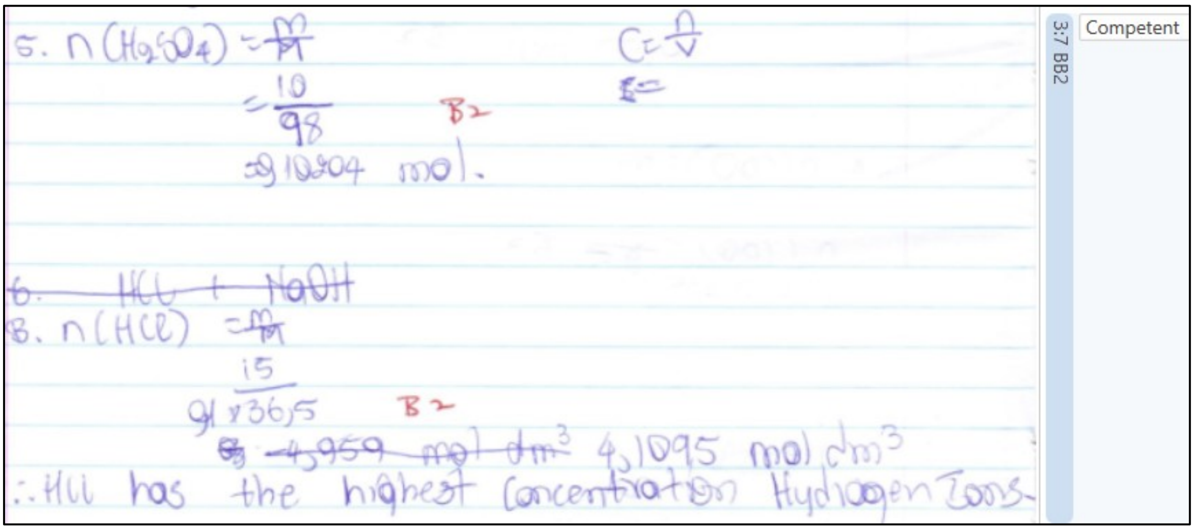
∴ b is tho ono with highest concentration

Intermediate response in question 5

This learner appropriately calculated the number of moles for each of the two substances given. They got the concentration of HCl without showing formula or calculation. The learner did not calculate the concentration of H_2SO_4 or the concentration of H^+ ions for both H_2SO_4 and HCl. This response was therefore classified as intermediate. An example of intermediate response to this question is shown on the figure 4.69.

Figure 4:69

Intermediate response in question 5



5. $n(H_2SO_4) = \frac{m}{M}$ $C = \frac{n}{V}$

$= \frac{10}{98}$ $c =$

$= 0,10204$ mol.

~~6. HCl + NaOH~~

8. $n(HCl) = \frac{m}{M}$

$\frac{15}{0,1 \times 36,5}$

~~4,959 mol dm³~~ 4,1095 mol dm³

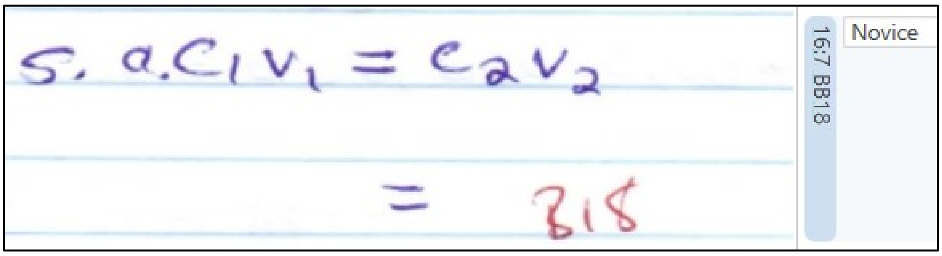
∴ HCl has the highest concentration Hydrogen Ions.

Novice response to question 5

The learner just managed to write an incorrect formula without any substitution. The work was classified as a novice idea since they did not complete the calculation. An example of a novice response to this question is shown in figure 4.70.

Figure 4:70

Novice response in question 5



5. a. $C_1V_1 = C_2V_2$

= 3/8

4.3.1.8 Question 6a

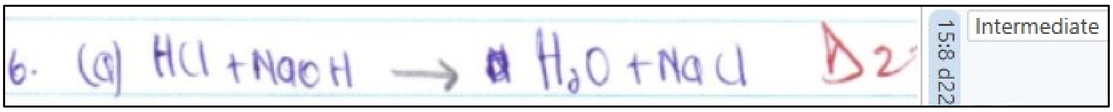
This question was a level II question requiring learners to balance the equation of a chemical reaction. The learners were expected to balance the number of atoms as well as writing the correct formulae of both reactants and products.

Intermediate response to question 6a

The learner who had an intermediate response to this question managed to write the correct formulae for all the chemical substances in the equation. The learner also balanced appropriately all the atoms in the equation. An example of intermediate response to this question is shown in figure 4.71.

Figure 4:71

Intermediate response to question 6a



6. (a) $HCl + NaoH \rightarrow H_2O + NaCl$ 2

Elementary response to question 6a

The learner was incorrect in this question. The number of elements were wrong because H atoms were not balanced. The learner did not know the correct formula of the products but had an idea of how to balance the reaction. An example of elementary response to question 6a is shown in figure 4.72.

Figure 4:72

Elementary response to question 6a

@ $HCl + Na_2oH \rightleftharpoons Cl^- + 2NaoH^-$

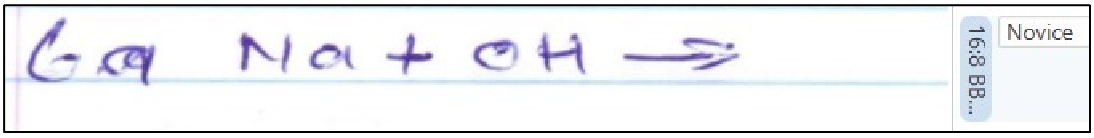
A7

Novice response to question 6a

The learner wrote incorrect reactants and there were no products. There was no indication of the learner having an idea of writing and balancing an equation of reaction. The work was classified as a novice idea. An example of a novice response to question 5 is shown in figure 4.73.

Figure 4:73

Novice response to question 5



6a Na + OH →

4.3.1.9 Question 6b

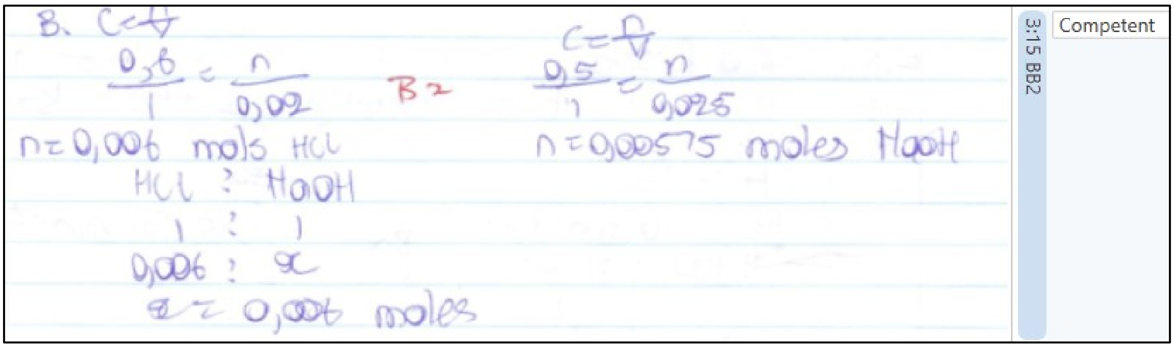
This was a level III question that required learners to calculate the number of moles of HCl and NaOH. After the calculation of the number of moles, the learners were supposed to use the mole ratio to identify the excess reactant between the two substances.

Competent response in question 6b

This learner appropriately calculated the number of moles of NaOH and the moles of HCl. The learner appropriately used the ratio technique to compare the number moles of HCl and NaOH. The learner appropriately identified that 0,006moles HCl react with 0,006moles NaOH. The final answer indicating that HCl is in excess was, however, not written down. The response was classified as competent since the learner correctly did three step calculations. Figure 4.74 shows an example of a competent response to question 6b in the post-intervention test.

Figure 4:74

Competent response to question 6b



8. $C=\frac{n}{V}$

$\frac{0,6}{1}=\frac{n}{0,02}$

B2

$n=0,006$ mols HCl

HCl : NaOH

1 : 1

0,006 : x

$x=0,006$ moles

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

$\frac{0,5}{1}=\frac{n}{0,025}$

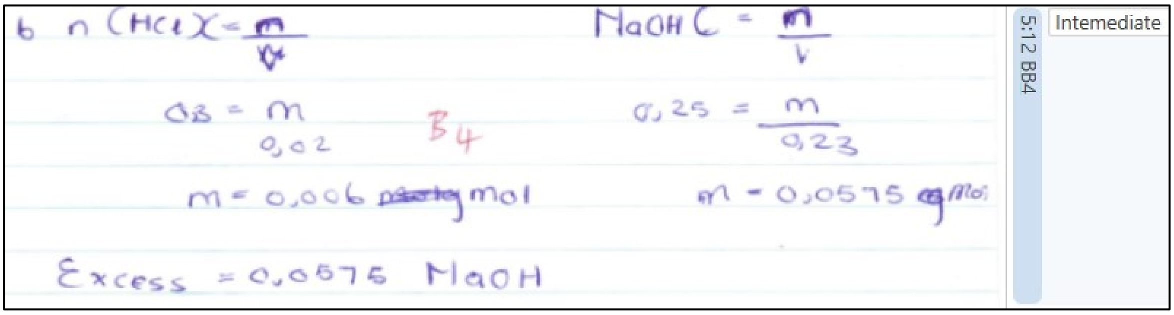
$n=0,00575$ moles NaOH

Intermediate response to question 6b

This learner appropriately calculated the number of moles of HCl but inappropriately calculated the number of moles of NaOH. The learner appropriately compared the number of moles without showing the ratio. They then found that the excess reactant was NaOH because of the positive marking after the error made in calculation of moles of NaOH. The response was classified as intermediate because the learner correctly performed two steps in calculations. An example of an intermediate response to this question is shown in figure 4.75.

Figure 4:75

Intermediate response to question 6b



b $n(HCl) = \frac{m}{V}$ NaOH $C = \frac{m}{V}$

$03 = \frac{m}{0{,}02}$ B4 $0{,}25 = \frac{m}{0{,}23}$

$m = 0{,}006$ ~~[illegible]~~ mol $m = 0{,}0575$ ~~g~~ mol

Excess $= 0{,}0575$ NaOH

5:12 BB4

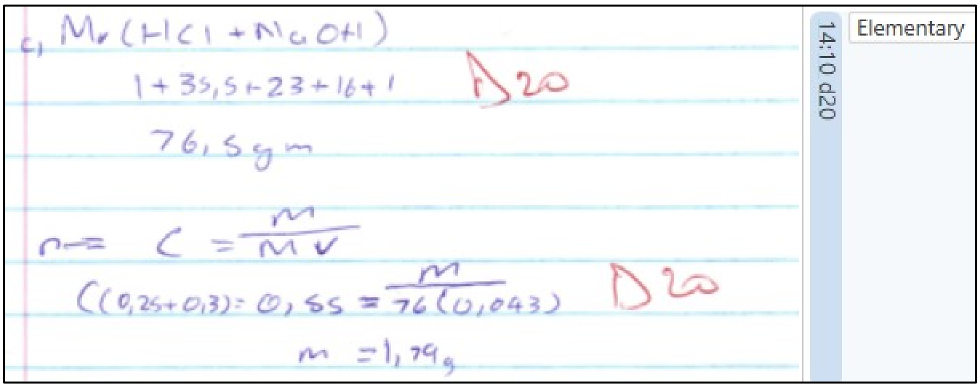
Intemediate

Elementary response to question 6b

The learner did a wrong calculation of relative molecular mass by adding the molecular masses of HCl and NaOH. The learner used that molecular mass in a wrong formula and got an answer. The learner's work was classified as elementary because the learner had an idea of calculating the relative molecular mass though she ended up with a wrong answer. She had an idea of using the formula to do further calculation. An example of an elementary response to this question is shown in figure 4.76.

Figure 4:76

Elementary response to question 6b



c) $M_r (HCl + NaOH)$

$1 + 35,5 + 23 + 16 + 1$ D20

$76,5$ gm

$n = \quad C = \frac{m}{MV}$

$C(0,25+0,3) = 0,55 = \frac{m}{76(0,043)}$ D20

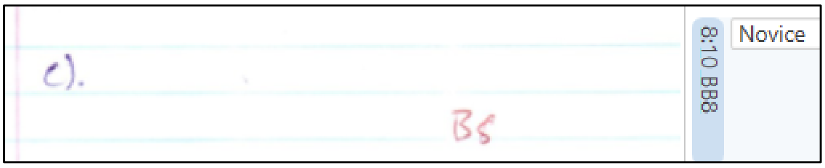
$m = 1,79$g

Novice response to question 6b

The learner in this case did not have an idea of how to respond to this question. That is why the learner did not write anything in response to this question. An example of novice response to question 6b is shown in figure 4.77.

Figure 4:77

Novice response to question 6b



c).

B5

4.3.1.10 Question 6c

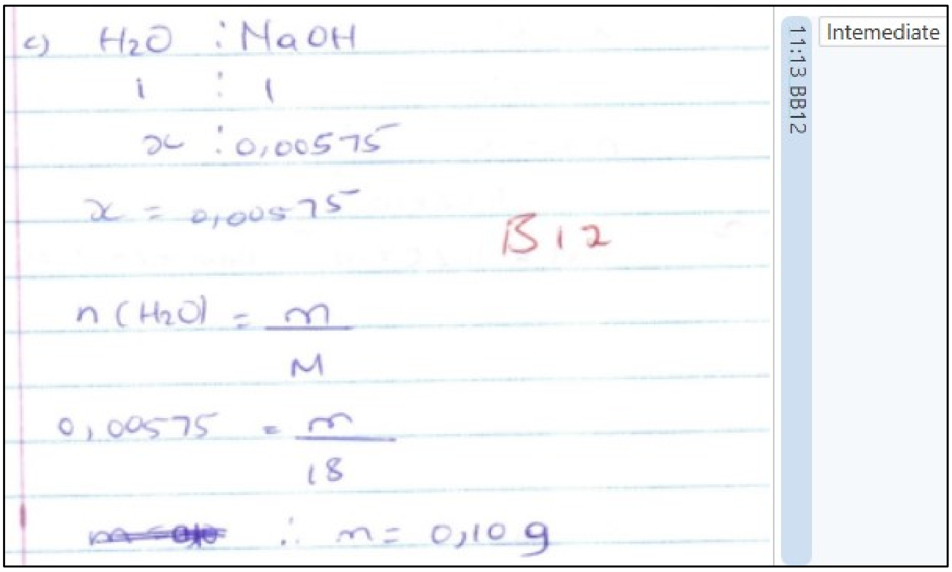
This was a level II question where learners were expected to make use of the balanced chemical equation. The learners were supposed to use the mole ratio from a balanced equation of reaction together with the number of moles of the limiting reactant to find the equivalent number of moles of water. Then they would use the formula to calculate the mass of water produced.

Intermediate response to question 6c

The learner with intermediate knowledge appropriately used the ratio between H_2O and NaOH to find the equivalent moles of H_2O. The learner then appropriately used the correct formula to calculate the mass of water. This learner made no mistake, and the work was classified as intermediate because it was solved through a two-step calculation. An example of an intermediate response to this question is shown in figure 4.78.

Figure 4:78

Intermediate response to question 6c



c) $H_2O : NaOH$

$1 : 1$

$x : 0,00575$

$x = 0,00575$

B12

$n(H_2O) = \frac{m}{M}$

$0,00575 = \frac{m}{18}$

~~[illegible]~~ $\therefore m = 0,10$ g

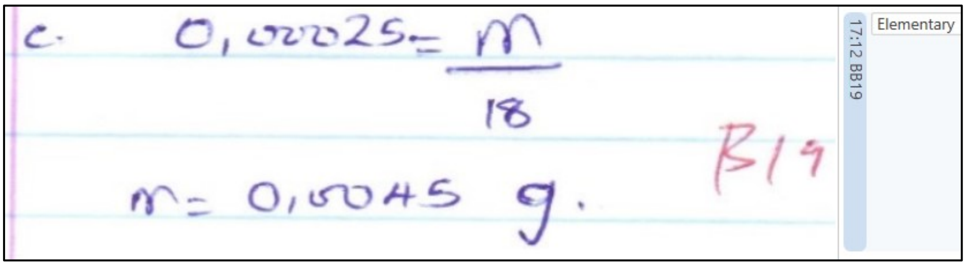
11:13 BB12

Elementary response to question 6c

The elementary response to question 6c is shown below. It is not clear how the learner found the wrong number of moles they used. This was possibly due to using the wrong ratio. The learner, however, used the correct formula to calculate the mass of oxygen. The answer is wrong, but the learner seemed to have a correct conception of how to solve the problem. An example of an elementary response to question 6c is shown in figure 4.79.

Figure 4:79

Elementary response to question 6c



c. $0,00025 = \frac{m}{18}$

$m = 0,0045$ g.

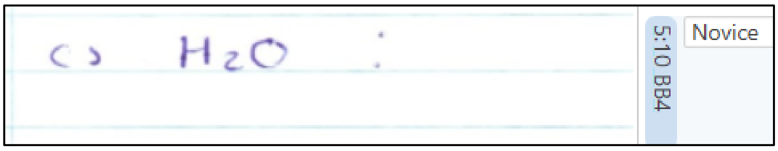
B19

Novice response in question 6c

The learner with a novice idea of how to solve question 6c only wrote the H_2O and nothing else. It appears as if the learner did not have any idea of how to solve it. An example of a novice response to question 6c is shown in figure 4.80.

Figure 4:80

Novice response to question 6c



c) H_2O :

4.3.2 Results of the post-intervention test data per participating school

Both classes were taught using POGIL worksheets which are specially designed to guide learners through a series of activities using similar analogies that helped them to develop their own understanding of the concepts. The post-intervention test was given to the learners after the intervention in stoichiometry. The following paragraphs analyses the results from both schools.

4.3.2.1 School A post-intervention test results

Analysis of post-intervention test results at school A indicates that a total of 9 responses showed advanced knowledge while 64 showed competent knowledge. The intermediate responses were 33 and the elementary responses were 87 while those with novice ideas were 27. This shows most of the learners had advanced, competent, and intermediate knowledge levels. More details of the post-intervention test results from school A are shown in table 4.4.

Table 4:4

Post-intervention test results School A

Question	Advanced	Competent	Intermediate	Elementary	Novice
1	0	0	0	22	0
2	0	16	1	4	1
3(a)	0	16	3	3	0
3(b)	0	0	9	12	1
4(a)	0	0	0	18	4
4(b)	2	15	3	0	2
5	7	7	4	2	2
6(a)	0	0	1	17	4
6(b)	0	10	2	5	5
6(c)	0	0	10	4	8
Totals	**9**	**64**	**33**	**87**	**27**
Percentage	**4.1%**	**29.1%**	**15.0%**	**39.5%**	**12.3%**

4.3.2.2 School B post-intervention test results

In school B there were a total of 15 advanced knowledge responses, 81 competent responses and 75 intermediate knowledge responses. The elementary and novice knowledge levels were 55 and 34 responses, respectively. More details about the post-intervention test results from school B are shown in table 4.5.

Table 4:5

Post-intervention test results School B

Question	Advanced	Competent	Intermediate	Elementary	Novice
1	0	0	0	25	1
2	0	19	5	1	1
3(a)	0	20	5	1	0
3(b)	0	0	18	3	5
4(a)	0	0	0	24	2
4(b)	4	13	8	0	1
5	11	11	0	1	3
6(a)	0	0	22	0	4
6(b)	0	18	2	0	6
6(c)	0	0	15	0	11
Totals	**15**	**81**	**75**	**55**	**34**
Percentage	**5.8%**	**31.2%**	**28.8%**	**21.2%**	**13.1%**

4.3.2.3 Combined post-intervention test results for both schools

An analysis of both classes in schools A and B indicate that 5% of their post-intervention test responses showed advanced knowledge of stoichiometry. The percentage of competent knowledge about stoichiometry was 30,2%, while the intermediate knowledge level was 22,5%. The elementary knowledge level was 29,6% of the learners' responses and the learners with novice ideas about the topic made up 12,7% of the learners' responses. Table 4.6 shows the combined post-intervention test results for both schools.

Table 4:6

Post-intervention test results for School A and B

Question	Advanced	Competent	Intermediate	Elementary	Novice
1	0	0	0	47	1
2	0	35	6	5	2
3(a)	0	36	8	4	0
3(b)	0	0	27	15	6

4(a)	0	0	0	42	6
4(b)	6	28	11	0	3
5	18	18	4	3	5
6(a)	0	0	23	17	8
6(b)	0	28	4	5	11
6(c)	0	0	25	4	19
Totals	24	145	108	142	61
Percentage	**5.0%**	**30.2%**	**22.5%**	**29.6%**	**12.7%**

4.3.3 Summary of the post-intervention test results

Very few learners demonstrated novice ideas of stoichiometry. Even fewer learners demonstrated advanced knowledge. Most of the learners demonstrated competent, intermediate, and elementary knowledge. Compared to the pre-intervention test, this suggests a shift from novice ideas to higher levels of competence in the post-intervention test. This suggests that the learners' reasoning after the intervention was much higher in the post-intervention test than in the pre-intervention test. The learners demonstrated that they could solve difficult questions more easily than they initially did in the pre-intervention test.

4.3.4 Comparison of post-intervention test and pre-intervention test results

Question 1 the both the post-intervention test and the pre-intervention test was a level I question. The results in the pre-intervention test indicate that 35 learners in the sample of 48 demonstrated elementary knowledge while 13 learners demonstrated novice ideas. In the post-intervention test, only 1 of these same learners demonstrated novice ideas. The rest (47) of the learners demonstrated elementary knowledge. The learners observed the data available and reasoned on the appropriate formula to use, reasoned well in doing proper substitution and solving the question correctly. The learners demonstrated improvement in reasoning to solve this single-step question.

Question 2 was level III in both the pre-intervention test and the post-intervention test. The results in the pre-intervention test suggest 37 learners in the sample demonstrated novice ideas. Seven learners demonstrated elementary knowledge on this question as they managed to solve only part of this three-step calculation by performing a single-step calculation. Two learners demonstrated intermediate knowledge by solving part of the problem through two steps, while 2 learners completed the three-step calculation correctly. In the post-intervention test following the intervention, only 2 learners demonstrated novice ideas in solving question 2. This was a huge improvement from the 37 who demonstrated novice ideas in the pre-intervention test. Five learners demonstrated elementary ideas in the post-intervention test and 6 learners demonstrated intermediate knowledge. The learners who demonstrated competent knowledge in question 2 were 35. These learners managed to correctly solve the three-step problem. This showed an improvement in learners' reasoning in a three-step problem. The learners demonstrated that their reasoning had increased after the intervention.

Question 3a was also a level III question in both the pre-intervention test and the post-intervention test. The results in the pre-intervention test suggest that 34 learners demonstrated novice ideas while in the post-intervention test there was no learner with novice ideas. A total of 9 demonstrated elementary knowledge in the pre-intervention test compared to 4 learners in the post-intervention test. Two learners in the pre-intervention test compared to 8 learners in the post-intervention test demonstrated intermediate knowledge. Three learners in the pre-intervention test compared to 36 in the post-intervention test demonstrated competent knowledge. This suggests that learners' reasoning had improved after the intervention as compared with before the intervention. The learners showed improved reasoning in solving a three-step calculation.

Question 3b was a level II question that needed to be solved through a two-step calculation. The pre-intervention test witnessed 36 learners with novice ideas while the post-intervention test showed only 6. Nine learners in the pre-intervention test compared to 15 learners in the post-intervention test demonstrated elementary knowledge. Three learners in the pre-intervention test compared to 27 learners in the post-intervention test demonstrated intermediate knowledge of solving this 2-step calculation without any errors. The results show that there was an improvement in learners' reasoning since the intermediate knowledge increased from 3 learners to 27 learners and the novice ideas decreased from 36 learners in the pre-intervention test to 6 learners in the post-intervention test.

Question 4a was a level I question in which learners had to recall the definition from memory. In the pre-intervention test, 36 learners demonstrated novice ideas while only 12 managed to define limiting reactant correctly. In the post-intervention test, there were only 6 learners with novice ideas while 42 correctly defined limiting reactant. Though this question did not require reasoning, the learners improved their knowledge to define the concept. This seems to indicate that the POGIL intervention was effective in improving learners' knowledge.

Question 4b was a level IV question that required a multi-step calculation. In the pre-intervention test, 37 learners demonstrated novice ideas to solve the question. This is compared to 3 learners in the post-intervention test. This seems to suggest that the intervention resulted in the improvement of learners who did not possess any mathematical reasoning in the pre-intervention test. The learners with elementary knowledge were 7 in the pre-intervention test compared to none in the post-intervention test. The learners with intermediate knowledge were 3 in the pre-intervention test compared to 11 in the post-intervention test. There was only 1 learner with competent knowledge in the pre-intervention test compared to 28 learners in the post-intervention test. This suggests that learners' reasoning to perform three-step calculations had improved because of the POGIL intervention. In the pre-intervention test, no learner demonstrated advanced knowledge while in the post-intervention test there were 6 learners with advanced knowledge. This demonstrated an improvement in learners' reasoning to solve multi-step calculations because of the POGIL approach.

Question 5 was a multi-step level IV question. In the pre-intervention test, there were 29 learners with novice ideas compared to 5 in the post-intervention test. This seems to show that the POGIL approach increased learners' reasoning as shown by a decrease in the number of learners with novice ideas. It means the intervention may have been effective in decreasing the number of learners with novice ideas. There were 9 learners with elementary knowledge in the pre-intervention test compared to 3 in the post-intervention test. This showed a reduction in the number of elementary solutions. There were 6 learners with intermediate knowledge in the pre-intervention test compared to 4 in the post-intervention test. In contrast, there were only 4 learners with competent knowledge in the pre-intervention test compared to 18 in the post-intervention test. This suggests that there was an improvement in learners' reasoning in solving calculations through three steps. No learner demonstrated advanced knowledge in the pre-intervention test compared to 18 in the post-intervention test. Overall, these figures suggest a sharp increase in learners' reasoning so solve multi-step calculations.

Question 6a was a level II question requiring learners to balance the equation of a chemical reaction by applying the ratio technique to balance the number of atoms of each element. In the pre-intervention test, there were 35 learners with novice ideas about balancing the equation of reaction, while in the post-intervention test the number decreased to 8. This seems to show that the POGIL way of teaching improved learners' reasoning. There were 7 learners with elementary knowledge compared to 17 in the post-intervention test. Six learners who demonstrated intermediate knowledge in the pre-intervention test compared to 23 in the post-intervention test. The results suggest that the learners' reasoning improved. They managed to work through the balancing of the equation of reaction applying the ratio technique and a great improvement was observed in the post-intervention test results.

Question 6b in the post-intervention test was a level III question that required learners to go through a three-step calculation. As with 6b, 6c, and 6d, the question was combined in the pre-intervention test. These three were all level I questions. The pre-intervention test results suggest that most of the learners demonstrated novice ideas. The post-intervention test results indicate that 28 learners demonstrated competent knowledge, 4 with intermediate knowledge and 5 showing elementary knowledge. This suggests an improvement of learners' reasoning after the intervention.

Question 6e in the pre-intervention test was similar to question 6c in the post-intervention test. Both were level II questions that required two-step calculation. In the pre-intervention test, 42 learners demonstrated novice ideas in answering this question, while 5 learners demonstrated elementary knowledge and 1 demonstrated intermediate knowledge. In the post-intervention test, 19 learners demonstrated novice ideas. The learners who demonstrated elementary and intermediate knowledge were 4 and 25, respectively. The increase in the number of learners with intermediate knowledge shows the increase in their mathematical reasoning as they correctly completed the two-step process. The decrease in the number of novice ideas in the post-intervention test demonstrates the increase in learners' reasoning as they managed to either perform one-step or two-step calculations.

The results suggest an improvement in advanced knowledge in the post-intervention test compared to the pre-intervention test results, shown by the shift to higher levels. This shows that there was a considerable increase in critical thinking as the learners increased their thinking skills to attain higher-order thinking which is associated with advanced knowledge level. The results also suggest an increase in the competent and intermediate knowledge levels. This shows an improvement of critical thinking and reasoning skills and understanding of the complex multi-step calculations in stoichiometry. There was a decrease in elementary and novice knowledge levels in the post-intervention test compared to the pre-intervention test. This shows that the learners who held elementary knowledge improved to higher levels of cognition. The results, therefore, indicate that the intervention may have been effective in reducing lower thinking skills and promoting higher-order thinking skills which entails improved reasoning.

The results suggest that there was an improvement in learners' levels of knowledge after the intervention. This increase suggests an increase in learners' mathematical reasoning. It suggests the increase in the learners' ability to analyse the given data and choose the appropriate formula. The learners also managed to correctly substitute and make the appropriate subject of the formula. The learners then correctly calculated the unknown value accompanied by the correct units. In the case of two-step calculations, the learners improved in the proper use of the answer in the first step to perform the next calculation. In the case of the three-step or multi-step calculations, the learners demonstrated improved ability to make use of different formulae and applying appropriate reasoning until they obtained the correct answers. The results suggest the learners increased their understanding of the topic. The improved reasoning suggests that the learners improved their ability to apply, analyse, evaluate, and create as they worked with the data and used different formulae to solve problems. It suggests that the POGIL way of teaching have been effective in increasing their reasoning skills, critical thinking skills and problem-solving techniques.

4.4 Analysis of ratio questions

One of the most challenging mathematical techniques in this topic is the use of ratios. Many learners fail to make use of mole ratios in stoichiometry and as a result they are unable to successfully solve advanced high-order questions which involve multi-step calculations. Manipulation of ratio is a mathematical technique that is associated with multi-step questions where learners link one step to the next. Reasoning and understanding and critical thinking are required at this stage to apply logic based on the use of the mole ratios in the balanced equation of reactions. This ability is particular to high-order complex questions where reasoning is required.

In this section, I present the analysis of the knowledge levels the learners demonstrated in the questions that required the use of ratios in the pre-intervention test. A similar analysis of the knowledge levels for the post-intervention test questions is also presented. Thereafter, I present a comparison of the pre-intervention test and the post-intervention test results in this regard as a conclusion of this section.

4.4.1 Learners' responses to items requiring the use ratios in the pre-intervention test

Most questions in the pre-intervention test such as 2, 3(a), 3(b), 4(b), 5, 6(a), 6(d) and 6(e) dealt with ratio. Questions 6a, 6d and 6e were level II questions. They had to be solved with two-step calculations. Question 6a was about balancing the equation of a chemical reaction where a lot of ratios are used. Questions 2 and 3a were level III questions that required a three-step process. Question 4b and 5 were multi-step level IV questions.

The data analysed in this section were taken from the original table of results in the pre-intervention test indicated in section 4.1.3 on table 4.3. Only the ratio questions have been used in this section. The results suggest that there was no learner with an advanced knowledge level. The number of competent knowledge levels in the results was 10, while the intermediate knowledge levels were 18. The elementary knowledge levels were 54 and the novice levels were 254. The results suggest that most of the learners' responses in the pre-intervention test were novice ideas. This suggests that overall, the learners had low-level reasoning and critical thinking. The learners did not have enough skill to solve high-order multi-step questions requiring mathematical reasoning about ratios. Table 4.7 shows the results of the ratio analysis in the pre-intervention test.

Table 4:7

Ratio analysis on the pre-intervention test

Question	Advanced	Competent	Intermediate	Elementary	Novice
2	0	2	2	7	37
3(a)	0	3	2	9	34
3(b)	0	0	3	9	36
4(b)	0	1	3	7	37
5	0	4	6	9	29
6(d)	0	0	1	8	39
6(e)	0	0	1	5	42
Total	**0**	**10**	**18**	**54**	**254**
Percentage	**0.0%**	**3.0%**	**5.4%**	**16.1%**	**75.6%**

4.4.2 Learners' responses to items requiring the use of ratios in the post-intervention test

The post-intervention test included six questions in which the ratio technique was applied. The questions were numbers 2, 3(a), 3(b), 4(b), 5 and 6(c). The data used to analyse the ratio technique were taken from the original table of results in the post-intervention test indicated in table 4.6.

In the post-intervention test, the advanced knowledge level had 24 responses and the competent knowledge level had 117. The intermediate knowledge level stood at 81 responses while the elementary and novice levels were 31 and 35 responses, respectively. This would suggest that the responses in the post-intervention test were mainly on the higher level of cognition in the post-intervention test. Only about 20% of the responses in the post-intervention test were in the lower-level category of elementary and novice levels. It appears to suggest that the POGIL intervention had effectively increased the higher levels of cognition of reasoning and critical thinking. Most of the learners displayed high reasoning ability in the post-intervention test. Table 4.8 shows the ratio analysis in the post-intervention test results.

Table 4:8

Ratio analysis Post-intervention test results

Question	Advanced	Competent	Intermediate	Elementary	Novice
2	0	35	6	5	2
3(a)	0	36	8	4	0
3(b)	0	0	27	15	6
4(b)	6	28	11	0	3
5	18	18	4	3	5
6(c)	0	0	25	4	19
Totals	**24**	**117**	**81**	**31**	**35**
Percentage	**8.3%**	**40.6%**	**28.1%**	**10.8%**	**12.2%**

4.4.3 Comparison of the pre-intervention test and post-intervention test ratio questions

For the discussion i this section, the data from tables 4.7 and 4.8 above were used. Analysis shows an improvement in the advanced knowledge level from 0,0% in the pre-intervention test to 8,3% in the post-intervention test results. There was also improvement in the competent knowledge level, from 3% in the pre-intervention test to 40,6% in the post-intervention test. The intermediate knowledge level improved from 5,4% in the pre-intervention test to 28,1% in the post-intervention test. This shows that the learners improved their knowledge in the high-order multi-step problems. The elementary knowledge level decreased from 16,1% in the pre-intervention test to 10,8% in the post-intervention test, while the novice ideas decreased from 75,6% in the pre-intervention test to 12,2% in the post-intervention test. The results suggest that the POGIL method decreased the number of novice ideas as well as elementary ideas and improved the number of higher-order thinking skills of critical thinking and reasoning. The learners solved ratio questions better after the POGIL intervention than they did before the intervention. Many learners who initially did not know reasoning and did not understand the use of ratio and critical thinking, showed great improvement after the intervention.

The pre-intervention test results suggest that most learners had novice or elementary ideas about stoichiometry to begin with. The results suggest very few intermediate and competent knowledge levels and almost no advanced knowledge levels. The results in both schools A and B were comparable in the pre-intervention test, indicating that they had similar levels of cognition to begin with.

The post-intervention test results suggest an improvement in the higher-order knowledge levels of advanced, competent, and intermediate. There was a clear decrease in the elementary and novice levels of cognition, suggesting cognitive improvement after the POGIL intervention. This also gives the impression that POGIL intervention may be effective in eliciting the development of higher levels of cognition and reasoning and critical thinking.

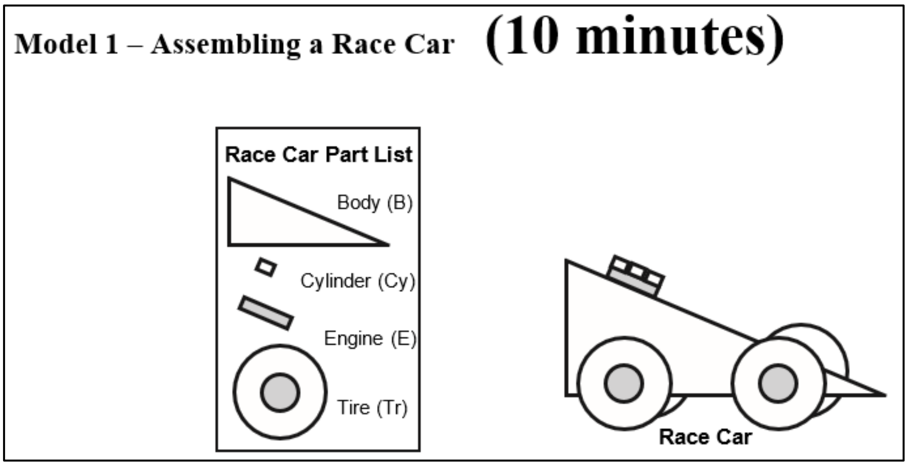
4.5 Results from the POGIL intervention

The analysis of data obtained during the intervention in the POGIL groups was done following the ICAP framework discussed in sections 2.5 and 3.6.6. In the intervention, learners' activities were grouped in four models. Each model was an activity and aimed at achieving the objectives of the learning cycle. The results for the intervention are presented one model after another. Quotes from the transcripts of the learners' discussions as they completed the POGIL tasks have been added to demonstrate the type of verbal interactions they had as they carried out the tasks. A summary of the findings is provided at the end of the section.

4.5.1 Learner responses to Model 1

Figure 4:81

The diagram showing Model 1.



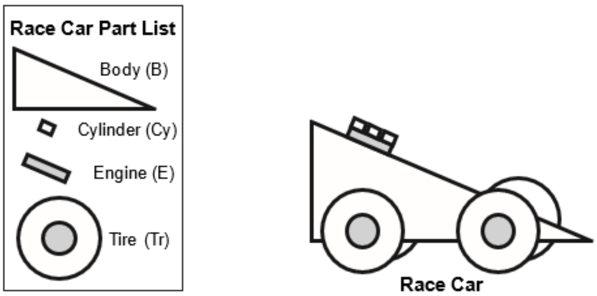
Model 1 question 1 read as follows:

How many of each part are needed to construct 1 complete race car?

Figure 4.81 was the introduction task for the topic "limiting reactant". It was designed to begin with easy and familiar concepts before introducing the chemistry concepts. The reader read the question and the rest of the group members listened carefully. This was the passive cognitive level. Table 4.9 summarizes the observations of the learners' activities to question 1.

Table 4:9

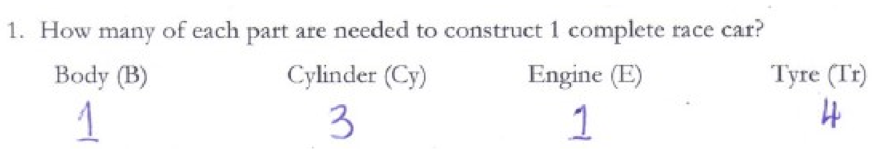
Learners' first activity, cognitive level, and the image for question 1

	Activities	Cognitive level
	Reading, listening	Passive
Image		

After the reading of the question the learners started responding in turn, asking *"how many bodies do we need"?* The next learner responded, *"one",* and another *"I go for one",* and yet another, *"okay one".* The reader then asked, *"and cylinders?"* to which all agreed on three cylinders, one engine and 4 tyres. The learners quickly responded by looking at the parts for constructing a model car. They did quick mental analysis and shared their views until they agreed. They then compiled their answers on the worksheet. The learners were in the interactive cognitive level since they shared ideas and assisted each other. Table 4.10 summarizes learners' cognitive level and its classification based on the ICAP framework.

Table 4:10

Learners' second activity, cognitive level, and the image for question 1

	Activities	Cognitive level
	Agree, elaborate, compile ideas	Interactive
Image	 1. How many of each part are needed to construct 1 complete race car? Body (B) 1 Cylinder (Cy) 3 Engine (E) 1 Tyre (Tr) 4	

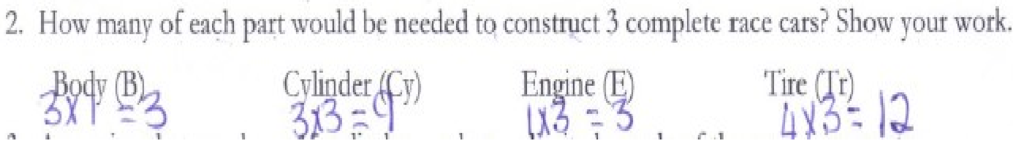
Model 1 question 2 read as follows:

How many of each part would be needed to construct 3 complete race cars? Show your work.

One learner spoke up saying, "*To make three complete race cars, okay we are going to multiply each part by three, right?"* The other learner responded, *"yeah".* Then the learners went, "*Bodies = 1x3 = 3 bodies; 3x3 = 9 cylinders; 1x3 = 3 engines and 4x3 = 12 tyres"* as a group. The learners quickly identified the clue of multiplying each part by 3. They quickly calculated the answers and began writing them on the worksheet using mathematical skills as justification. They agreed on the answers before writing them down. The cognitive level of the learners was interactive since they shared ideas and agreed on the collective response to the question. Table 4.11 shows below shows a summary of learners’ cognitive level and its classification of question 2 based on the ICAP framework.

Table 4:11

Learners’ activities, cognitive level, and the image for question 2

	Activities	Cognitive level
	Agree, elaborate, compile ideas, justify	Interactive
Image	2. How many of each part would be needed to construct 3 complete race cars? Show your work. Body (B) 3x1 =3 Cylinder (Cy) 3x3 =9 Engine (E) 1x3 = 3 Tire (Tr) 4x3= 12	

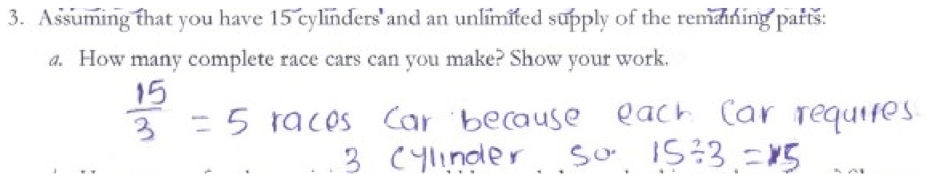
Model 1 question 3a read as follows:

> *Assuming that, you have 15 cylinders and an unlimited supply of the remaining parts. How many complete race cars can you make? Show your work.*

The learners quickly identified the clue and elaborated it *“divide 15 by 3”.* To which another learner asked, *“why?”* The other learner responded, *“because a car only needs 3 cylinders so 15÷3 = 5 cars.”* The learners worked collectively and helped each other until they found their answers to the question. After agreeing, they compiled their answer. The cognitive level in the question was interactive. Table 4.12 shows a summary of the analysis of question 3a based on learners’ cognitive levels and classification of activities based on the ICAP framework.

Table 4:12

Learners’ activities, cognitive level, and the image for question 3a

	Activities	Cognitive level
	Agree, elaborate, justify, compile ideas	Interactive
Image	3. Assuming that you have 15 cylinders and an unlimited supply of the remaining parts: a. How many complete race cars can you make? Show your work. $\frac{15}{3}$ = 5 races Car because each Car requires 3 cylinder so 15÷3 =5	

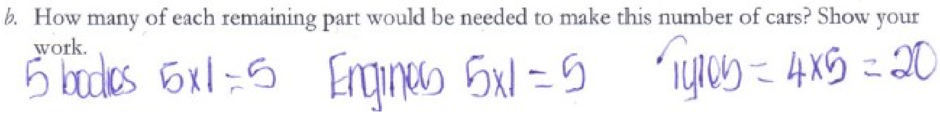
Model 1 question 3b read as follows:

> *How many of each remaining part would be needed to make this number of cars? Show your work.*

After reading the question while the other learners were listening, the learners waited. They were confused at first as one said, *"because they are unlimited meaning, they are so many parts?"* Another learner asked, *"so how can we find how many they are?"*. They read through the question again until they overcame this challenge and said *"Ooh, how many of each part…?" So, to make 5 cars how many engines do we need?" "5 engines"*. They proceeded and found 5 bodies and 20 tyres. They justified their answers with mathematical calculations. They discussed and elaborated on each answer in the group. The interactive cognitive level was evident in this question. Table 4.13 shows a summary of the analysis of question 3b.

Table 4:13

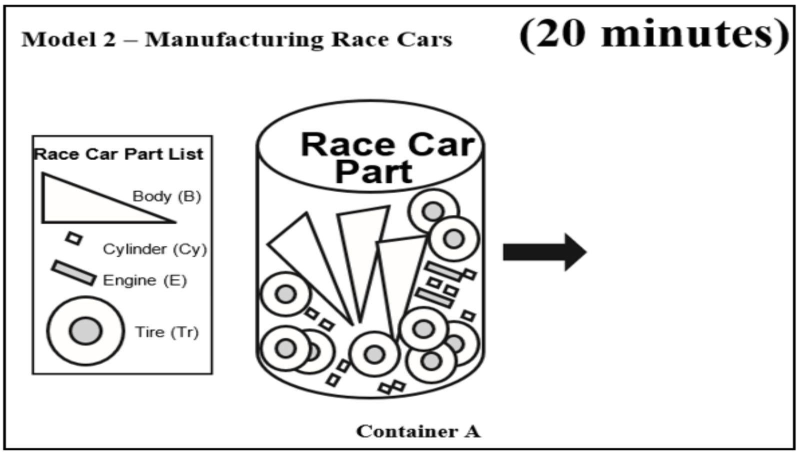
Learners' activities, cognitive level, and the image for question 3b

	Activities	Cognitive level
	Elaborate, justify, compile ideas, "Aha" challenge, agree	Interactive
Image	 b. How many of each remaining part would be needed to make this number of cars? Show your work. 5 bodies 5x1 = 5 Engines 5x1 = 5 Tyres = 4x5 = 20	

4.5.2 Learner responses to Model 2

Figure 4:82

The diagram showing Model 2.



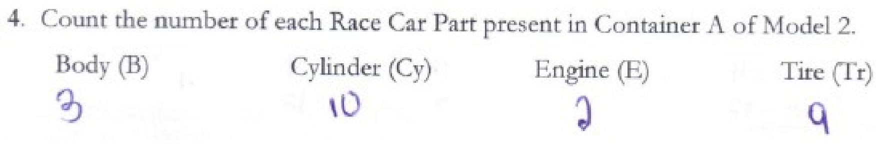
Model 2 question 4 read as follows:

Count the number of each Race Car Part present in Container A of Model 2.

The learners quickly understood the easy activity of counting the parts for the construction of the model car. They collectively counted and agreed on the answer before writing it down. *“How many bodies?”* and the answer went *“three”*. The learners’ cognitive level was interactive as they share knowledge and argued their answers in the group giving correct justification for their responses. Table 4.14 summarizes the analysis for question 4.

Table 4:14

Learners’ activities, cognitive level, and the image for question 4

	Activities	Cognitive level
	Justify, compile ideas, elaborate, argue, agree	Interactive
Image	 4. Count the number of each Race Car Part present in Container A of Model 2. Body (B) 3 Cylinder (Cy) 10 Engine (E) 2 Tire (Tr) 9	

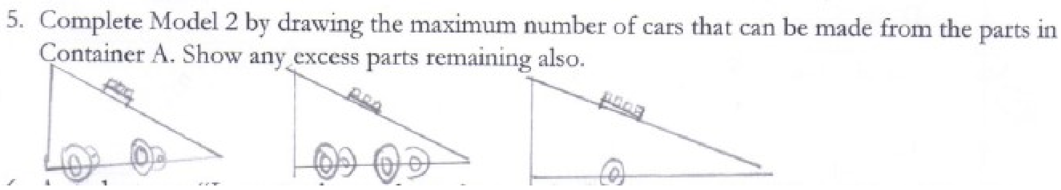
Model 2 question 5 read as follows:

> *Complete Model 2 by drawing the maximum number of cars that can be made from the parts in Container A. Show any excess parts remaining also.*

The learners understood the question after taking some time to brainstorm. They asked for assistance from the teacher who came to assist them by giving guiding questions to get them on the right track. The teacher did not tell the learners the answers but only guided them on how to get to the answer. The learners were left with clarity and were able to answer the question. The learners elaborated their answer by making careful drawings of the race cars, showing all the parts. They agreed on their answers, asking for consensus from the rest of the group members. The cognitive level of the learners was interactive. Table 4.15 summarizes the analysis of question 5.

Table 4:15

Learners' activities, cognitive level, and the image for question 5

	Activities	Cognitive level
	Justify, compile ideas, elaborate, argue, agree	Interactive
Image	 5. Complete Model 2 by drawing the maximum number of cars that can be made from the parts in Container A. Show any excess parts remaining also.	

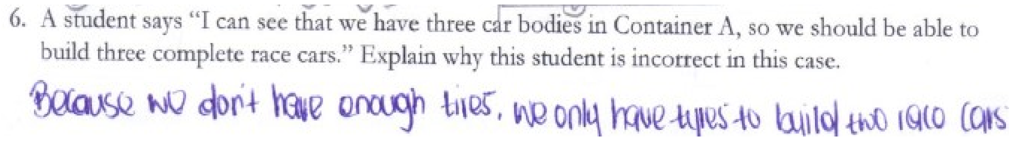
Model 2 question 6 read as follows:

A student says, "I can see that we have three car bodies in Container A, so we should be able to build three complete race cars." Explain why this student is incorrect in this case.

The learners argued over the number of cars that could be formed. *"we have four engines so we must get four cars"* and another said, *"no we don't have so many cylinders"*. The learners brainstormed for a while. Then another learner said, *"We only have two complete cars; we cannot make another car because of the shortage of the parts".* The learners were correct that the parts were not enough to make an extra car. This means the learners correctly analysed the parts needed and made a correct judgement after reflection when they were initially confused. The cognitive level was interactive. Table 4.16 summarizes the analysis of question 6.

Table 4:16

Learners' activities, cognitive level, and the image for question 6

	Activities	Cognitive level
	Justify, compile ideas, elaborate, argue, agree	Interactive
Image	 6. A student says "I can see that we have three car bodies in Container A, so we should be able to build three complete race cars." Explain why this student is incorrect in this case. Because we don't have enough tires. we only have tyres to build two race cars	

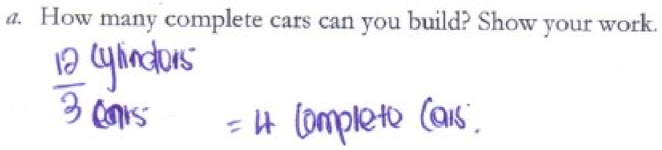
Model 2 question 7a read as follows:

> *Suppose you have an exceptionally large number (dozens or hundreds) of tyres and bodies, but you only have 5 engines and 12 cylinders. How many complete cars can you build? Show your work.*

The learners were not challenged by this question. They quickly said, "we are going to make 4 cars, right?". "Yes, because 12 cylinders can only make 4 cars." The learners did a quick and correct analysis of the question. They, however, did not say anything about the engines. It seems that the learners realised that the number of cylinders limited the number of cars, so they can only build 4 cars. So, they did develop the concept of "limiting part". The learners agreed on each of their answers before taking them down. The answer was properly justified using facts and calculations. The cognitive level was interactive because the learners shared their ideas with each other. Table 4.17 shows detailed analysis of question 7a.

Table 4:17

Learners' activities, cognitive level, and the image for question 7a

	Activities	Cognitive level
	Justify, compile ideas, elaborate, argue, agree	Interactive
Image	 a. How many complete cars can you build? Show your work. $\frac{12 \text{ cylindors}}{3 \text{ cars}}$ = 4 complete cars.	

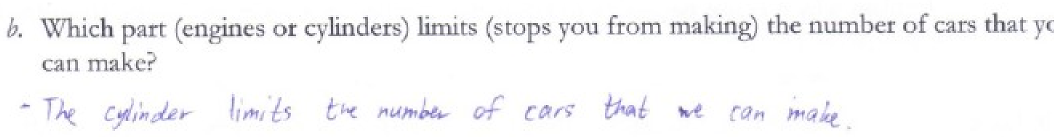
Model 2 question 7b read as follows:

> *Suppose you have an exceptionally large number (dozens or hundreds) of tyres and bodies, but you only have 5 engines and 12 cylinders. Which part (engines or cylinders) limits (stops you from making) the number of cars that you can make?*

After listening to the reader, one learner said, *"It's the engine".* Another learner responded, *"What did the engine do"* and the first learner said*, "if the engine is not there you cannot make a car"*. After some debate, the group agreed that the engine was the limiting part. This answer was incorrect. The group members did not make a thorough justification of the answer to find if it was correct. The learners just agreed to the one who said the wrong answer. The cognitive level was interactive since learners shared their opinions though on learner seem to have dominion over the others. Careful consideration should be taken when grouping learners, since the brighter learners may overshadow others. Another group, however, correctly identified the cylinder as the limiting part. They said, *"because all the cylinders are used up, and one engine still remains."* Table 4.18 summarizes the analysis of question 7b.

Table 4:18

Learners' activities, cognitive level, and the image for question 7b

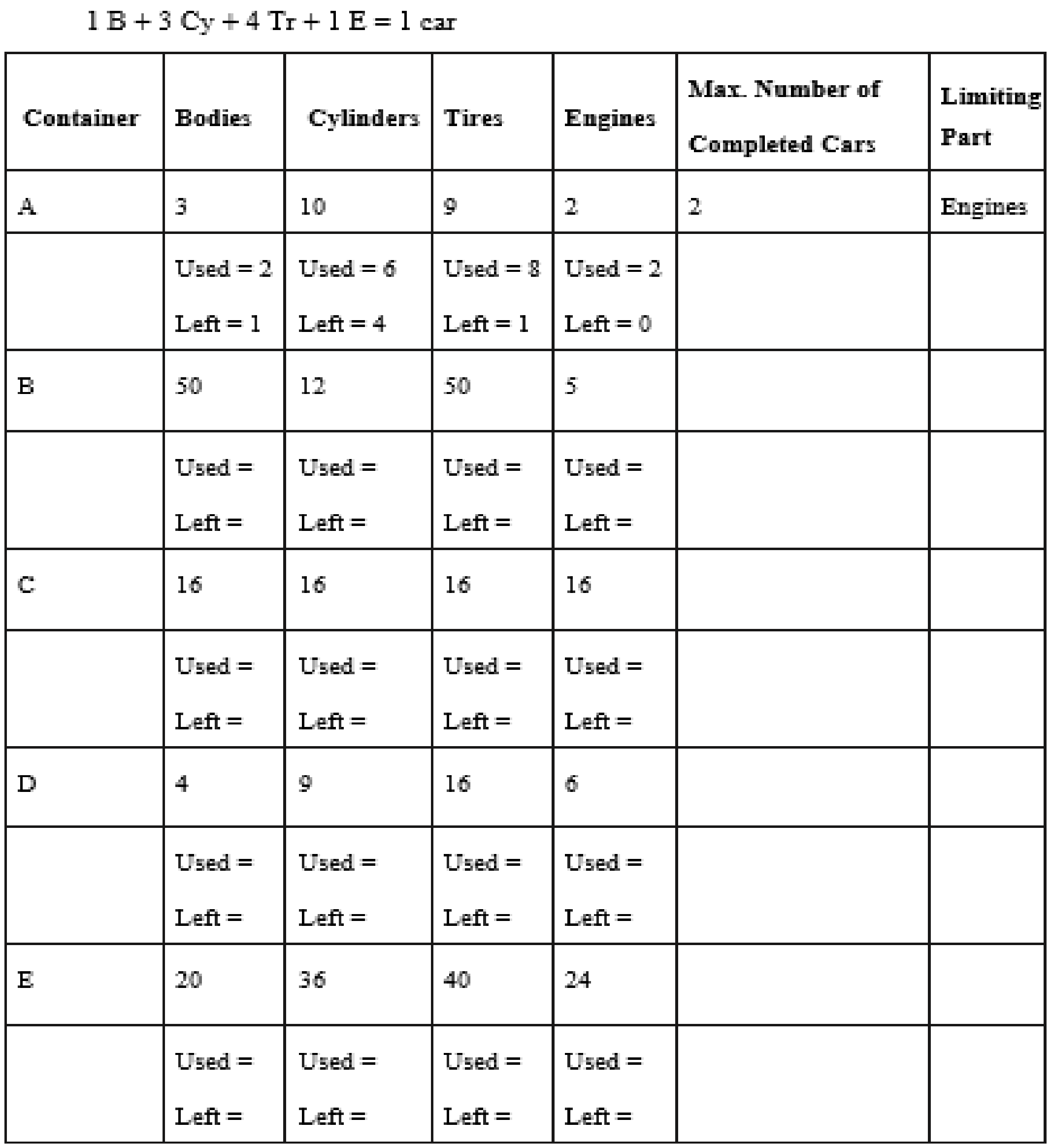
	Activities	Cognitive level
	Justify, compile ideas, elaborate, argue, agree	Interactive
Image	 *b.* Which part (engines or cylinders) limits (stops you from making) the number of cars that yc can make? - The cylinder limits the number of cars that we can make.	

Model 2 question 8 read as follows:

Fill in the table below with the maximum number of complete race cars that can be built from each container of parts (A–E), and indicate which part limits the number of cars that can be built. The answers for container A were provided as an example.

Table 4:19

Table for model 2 question 8



1 B + 3 Cy + 4 Tr + 1 E = 1 car

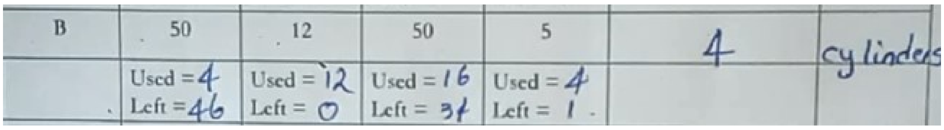
Container	Bodies	Cylinders	Tires	Engines	Max. Number of Completed Cars	Limiting Part
A	3	10	9	2	2	Engines
	Used = 2 Left = 1	Used = 6 Left = 4	Used = 8 Left = 1	Used = 2 Left = 0		
B	50	12	50	5		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		
C	16	16	16	16		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		
D	4	9	16	6		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		
E	20	36	40	24		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		

Model 2 question 8B:

The learners read and calculated their answers as they read through the question. *“We have 5 engines, and 5 engines make 5 cars, and we have 50 tyres, and 12 cylinders, and 12 cylinders can make 4 cars. Meaning we can only make 4 cars due to our 12 cylinders?”.* Another asked, *“Right?”* The other learner proceeded, *“and 4 bodies and we will be left with 46 bodies, and cylinders we use all 12”.* Yet another learner added, *“Meaning maximum number of complete cars is 4 and limiting part is cylinder”.* The learners brainstormed through the available information. They calculated how many cars they could make using each of the given parts. They identified that the limiting part was cylinders because they could produce the lowest number of cars using the available cylinders. After getting the maximum number of complete cars the learners then filled in the table about the parts used and parts left over. They gave the correct justification of their ideas and agreed on the same answer as a team, and they compiled their answers on the worksheet. The learners were working on the interactive cognitive level since they produced answers from mutual discussions. Table 4.20 shows a summary of the analysis of question 8B.

Table 4:20

Learners' activities, cognitive level, and the image for question 8B

	Activities	Cognitive level
	Justify, compile ideas, elaborate, argue, agree	Interactive
Image		

B	50	12	50	5	4	cylinders
	Used = 4 Left = 46	Used = 12 Left = 0	Used = 16 Left = 34	Used = 4 Left = 1		

Model 2 question 8C:

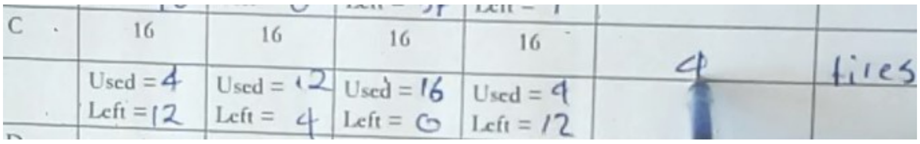
The learners were initially challenged by seeing that there were 16 of each part. *"Ooh everything is 16, 16, 16, 16?",* Another learner said, *"Oh yeah".* They brainstormed a little bit and then reflected on the way forward. *"It means we are going to have due to 16 cylinders we get 5 cars"*, and the other learner added *"and 1 cylinder remains."* Then they went on analysing using the number of cylinders. *"For 5 cars we will need 5 bodies",* and the other learner added *"for 5 cars we are going to use 20 tyres." "Oh no, we can't use tyres."* The other learner said, *"so our limiting part is tyre, so we will use 4 bodies and be left with 12*". The learners went on to use 12 cylinders and were left with 4, and used all 16 tyres, *"all 16 tyres? …. All 16 tyres and remain zero."*

The learners used the trial-and-error method differently from the previous question. They took a part and decided to find how many other parts may be needed. Their first choice was not appropriate, and they saw that they would need more tyres than what they had. They reflected and decided to use tyres and do the same calculations all over again. The learners appropriately elaborated how many parts would be needed.

At each stage, they agreed to proceed or to change their opinion. They compiled their answers onto the table. The cognitive level was interactive since the learners worked collectively. Table 4.21 summarizes the analysis for question 8C.

Table 4:21

Learners' activities, cognitive level, and the image for question 8C

	Activities	Cognitive level
	Brainstorming, agree challenge, elaborate, reflect	Interactive
Image		

C	16	16	16	16		
	Used = 4 Left = 12	Used = 12 Left = 4	Used = 16 Left = 0	Used = 4 Left = 12	4	tires

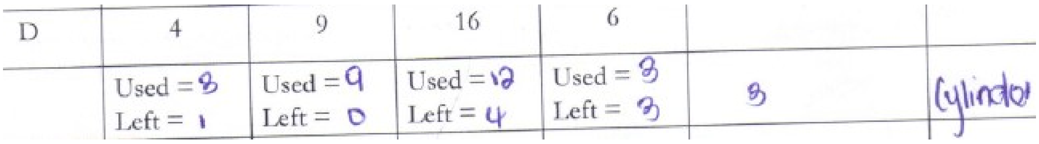
Model 2 question 8D

One of the learners quickly said, *"We have 4 bodies we can make 4 cars"* and another learner responded, *"we have 9 cylinders, we can make 3 cars*". Another learner says, *"we have 16 tyres we can make 4 cars and we have 6 engines we can make 6 cars."* The reader asked, *"So what is our limiting part?"* And the response was *"cylinder", "cylinder is the limiting part since we can make fewer cars".*

The learners used the method of analysing part by part to see how many complete cars could be formed by each. The elaboration and justification show that the learners were aware of what they were doing. They agreed with each other before compiling their answers showing that they were co-generating their answers. This method makes them find the limiting part without making an error and not facing any challenges. They were in the interactive cognitive level. Table 4.22 summarizes the analysis for question 8D.

Table 4:22

Learners' activities, cognitive level, and the image for question 8D

	Activities	Cognitive level
	Brainstorming, agree challenge, elaborate, reflect	Interactive
Image		

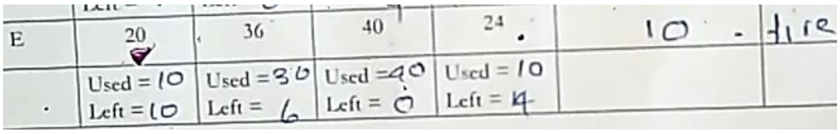
D	4	9	16	6		
	Used = 8 Left = 1	Used = 9 Left = 0	Used = 12 Left = 4	Used = 3 Left = 3	8	Cylinder

Model 2 question 8E

When looking at the question, one of the learners said, *"We have 20 bodies so we can make 20 cars …" "So, what is our limiting part?"* Another learner responded, *"our limiting part is the tyre, since we used all tyres, we get 10 cars, and we are left with zero."* The learners continued compiling their answers as they elaborated with calculations of the used and excess parts. They justified their answers by making quick mental calculations and agreeing on their answers before proceeding to the next calculation. They were at the interactive cognitive level since they co-generated their answers. Table 4.23 summarizes the analysis of question 8E.

Table 4:23

Learners' activities, cognitive level, and the image for question 8E

	Activities	Cognitive level
	Elaborate, agree, compiling ideas, justify	Interactive
Image		

E	20	36	40	24	10 -	tire
	Used = 10 Left = 10	Used = 30 Left = 6	Used = 40 Left = 0	Used = 10 Left = 4		

Model 2 question 9 read as follows:

The Zippy Race Car Company builds toy race cars by the thousands. They do not count individual car parts. Instead, they measure their parts in "oodles" (a large number of things).

Model 2 question 9a read as follows:

a. Assuming the inventory (list) in their warehouse below, how many race cars could the Zippy Race Car Company build? Show your work.

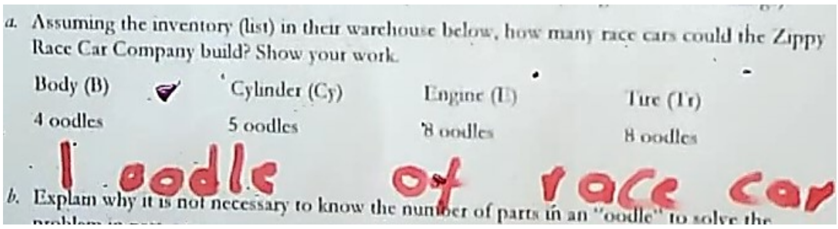
Body (B)	*Cylinder (Cy)*	*Engine (E)*	*Tire (Tr)*
4 oodles	*5 oodles*	*8 oodles*	*8 oodles*

One of the learners said, *"Oodles!! Eish, I don't understand"*. The learners were challenged by the word "*oodles*" which they seemed not to understand during the reading time. They remained silent for some time while reading over the problem again. Then one said, *"What are they trying to say?"* After brainstorming for a while, another learner said, *"we have 4 bodies we can make 4 cars, we have 5 cylinders we can make 1 car."* And the other said *"so we are going to make only 1 car?"* Another learner responded, *"no, 1 oodle, not 1 car"*. The learners became disengaged and started doing other things, though they had stumbled on a clue that could assist them. They were confused by the word *oodle* (a large number of things) being used instead of *cars*.

When the learners were disengaged, they were also laughing. After some time, they returned to the work with the answer saying, *"It's 1 oodle."* They deduced that the correct word to use was oodles and not cars. They did not elaborate on this answer, showing that they may have found the answer from another group. The cognitive level for this question was both interactive because of the mutual discussions and disengaged because of the time they abandoned their workstation. Table 4.24 summarizes the analysis for this question.

Table 4:24

Learners' activities, cognitive level, and the image for question 9a

	Activities	Cognitive level
	Challenge, agree, brainstorming, doing other things	Interactive, disengaged
Image	 *a.* Assuming the inventory (list) in their warehouse below, how many race cars could the Zippy Race Car Company build? Show your work. Body (B) 4 oodles Cylinder (Cy) 5 oodles Engine (E) 8 oodles Tire (Tr) 8 oodles 1 oodle of race car *b.* Explain why it is not necessary to know the number of parts in an "oodle" to solve the	

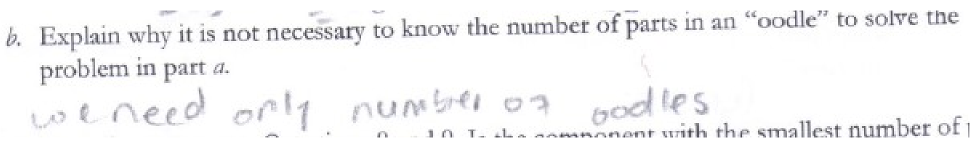
Model 2 question 9b read as follows:

> *Explain why it is not necessary to know the number of parts in an "oodle" to solve the problem in part a.*

The learners just answered, *"because we are given the tip – oodles."* This was not the appropriate answer, and it shows that the previous question was not properly understood. They did not explain the answer but just agreed to that as their answer using a piece of paper which could have been one member's idea or an answer from another group. The cognitive level was still coded as interactive since they agreed on one answer, though it was not a productive co-generation of answers. Table 4.25 summarizes the analysis for question 9b.

Table 4:25

Learners' activities, cognitive level, and the image for question 9b

	Activities	Cognitive level
	Challenge, agree, brainstorming, doing other things	Interactive
Image	 *b.* Explain why it is not necessary to know the number of parts in an "oodle" to solve the problem in part *a.* we need only number of oodles	

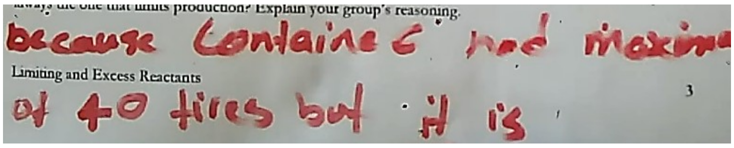
Model 2 question 10 read as follows:

> *Look back at the answers to Questions 8 and 9. Is the component with the smallest number of parts always the one that limits production? Explain your group's reasoning.*

One learner said, *"No, no, because container E had 40 tyres, but we did not make 40 cars."* The learners compared their answer with the previous question to find the answer. They did not answer the question fully by explaining that it depends on the number of parts needed to make one complete car. They seemed unsure of their response and just answered for the sake of it. The learners seemed to have been demoralized by the word "oodles" which was introduced to them in the previous question. However, their cognitive level was interactive because they agreed on the answer. Table 4.26 shows a summary of the analysis of question 10.

Table 4:26

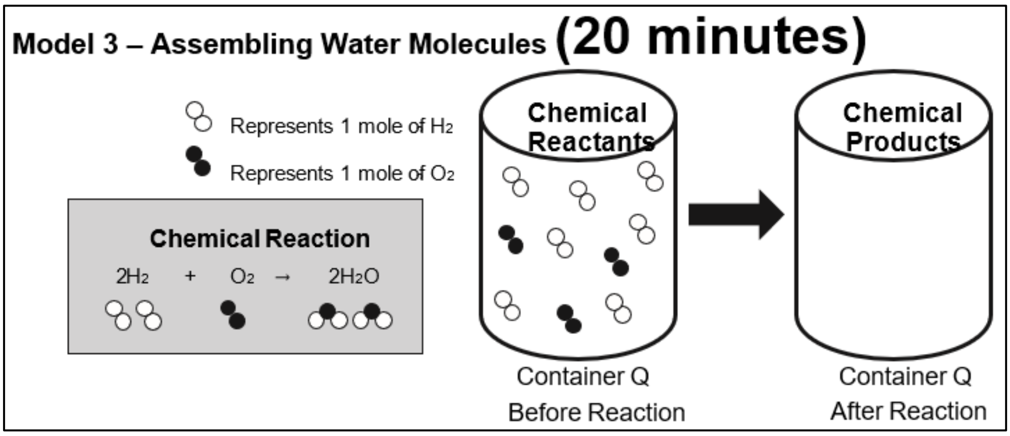
Learners' activities, cognitive level, and the image for question 10

	Activities	Cognitive level
	Elaborate, challenge, agree, compare, reason	Interactive
Image	 production? Explain your group's reasoning. because Containe E had maxim Limiting and Excess Reactants 3 of 40 tires but it is	

4.5.3 Learner responses to Model 3

Figure 4:83

The diagram showing Model 3.



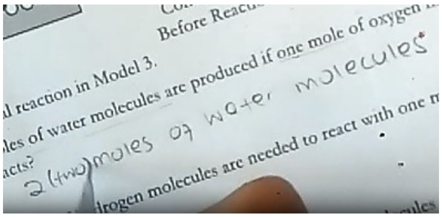
Model 3 question 11a read as follows:

> *How many moles of water molecules are produced if one mole of oxygen molecules completely reacts?*

The first learner explained, *"in each reaction we only need a single oxygen and 2 hydrogen."* To which the second learner responded, *"No, we are going to have 2 water molecules … 2 moles"*. The learners may have confused the words mole and molecule. The one who initially said "molecules" now changes to "moles" without any reason. The learners then compiled their answers as they encircle the molecules of H_2 and O_2 reacting, and the molecules of water formed using ratio technique. They did this collectively and constructively, so the cognitive level is interactive and, therefore, active learning. The learners were able to appropriately answer the question by identifying the number of water molecules produced. Table 4.27 shows a summary of the analysis of question 11a.

Table 4:27

Learners' activities, cognitive level, and the image for question 11a

	Activities	Cognitive level
	Elaborate, challenge, agree, compare, reason	Interactive
Image	 Before Reac l reaction in Model 3. les of water molecules are produced if one mole of oxygen acts? 2 (two) moles of water molecules lrogen molecules are needed to react with one m	

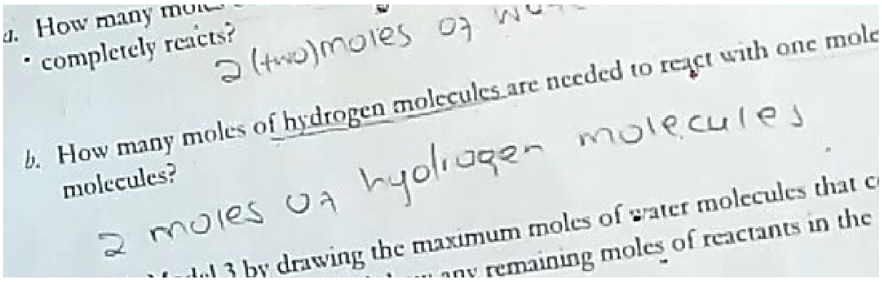
Model 3 question 11b read as follows:

> *How many moles of hydrogen molecules are needed to react with one mole of oxygen molecules?*

One learner said, *"So, we are going to have these 2 moles of hydrogen molecules to react with 1 mole of oxygen."* Another learner responded, *"Oh yeah, because each molecule of* O_2 *reacts with 2 molecules of* H_2*."* The learners did not struggle to find the pattern of the reaction between hydrogen and oxygen. They found that 2 moles of hydrogen are needed. They collectively agreed on the answer, so the cognitive level is interactive. Table 4.28 shows a summary of the analysis of question 11b.

Table 4:28

Learners' activities, cognitive level, and the image for question 11b

	Activities	Cognitive level
	Justify, elaborate, compile ideas, agree	Interactive
Image	 a. How many mol completely reacts? 2 (two) moles of wa b. How many moles of hydrogen molecules are needed to react with one mole molecules? 2 moles of hydrogen molecules odel 3 by drawing the maximum moles of water molecules that c any remaining moles of reactants in the	

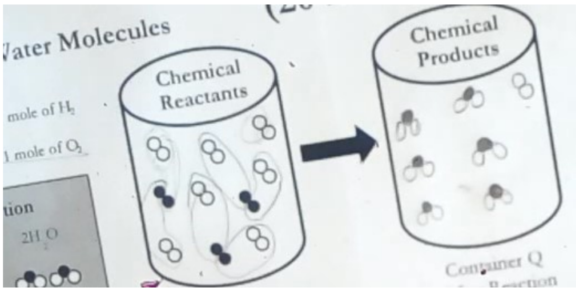
Model 3 question 12 read as follows:

> *Complete Model 3 by drawing the maximum number of moles of water molecules that could be produced from the reactants shown and draw any remaining number of moles of reactants in the container after reaction as well.*

The learners discussed the number of atoms for each water molecule by referring to the model drawn for them. After deliberating, they agreed that each water molecule has 1 oxygen atom. *"So, each water molecule has 1 oxygen and 2 hydrogens, right?",* Another learner said, *"Yes"*. They circled the 2 hydrogen atoms together with 1 oxygen atom. They did that 6 times and then drew the water molecules in the other container. The learners demonstrated an understanding of the formula of water. They worked collectively, so the cognitive level was interactive. Table 4.29 summarizes the analysis of question 12.

Table 4:29

Learners' activities, cognitive level, and the image for question 12

	Activities	Cognitive level
	Justify, elaborate, argue, compile ideas, agree, highlight	Interactive
Image		

Model 3 question 12a read as follows:

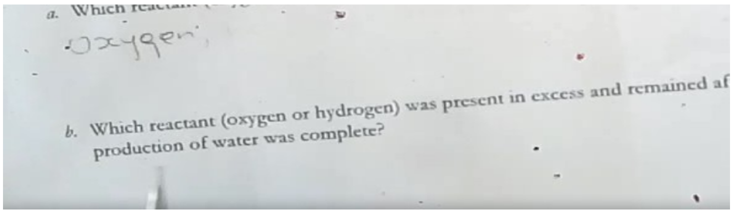
> *Which reactant (oxygen or hydrogen) limited the production of water in Container Q?*

One learner said, *"The answer is oxygen because there was a shortage of them".* Another learner said, *"No, not because there was a shortage of them."* The learners have found the answer but are now arguing about the reason why it is oxygen the limiting reactant. To get a reason was a challenge for them. *"Okay then we'll write it without a reason."*

It appears the question was not clear for the learners. The learners may have not acquired the concept "limiting reactant" though they had understood which substance is used up first. This shows that the learners had not fully grasped the meaning of 'limiting reactant'. The question could have read *"which substance was completely used up?"* The learners may have understood the question better if it was asked that way and may have answered it with reason since it was like the earlier models about the race cars in which they did well. The cognitive level was interactive since the learners shared ideas. Although there was little disagreement, they eventually had an incomplete answer. Table 4.30 summarizes the analysis of question 12a.

Table 4:30

Learners' activities, cognitive level, and the image for question 12a

	Activities	Cognitive level
	Argue, elaborate, challenge, agree, reason	Interactive
Image	 a. Which oxygen b. Which reactant (oxygen or hydrogen) was present in excess and remained af production of water was complete?	

Model 3 question 12b read as follows:

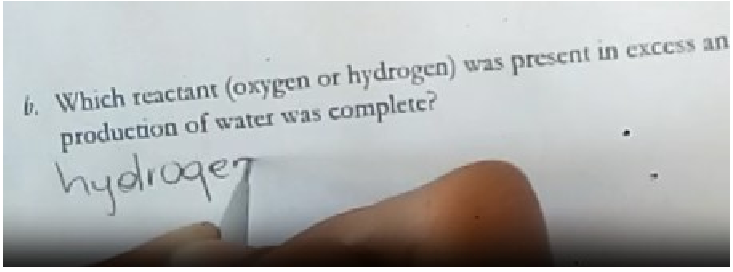
> *Which reactant (oxygen or hydrogen) was present in excess and remained after the production of water was complete?*

One learner said, "Hydrogen, the answer is hydrogen". The learners quickly identified the excess substance. They previously had difficulty finding the limiting reactant but faced no challenge in finding the excess. Excess is an easier concept as it is visible. The limiting agent is not visible and, therefore, a more abstract concept. So, it was acceptable that the learners understood 'excess' reactant but not 'limiting' reactant.

The question was extremely easy for the learners and their cognitive level was interactive since they shared knowledge and agreed on the final answer before writing down. Table 4.31 shows the summarized analysis of question 12b.

Table 4:31

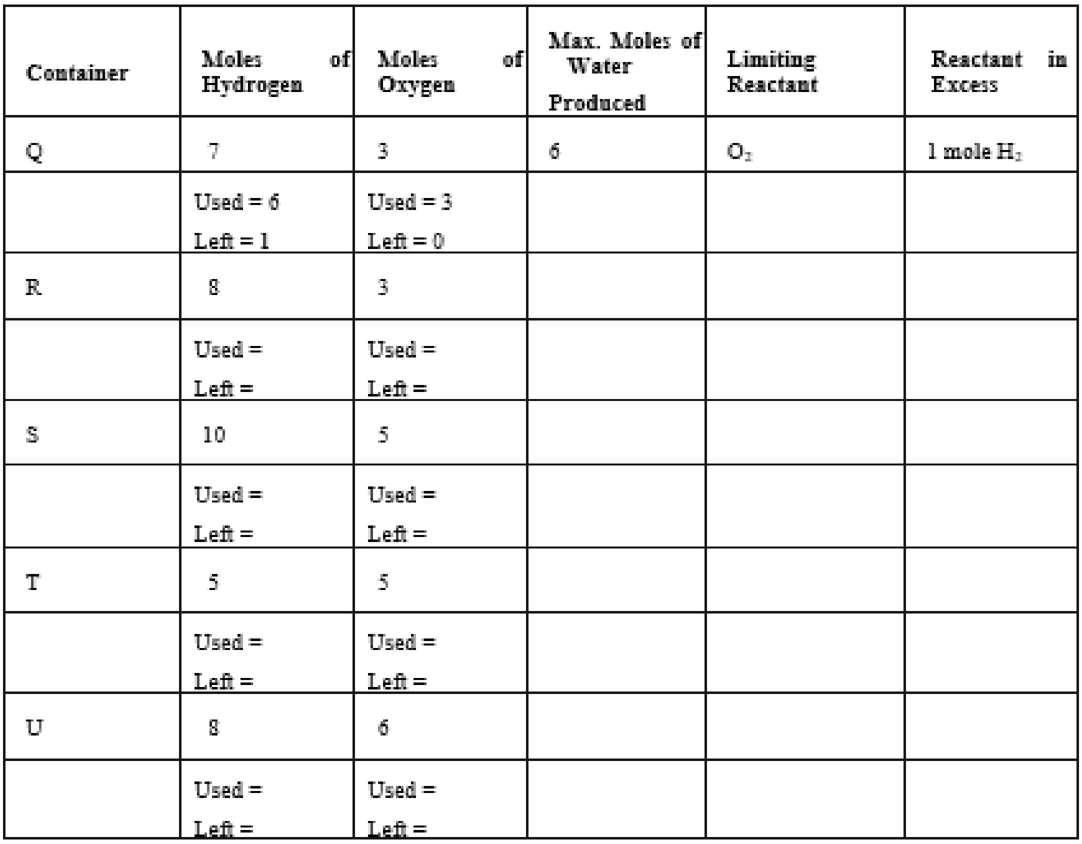
Learners' activities, cognitive level, and the image for question 12b

	Activities	Cognitive level
	Elaborate, compile ideas, agree	Interactive
Image	 b. Which reactant (oxygen or hydrogen) was present in excess an production of water was complete? hydroge	

Model 3 question 13

13. *Fill in the table below with the maximum number of moles of water that can be produced in each container (Q–U). Indicate which reactant limits the quantity of water produced—this is the* ***limiting reactant****. Also show how much of the other reactant—the* ***reactant in excess****—will be left over. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of moles of water produced and the moles of reactant in excess. Container Q from Model 3 is already completed as an example.*

$$2H_2 \quad + \quad O_2 \quad \rightarrow \quad 2H_2O$$



Container	Moles of Hydrogen	Moles of Oxygen	Max. Moles of Water Produced	Limiting Reactant	Reactant in Excess
Q	7	3	6	O_2	1 mole H_2
	Used = 6 Left = 1	Used = 3 Left = 0			
R	8	3			
	Used = Left =	Used = Left =			
S	10	5			
	Used = Left =	Used = Left =			
T	5	5			
	Used = Left =	Used = Left =			
U	8	6			
	Used = Left =	Used = Left =			

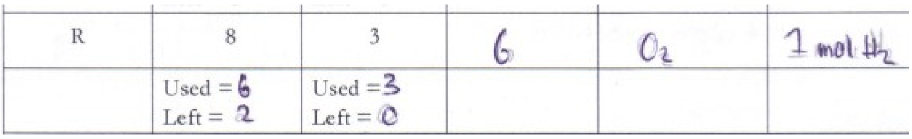
Question 13Q was given as an example to guide learners on how to respond to the questions R to U. in the following paragraphs I presented the learners' responses to these questions including their discussions.

Model 3 question 13 R

As the reader read for the group, the group members repeated what she was reading and nodded in agreement. The reader pointed to the model and the text saying, *"So, the reactant in excess is 1 mole of hydrogen, am I correct?".* The other learners echoed, *"Oh yes",* Another learner said, *"No, no, no, why?".* Another learner said, *"Because we use 6 moles of hydrogen and 3 moles of oxygen."* This was appropriate reasoning according to the mole ratio of 2:1 for the water molecule. But there was an argument between the learners as they continued to disagree. One of the learners explained, *"If you check on our paper here (pointing on the worked example container Q). If you check on our data, there are six hydrogens. 2 hydrogen is equal to 1 mol oxygen and this is also 1 mole of water formed". "If there are 7 moles of hydrogen so we have 14 of those little balls (H atoms)".* The learner who was confused said, *"Oh, I now understand … moles of oxygen are 3 so we have this (O atoms), times 3".* This was the “Aha” moment when learners discovered a hidden clue. The learners eventually agreed that because they had 3 moles of oxygen, they needed 6 moles of hydrogen. They identified that oxygen was the limiting reactant, 3 moles of water were formed, and 2 moles of hydrogen remain in excess. The learners elaborated their answer very well through long but productive arguments. They justified their ideas with careful calculations. The learners were operating at an interactive cognitive level. Table 4.32 shows the summary of the analysis of question 13R.

Table 4:32

Learners’ activities, cognitive level, and the image for question 13R

	Activities	Cognitive level
	Elaborate, highlight, compile ideas, challenge, agree, repeat, argue	Interactive
Image		

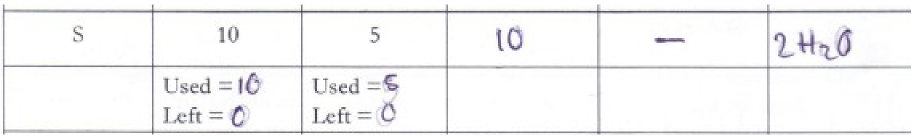
R	8	3	6	O_2	1 mol H_2
	Used = 6 Left = 2	Used = 3 Left = 0			

Model 3 question 13S

One of the learners responded, *“Oh, H_2 is the reactant in excess,”* Another said, *“H_2? I don’t understand.”* The other learner said, *“2 moles of H_2!”.* Then the other learner said, *“Oh, now I get it.”.* The other learner added that “*Moles of oxygen are 5 and so we need 10 moles of hydrogen”* Another learner said, *“so we are going to use all of them because it must be 2 as to 1”* The learners used the ratio properly and made the correct calculation to get the answer. They were, however, challenged by the fact that both reactants were used up. One of the learners said, *“In this case, there is no limiting reactant”.* Another said, *“they are both limiting reactants because they are both used up”.* The other learner asks, *“so what’s a limiting reactant?”* This shows that the learners reflected on the concept of limiting reactant. The learners agreed that they will use all 10 moles of hydrogen and leave zero. They are using 5 moles of oxygen, also leaving zero. They identified that 5 moles of water are formed. The learners did very well, and their answer is justified with appropriate calculations. The learners were working at the interactive cognitive level. Table 4.33 shows a summary of the analysis of question 13S.

Table 4:33

Learners' activities, cognitive level, and the image for question 13S

	Activities	Cognitive level
	Elaborate, highlight, compile ideas, challenge, agree, repeat, argue	Interactive
Image		

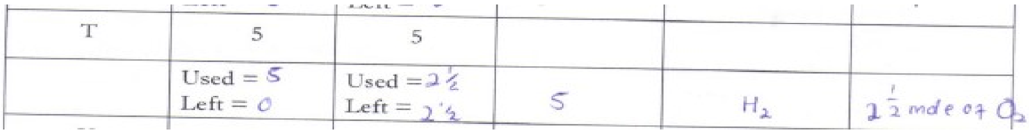
S	10	5	10	—	$2H_2O$
	Used = 10 Left = 0	Used = 5 Left = 0			

Model 3 question 13T

The learners quickly identified the limiting reactant in this question. *"I feel the limiting reactant is hydrogen".* Another learner said, *"We are going to use 5 moles of hydrogen and have zero left and we are going to…"* The learners then got stuck because the ratio must be 2:1 and in this case, if they use 5 moles of hydrogen then they must use 2,5 moles of oxygen. The learners debated whether to use 2 or 2,5 moles of oxygen. *"Is there anything like 2,5 moles?"* meaning is it possible to have a decimal number of moles. The learners finally agreed to 2,5 moles and appropriately calculated the excess moles and the number of moles of water produced. Their thinking was at the interactive cognitive level. Table 4.34 summarizes the analysis for question 13T.

Table 4:34

Learners' activities, cognitive level, and the image for question 13T

	Activities	Cognitive level
	Elaborate, highlight, compile ideas, challenge, agree, argue	Interactive
Image		

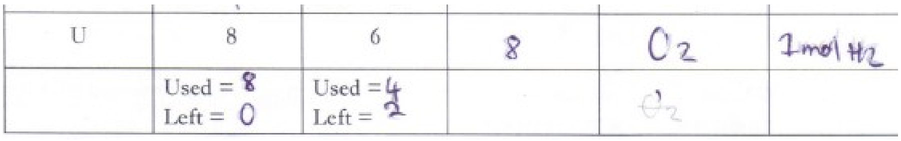
T	5	5			
	Used = 5 Left = 0	Used = $2\frac{1}{2}$ Left = $2\frac{1}{2}$	5	H_2	$2\frac{1}{2}$ mole of O_2

Model 3 question 13U

The learners quickly responded, *"We use all the 8 moles of hydrogen and are left with zero. The limiting reactant is hydrogen because we have 12 oxygen atoms."* The learners elaborated their answer explaining how they get the limiting and the excess reactant. They appropriately calculated the number of moles of water produced. Each time they agreed before compiling their answers. They argued but eventually agreed on one common answer for the group. This was at the interactive cognitive level. Table 4.35 shows the summary of the analysis of question 13U.

Table 4:35

Learners' activities, cognitive level, and the image for question 13U

	Activities	Cognitive level
	Elaborate, highlight, compile ideas, challenge, agree, repeat, argue	Interactive
Image		

U	8	6	8	O_2	1mol H_2
	Used = 8 Left = 0	Used = 4 Left = 2		O_2	

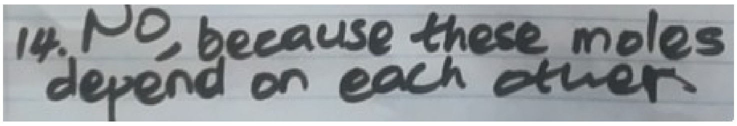
Model 3 question 14 read as follows:

> *Look back at Questions 12 and 13. Is the reactant with the smaller number of moles always the limiting reactant? Explain your group's reasoning.*

The learners quickly responded to this question. *"No, in the previous question hydrogen was the limiting reactant but it was 8 moles and oxygen had 6 moles."* Another learner answered, *"Oh yeah, it depends"*. The learners appropriately observed that it is not always the one with the lowest number of moles that becomes the limiting reactant. But they did not give a reason to generalize the answer. Instead, they used examples they had done as observations. They reflected appropriately on the previous work. Once they agreed, the learners compiled the answers, which were at the interactive level. Table 4.36 shows the summary of the analysis of question 14.

Table 4:36

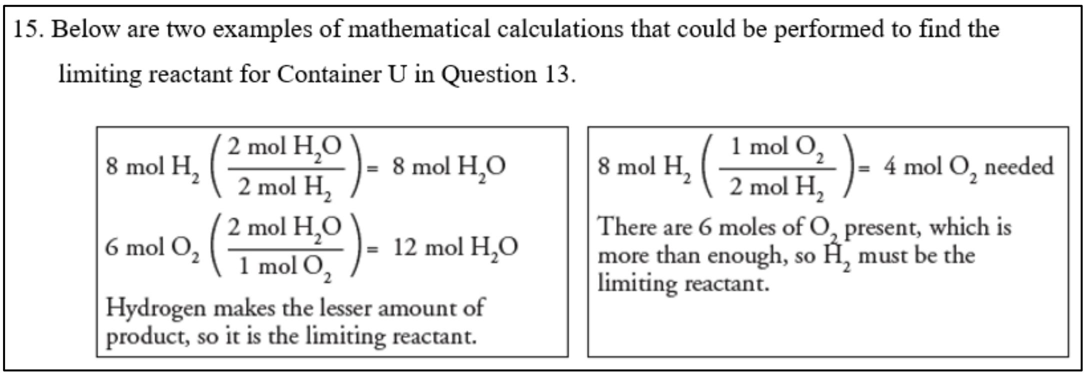
Learners' activities, cognitive level, and the image for question 14

	Activities	Cognitive level
	Elaborate, reflect, compile ideas challenge, agree, reason	Interactive
Image	 14. NO, because these moles depend on each other.	

4.5.4 Learner responses to Model 4

Figure 4:84

The scenario showing Model 4.



15. Below are two examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13.

$$8 \text{ mol } H_2 \left(\frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2}\right) = 8 \text{ mol } H_2O$$

$$6 \text{ mol } O_2 \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}\right) = 12 \text{ mol } H_2O$$

Hydrogen makes the lesser amount of product, so it is the limiting reactant.

$$8 \text{ mol } H_2 \left(\frac{1 \text{ mol } O_2}{2 \text{ mol } H_2}\right) = 4 \text{ mol } O_2 \text{ needed}$$

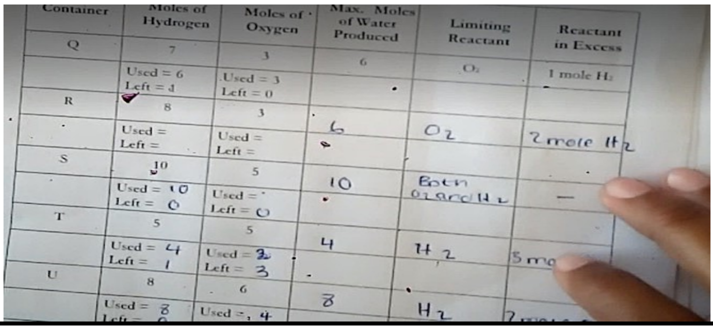
There are 6 moles of O_2 present, which is more than enough, so H_2 must be the limiting reactant.

Question 15

The group members listened attentively as the question was read. When the learner read *"… in container U question 13"*, the reader quickly asks the group *"do you remember container U question 13? Or must I remind you?"*. To this, the group members indicated they did not remember, saying *"yes remind me please"*. This showed that learners had already encountered a challenge. The reader brought back the worksheet where they had done question 13. This showed that learners want to learn starting from what they already know and building towards new knowledge. The group then remembered and reflected on their prior knowledge and agreed to move on after the elaboration of the question. This shows that the learners worked as a team and interacted even before getting into the actual question to be answered. After this, the question was read again as the member listened on. Table 4.37 shows a summary of the analysis of question 15.

Table 4:37

Learners' activities and cognitive level on question 15

	Activities	Cognitive level
	Challenge, elaborate, agree, reflection	Interactive
Image		

Container	Moles of Hydrogen	Moles of Oxygen	Max. Moles of Water Produced	Limiting Reactant	Reactant in Excess
Q	7	3	6	O_2	1 mole H_2
	Used = 6 Left = 1	Used = 3 Left = 0			
R	8	3			
	Used = Left =	Used = Left =	6	O_2	2 mole H_2
S	10	5			
	Used = 10 Left = 0	Used = Left = 0	10	Both O_2 and H_2	—
T	5	5			
	Used = 4 Left = 1	Used = 3 Left = 3	4	H_2	5 mo
U	8	6			
	Used = 8	Used = 4	8	H_2	2

After reflecting on question 13, the reader started to read the question again and all the learners were listening attentively. These behaviours show that they operated in the passive level of the ICAP framework at this stage.

At that point, the teacher intervened, asking the group, *"what happened here?"* because some group members had moved away from their group and only two members were left in the group of four. One of the learners responded, *"they disappeared"*. The teacher called the learners back to their group. The possible reason for the learners going away is that they may have been uncomfortable working in that group, or they went to consult for the answers. This shows the special responsibility that a POGIL facilitator must take when grouping learners.

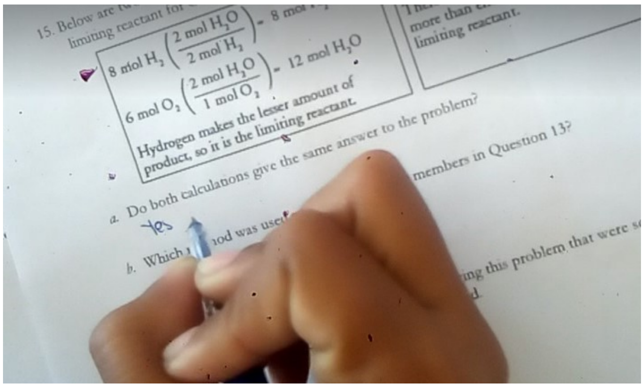
Model 4 question 15a read as follows:

> *Do both calculations give the same answer to the problem?*

After reading this question, the reader seemed challenged because she said, *"you may explain … you may explain"*. The learners brainstormed for a while, comparing the two methods. One of the learners then said, *"our answer is Yes"*. To this, the second learner said, *"yes, because the first method says hydrogen is the limiting reactant and the second also says hydrogen is the limiting reactant"*. The whole group agreed and then compiled their answer onto the worksheet. The group co-generated the answer, so they were operating on the interactive level. Table 4.38 shows a summary of the analysis of question 15a.

Table 4:38

Learners' activities and cognitive level on question 15a

	Activities	Cognitive level
	Challenge, agree, compile brainstorm, compare	Interactive
Image		

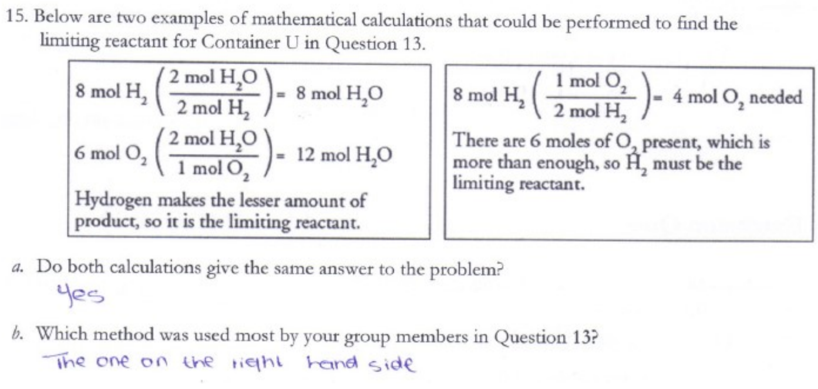
Model 4 question 15b read as follows:

Which method was used most by your group members in question 13?

One of the learners said, *"So, we used method A".* Another learner said, *"Ooh yeah we used method A"*. The learners quickly identified the method like the one they used. The learners had therefore compared the two methods to the method they previously used and agreed on the answer, which they wrote on the worksheet. The learners were operating at the interactive cognitive level because they were working as a group and agreeing on one answer. They used the collective "we", as in "we used" as opposed to "I used". Table 4.39 shows a summary of the analysis to question 15b.

Table 4:39

Learners' activities, cognitive level, and the image for question 15b

	Activities	Cognitive level
	Challenge, agree, compile brainstorm, compare	Interactive
Image	 15. Below are two examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13. $8\ \text{mol}\ H_2 \left(\frac{2\ \text{mol}\ H_2O}{2\ \text{mol}\ H_2}\right) = 8\ \text{mol}\ H_2O$ $6\ \text{mol}\ O_2 \left(\frac{2\ \text{mol}\ H_2O}{1\ \text{mol}\ O_2}\right) = 12\ \text{mol}\ H_2O$ Hydrogen makes the lesser amount of product, so it is the limiting reactant. $8\ \text{mol}\ H_2 \left(\frac{1\ \text{mol}\ O_2}{2\ \text{mol}\ H_2}\right) = 4\ \text{mol}\ O_2$ needed There are 6 moles of O_2 present, which is more than enough, so H_2 must be the limiting reactant. a. Do both calculations give the same answer to the problem? Yes b. Which method was used most by your group members in Question 13? The one on the right hand side	

Model 4 question 15c read as follows:

Which method seemed easier and why?

The reader read the question while the group members listened attentively. This was the passive stage of cognition.

Soon after reading, one of the learners responded, *"method B is the easiest, right?"* Another learner also responded, *"Yes, because it goes straight to the answer"*. The learners in this instant compare the two methods and found method B to be the easiest. It means the learners analysed how they would use any of the two methods. They observed that method A was long and increased the possibility of them making a mistake. They preferred the quicker method over the long one, which was a wise justification for the selection of their answer. They reasoned that *"you don't have to calculate the moles of hydrogen and oxygen. You just go straight to the answer"*. Table 4.40 shows a summary of the analysis of question 15b.

Table 4:40

Learners' activities, cognitive level, and the image for question 15b

	Activities	Cognitive level
	Agree, compile, compare, justify, reason	Interactive
Image	 c. Which method seems "easier," and why? The method on the right hand side because it only has one step.	

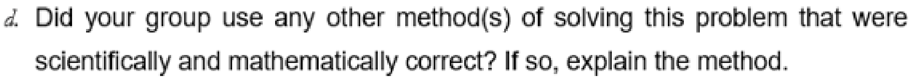
Model 4 question 15d read as follows:

> *Did your group use any other method(s) of solving this problem that were scientifically and mathematically appropriate? If so, explain the method.*

As one learner read to the group, only one member was listening. Some members had become distracted by other things and the teacher asked, *"what's going on here?"* to which the learners responded that *"they have swopped the groups"*. This shows that the learners were not happy working in their previous groups. Great care should be taken in forming groups because sometimes the required work may not be done if learners are not comfortable with the group, they are in. At this stage, half of the group was in the passive cognitive stage because of reading and listening while the other half was distracted and, therefore, disengaged. Table 4.41 summarizes the analysis of question 15d.

Table 4:41

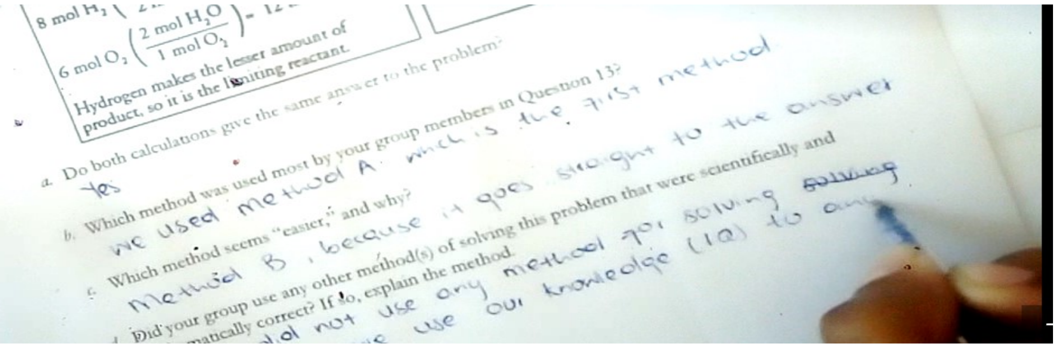
Learners' activities, cognitive level, and the image for question 15d first attempt

	Activities	Cognitive level
Image	Reading, listening, doing other things  d. Did your group use any other method(s) of solving this problem that were scientifically and mathematically correct? If so, explain the method.	Passive, disengaged

After initially being disengaged, the learners discussed and agreed that they did not use any method to find the answers. *"So, we didn't use any method?".* Another responded, *"Yeah, we didn't use any method, we used our IQ to solve the problem"*. While another learner said, *"we used our natural knowledge and primary equation to answer the question"*. Though the learners agreed that they did not use any method, they were wrong. They initially said they used method A on 15b, but changed their minds, saying they didn't use any method. The learners used method A, but the difference was that in answering question 13 they were not showing the work, so it was done mentally. They did not seem to reflect on what they did as compared to method A. The learners did not realize that there was a pattern in how they solved question 13. The pattern had crystalised in their minds and, thinking that it came naturally, did not take time to analyse it. The cognitive level is still at the interactive level because the learners are co-generating knowledge. Table 4.42 shows the analysis of question 15d's second attempt.

Table 4:42

Learners' activities, cognitive level, and the image for question 15d second attempt.

	Activities	Cognitive level
	Agree, compiling answers, justify	Interactive
Image		

8 mol H_2

6 mol $O_2 \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2} \right) = 12$

Hydrogen makes the lesser amount of product, so it is the limiting reactant.

a. Do both calculations give the same answer to the problem?

Yes

b. Which method was used most by your group members in Question 13?

we used method A which is the first method

c. Which method seems "easier," and why?

Method B, because it goes straight to the answer

d. Did your group use any other method(s) of solving this problem that were scientifically and matically correct? If so, explain the method.

ol not use any method for solving ~~solving~~

e use our knowledge (IQ) to an

Model 4 question 16 read as follows:

16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H_2 and 5.0 g of O_2.

Model 4 question 16a1 read as follows:

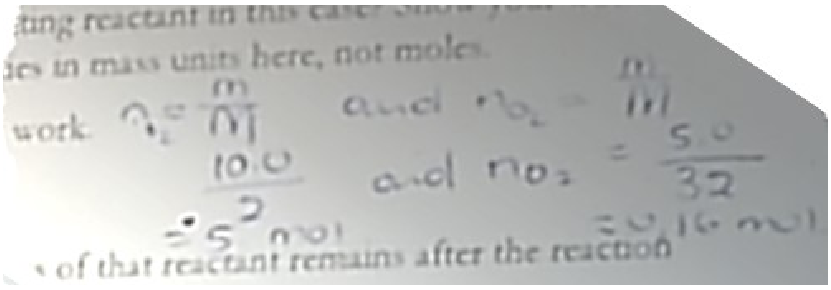
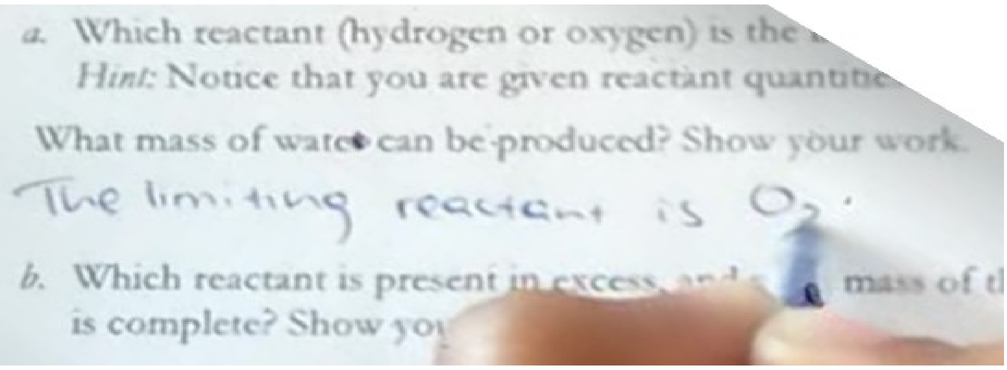
Which reactant (hydrogen or oxygen) is the limiting reactant in this case? Show your work.

The learners did not take the time to read this question properly. Instead, they started by saying, *"so here we have to find the number of moles of oxygen and hydrogen, right"* and someone responded *"yeah"*. Then they started doing the calculation. One learner said, *"So, we have 10g of hydrogen and the formula is n =* $\frac{m}{M}$*,* = $\frac{10g}{2g}$ *, = 5 moles hydrogen and we have 5g of oxygen so n =* $\frac{m}{M}$*,* = $\frac{5g}{32g}$ *, = 0,16 moles oxygen".*

The learners used the formula appropriately, thereby justifying their calculation. They did elaborate as they answered collectively, communicating with each other by asking, *"what is 16x2?"* and some then responding, *"32"*. They compiled their answers in the calculation and reached a conclusion based on their answers. "The limiting reactant is oxygen, right? Because it has the lowest number of moles". They reached this conclusion by comparing the number of moles of hydrogen and oxygen from their calculations. Although they found the correct limiting reactant, their reasoning was inappropriate. The learners failed to reflect on their answer to question 14, that the substance with the lowest number of moles is not necessarily the limiting substance. The learners are on the interactive cognitive level. Table 4.43 shows a summary of the analysis of question 16a1.

Table 4:43

Learners' activities, cognitive level, and the image for question 16a1

	Activities	Cognitive level
	Agree, compiling answers, justify, elaborate, compare	Interactive
Image	 ting reactant in this case? Show you ies in mass units here, not moles. work $n_{2} = \frac{m}{M}$ and $n_{O_2} = \frac{m}{M}$ $\frac{10.0}{2}$ and $n_{O_2} = \frac{5.0}{32}$ $= 5$ mol $= 0,16$ mol of that reactant remains after the reaction  *a.* Which reactant (hydrogen or oxygen) is the *Hint:* Notice that you are given reactant quantitie What mass of water can be produced? Show your work. The limiting reactant is O_2. *b.* Which reactant is present in excess, and mass of t is complete? Show yo	

Model 4 question 16a2 read as follows:

What mass of water can be produced? Show your work.

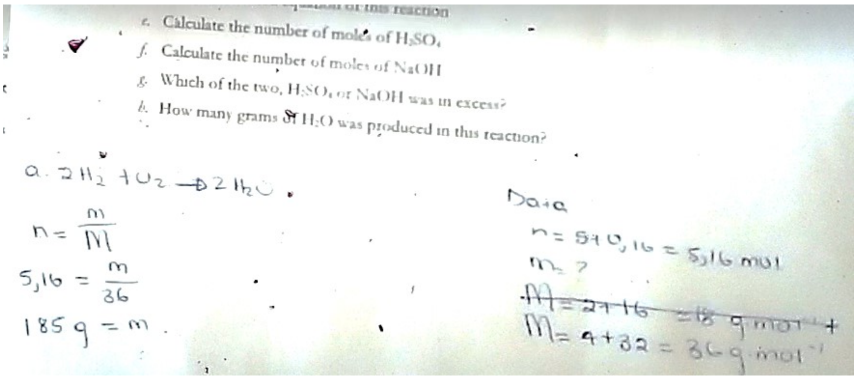
The learners read through the question and quickly started to answer. One learner said, *"We are going to use the number of moles. Let's have our data". n = 5 moles Hydrogen + 0,16 moles oxygen = 5,16 moles H_2O and we do not have the mass. The molar mass of H_2O is 2+16 = 18g/mole."* Another learner said, "remember the coefficient from the equation" and someone else responded, *"Oh, I am confused."* They agreed on 2x2 + 2x16 = 36g/mole of H_2O and went on to substitute into the formula $n = \frac{m}{M}$,

$5{,}16 = \frac{m}{36}$, m = and then *"Eish guys, ha no"*.

The learners tried to get the number of moles of water by adding the moles of hydrogen and oxygen to get 5,16 moles. The method agreed on was inappropriate. They used the appropriate formula to calculate the mass of water and it seemed that the learners did not know if this was correct or not. Only one learner said “eish guys, no” while the rest did not respond. During this work, some group members were not paying attention and, therefore, disengaged. The two learners who were busy with the question decided to give up and move one to the next question. Although the two learners remaining in the group thoroughly elaborated on their calculation, their method was inappropriate. They lacked support but they justified their incorrect method mathematically and agreed as they compiled their answers. A lot of time was wasted because not all learners paid attention to the activity. There was no appropriate answer to this question and there was little co-generation. The cognitive level of these learners was interactive with regards to the two co-operating learners and disengaged with regards to the other two. Table 4.44 summarizes the analysis of question 16a2.

Table 4:44

Learners’ activities, cognitive level, and the image for question 16a2

	Activities	Cognitive level
	Agree, compiling answers, justify, elaborate, compare	Interactive
Image	 e. Calculate the number of moles of H_2SO_4 f. Calculate the number of moles of NaOH g. Which of the two, H_2SO_4 or NaOH was in excess? h. How many grams of H_2O was produced in this reaction? a. $2H_2 + O_2 \rightarrow 2H_2O$. $n = \frac{m}{M}$ $5{,}16 = \frac{m}{36}$ $185\ g = m$. Data $n = 5 + 0{,}16 = 5{,}16$ mol $m = ?$ ~~$M = 2 + 16 = 18\ g\ mol^{-1}$~~ $M = 4 + 32 = 36\ g \cdot mol^{-1}$	

Model 4 question 16b read as follows:

16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H_2 and 5.0 g of O_2.

b. Which reactant is present in excess, and what mass of that reactant remains after the reaction is complete? Show your work.

Soon after reading the question, the reader lamented, *"because our answer to 16a is wrong … we can't do this"*. The learners admitted that their answer to question 16a was incorrect, but they had not told the teacher. This indicates that the learners were not well experienced in learning using POGIL. They were not aware that they should ask the teacher when they encounter challenges. The cognitive level, in this case, is passive because they just read the question and the other listened and did nothing else. The learners were in the passive mode for a while before reverting to the previous question 16a2.

Second attempt to model 4 question 16a2

Question: What mass of water can be produced? Show your work.

After realizing that they could not proceed with the activity before answering question 16a2, the learners attempted the question a second time. Some group members were not attentive to the question. One learner said, *"So, we are only going to use the molar mass of* O_2 *because it is the limiting reactant?"*. A second learner responded, *"yes, we use the ratio of*

O_2*:* H_2O*" is 1: 2 from the equation,*

0,16: x from the data"

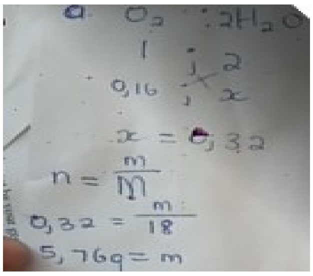
and other learner shouted, *"we cross-multiply, so x = 2x0,16" "So, x = 0, 32 moles of* H_2O*.*

To get the mass of water, we use the formula $n = \frac{m}{M}$*,* $0{,}32 = \frac{m}{18}$*, m = 0,32 x 18 = 5,76g"*

Although the learners jumped back to a previous question, they elaborated on it quite well. They used the appropriate ratio to compare and find the number of moles of H_2O. They proceeded and did well to use the appropriate formula and substituted appropriately to find the correct mass of H_2O. They gave proper justification in each case and compiled their answers cooperatively. Some group members may have snuck away to consult with other groups or with the teacher or had worked it out separately from the rest of the group members. Either way, what they did is acceptable with POGIL because the basis of inquiry is that the learners should seek information they do not have. Table 4.45 shows a summary of the analysis of question 16a2.

Table 4:45

Learners' activities, cognitive level, and the image for question 16a2 second attempt

	Activities	Cognitive level
	Agree, compiling answers, justify, elaborate, compare	Interactive
Image		

Model 4 question 16b read as follows:

> *Which reactant is present in excess, and what mass of that reactant remains after the reaction is complete? Show your work.*

The manager read the question while the rest of the group listened. They were operating on the passive cognitive level. Soon after reading, one learner responded, *"the reactant in excess is hydrogen."* To which the other responded, *"why is that?"* and the answer came from the third learner, *"because it has the highest number of moles than oxygen."* Yet another learner added that *"they want the calculation, not the reason. They want us to calculate the remaining mass."* The learners were challenged again by this question and switched to the next question. *"Reactant in excess is hydrogen … the reason being?"* Their answer that hydrogen was in excess was appropriate, but they could not calculate the mass of the hydrogen that remained in excess. They again did not ask the teacher for assistance and jumped the question. The learners are at the interactive cognitive level because they exchanged ideas. However, they did not answer the question correctly.

Extension Questions

Model 4 extension question (a) read like this:

18cm^3 of 0,25moldm^{-3} solution of H_2SO_4 reacted with 23cm^3 of NaOH of concentration 0,35 moldm^{-3}.

a. *Write a balanced equation of this reaction.*

The group was disengaged at this stage. Only one learner worked on the question. The learner jumped to answer the question before carefully reading the entire question. As a result, she did not follow the instructions on the question. After a while, she realized the first question and said, “so we’re supposed to balance and write the balanced equation”. She wrote down:

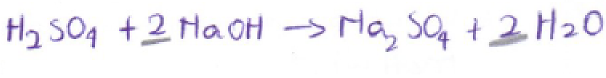
$H_2SO_4 + NaOH \longrightarrow NaSO_4 + H_2O$

She did not balance it correctly, as the formula for sodium sulphate is incorrect. At this stage, the cognitive level was constructive since she was generating her own ideas.

A moment later, the rest of the group members reappeared and asked, *“which question are we?”* The reply was *“… here, I haven’t balanced the equation yet”*. The response was *“put 2 on the NaOH and another 2 on the water then it will balance.”* Eventually, the equation was balanced after correcting the formula for sodium sulphate. The cognitive level for this first extension question was interactive since learners shared their knowledge in getting the answer as shown in table 4.46.

Table 4:46

Learners’ activities, cognitive level, and the image for third extension question

	Activities	Cognitive level
	justify, elaborate, reflection, challenge	Interactive
Image	 $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$	

Model 4 extension question (b) read like this:

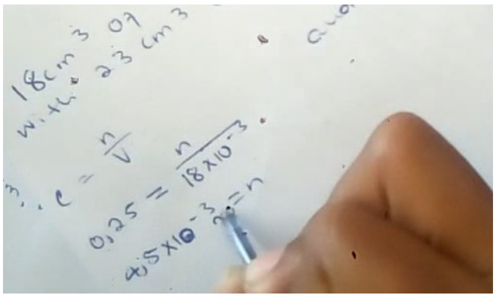
18cm^3 of 0,25moldm^{-3} solution of H_2SO_4 reacted with 23cm^3 of NaOH of concentration 0,35 moldm^{-3}.

b. Calculate the number of moles of H_2SO_4.

The reader read the question, but it appears like there was no one listening to her. She started copying the question and reading it aloud, *"so the formula is* $c = \frac{n}{V}$ *so we have 0,25moles…. So,* $0{,}25 = \frac{n}{18x10-3}$ *;* $n = 4{,}5x10^{-3}$ *moles* H_2SO_4*.* The learner who did the first question appropriately completed this question on her own. The rest of the group members were silent or had moved away. Her actions were constructive although not interactive. The rest of the group members were doing other things or discussing other question off-camera. Figure 4.47 shows the response.

Table 4:47

Learners' activities, cognitive level, and the image for first extension question

	Activities	Cognitive level
	justify, copy, elaborate, reflection, challenge, doing other things,	Constructive, disengaged
Image		

Model 4 extension question (c) read like this:

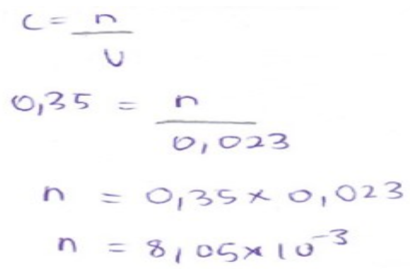
18cm^3 of 0,25moldm^{-3} solution of H_2SO_4 reacted with 23cm^3 of NaOH of concentration 0,35 moldm^{-3}.

c. Calculate the number of moles of NaOH.

The group was working cooperatively at this stage. One learner asked, “We use the same formula?” Another responded saying, “Yes, it is the same method we use.” Then they started writing the formula, “c= $\frac{n}{V}$ so 0,35moles…. So, 0,35 = $\frac{n}{23x10-3}$; n = 8,05x10^{-3} moles”. The learners did the appropriate substitution and got the correct answer. They worked as follows. Table 4.48 shows learners’ response to extension question (c)

Table 4:48

Learners’ activities, cognitive level, and the image for extension question (c).

	Activities	Cognitive level
	justify, elaborate, reflection, challenge, argue	Interactive
Image	 $c = \frac{n}{v}$ $0,35 = \frac{n}{0,023}$ $n = 0,35 \times 0,023$ $n = 8,05 \times 10^{-3}$	

Model 4 extension question (d) read like this:

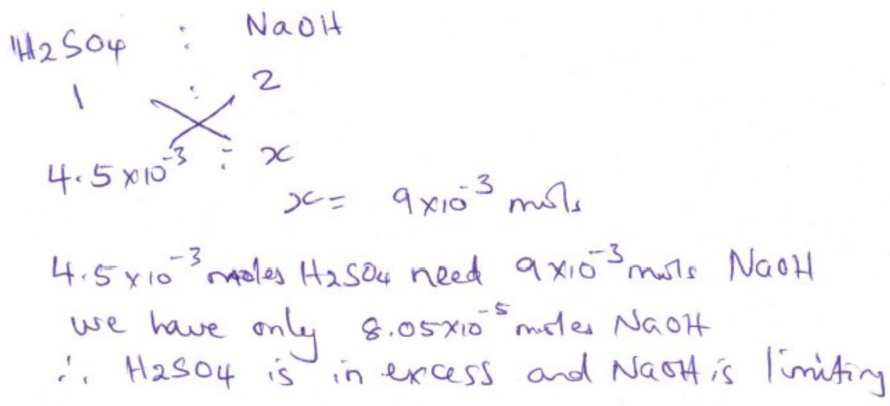
18cm^3 of 0,25moldm^{-3} solution of H_2SO_4 reacted with 23cm^3 of NaOH of concentration 0,35 moldm^{-3}.

d. *Which of the two, H_2SO_4 or NaOH was in excess?*

The learners were initially challenged by the question and disengaged for a while. Later, they came back to the question saying *“this is simple guys, we have H_2SO4 reacting with NaOH. What is the ratio*?” The other learner said, *“it’s 1:2”.* The learners agreed to use the ratio to identify the limiting reactant. The learners went on to write down the substances sulphuric acid and sodium hydroxide. They put the ratios underneath and used the ratio technique to calculate the number of moles of NaOH needed. After the calculation, they reasoned that the number of moles of NaOH needed is greater than the available number of moles. They appropriately concluded that sulphuric acid was in excess and sodium hydroxide was the limiting reactant. Table 4.49 shows a summary of the analysis of extension question d.

Table 4:49

Learners' activities, cognitive level, and the image for extension question (d)

	Activities	Cognitive level
	Reading, listening, challenge, agree, reason	Passive, interactive
Image	 H_2SO_4 : NaOH 1 : 2 4.5×10^{-3} : x $x = 9 \times 10^{-3}$ mols 4.5×10^{-3} moles H_2SO_4 need 9×10^{-3} mols NaOH we have only 8.05×10^{-5} moles NaOH ∴ H_2SO_4 is in excess and NaOH is limiting	

Model 4 extension question (e) read like this:

18cm^3 of 0,25moldm^{-3} solution of H_2SO_4 reacted with 23cm^3 of NaOH of concentration 0,35 moldm^{-3}.

e. *How many grams of H_2O was produced in this reaction?*

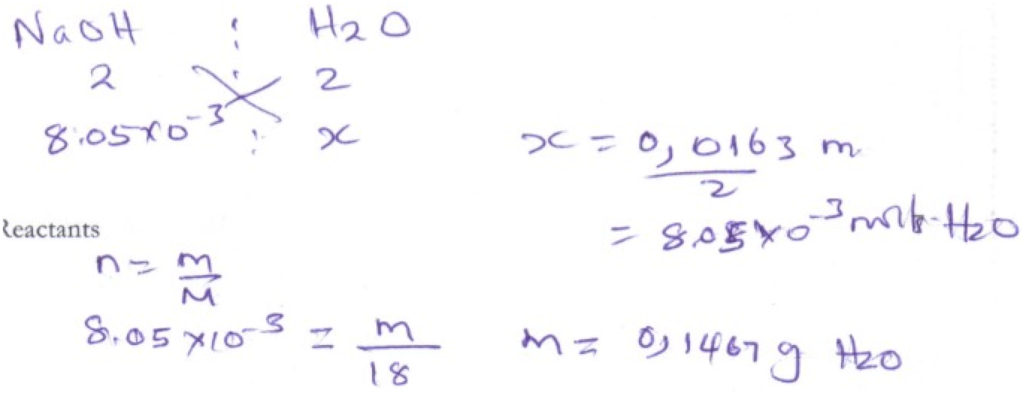
The calculation for this question was done by only three groups. One of the groups asked the question, *"which moles do we use here?"* A learner responded, *"the moles of sulphuric acid from question (b)".* The other learner said, *"Really? Because it is in excess right?"* Yet another learner argued that, *"No, we must use the moles of the limiting reactant".* The rest of the learners said, *"Oh yes, the limiting reactant limits the number of moles produced."* It appears that at this stage, the learners in this particular group had mastered the concept of a limiting reactant. The learners showed awareness around when to use the excess or the limiting reactant. Thus, their understanding of the concept had reached the application stage of the learning cycle (section 2.5.1).

The learners proceeded to use the ratios of NaOH: H_2O which was 2:2 from the balanced equation. They correctly calculated the number of moles of H_2O and found $8.05x10^{-3}$ moles. Thereafter they used the formula n= $\frac{m}{M}$, did appropriate substitution and got the correct answer of 0,1467g.

The discussion of the learners and their development of the response suggests that they were working at the interactive cognitive level. They constructed knowledge as a group. Table 4.50 shows summary of the analysis of extension question (e)

Table 4:50

Learners' activities, cognitive level, and the image for extension question (e)

	Activities	Cognitive level
	Reading, listening, argue, agree, reason	Interactive
Image	 NaOH : H_2O 2 : 2 8.05×10^{-3} : x $x = \frac{0,0163\ m}{2}$ $= 8.05\times10^{-3}$ mol H_2O Reactants $n = \frac{m}{M}$ $8.05\times10^{-3} = \frac{m}{18}$ $m = 0,1467$ g H_2O	

4.5.5 Discussion of intervention results

The analysis of the intervention was done with the aid of ATLAS.ti software for qualitative data analysis. The videos recorded during the intervention were loaded onto the software. Code groups which were previously prepared following the modified ICAP framework were used to characterise events that happened during the lessons (chapter 2 describes the ICAP framework modified to ICAPD for the current study). The summarized findings of all the activities of the learners during the intervention are tabled below. The code represents the activity of the learners, the frequency represents the number of times the activity was noticed, and the code groups represent the classification of the activity according to the ICAPD framework. Some of the actions of the learners such as “match” or “absentminded” which were not noticed during the analysis were therefore removed from the table of results to focus on what was observed. Table 4.51 shows a summary of the learner’s engagement from the video analysis of some of the selected videos based on the ICAPD framework.

Table 4:51

Video analysis of the intervention adapted from the ICAP framework.

Learner behaviour	**Frequency**	**Code Groups**
Copy	1	Active
Highlight	1	Active
Repeat	1	Active
Brainstorming	7	Constructive
Reason	5	Constructive
Doing other things	6	Disengaged
Agreement	33	Interactive
Aha moment	2	Interactive
Arguments	14	Interactive
Challenge	21	Interactive
Comparing	6	Interactive
Compiling ideas	30	Interactive
Elaborate	29	Interactive
Justify	21	Interactive
Reflection	11	Interactive
Listening to reader	35	Passive
Reading for group	36	Passive

The passive level, as indicated on the table, was mainly because learners were working in a group. So, the reader was supposed to read the question for the group and the whole group was supposed to listen to the reading. This was consistent with the cooperative learning characteristic of POGIL. Each question was read and listened to in the same way except for the one noticed occasion when the reader was reading without anyone listening to her because they were distracted.

Disengagement was noticed on six occasions when learners were doing other things not related to the activity at hand. It must be stressed that it was not clear if the learners were really disengaged or rather working on the problem off camera. The camera could not record what they were doing at those moments. There is a possibility they may have been working because the learners would at times come up with the answer to the question. Table 4.53 was produced from table 4.52 as a summary of the findings based on the ICAPD framework.

Table 4:52

Summary of results for video analysis of the intervention

Cognitive level	Number of times
(I) Interactive	167
(C) Constructive	12
(A) Active	3
(P) Passive	71
(D) Disengaged	6

The active level of engagement consists mainly of hands-on activities such a practical activity or physical projects. In this case, the activities were written work which only had a few areas for active work such as copying, highlighting or repeating. As a result, the active level was not prevalent in the observed current class activities.

The constructive level focuses on the state of construction of knowledge in the mind of the learner and the development of mental constructs in the mind of the learner. In this case the ICAPD framework considered the constructive level to be when mental models were developed by an individual learner. Such actions were observed in the current study when learners were brainstorming, and sometimes reasoning to defend their answer. Examples of working at the constructive level could have been displayed during the intervention but because the learners worked as groups, all the constructive actions translated into the interactive level.

The interactive level is composed of all group-related collective actions done by learners as they co-generate knowledge. The intervention during this study was characterized by collective work. The learners literally thought as teams and spoke their ideas to the group without doing anything else separately apart from the few occasions mentioned earlier. As a result, the activities of the learners were collective and fell into the interactive level. They did not have discussions like *"what did you do?"* but rather *"what do you think?"*. They worked at the same station and made mistakes, faced challenges, corrected each other, and elaborated on their answers collectively. They built upon each other's ideas and moulded the answers until perfect answers were produced. They achieved more as a team than they would have been able to do individually.

The POGIL intervention witnessed predominantly interactive, constructive, and active levels of engagement. These fall under the active learning method. During active learning, the learners are performing high order thinking skills such analysis, synthesis, critical thinking, and problem solving. This was evident in the intervention when learners analysed questions and solved challenging questions by brainstorming and justifying their ideas. They did not give answers without providing reasons for why they thought it was the appropriate answer. Such a method of teaching is active in the sense that learners pay close attention to the classwork and think deeply and respond with justification as they elaborate on their responses as a team. Learners collectively generated knowledge, and each member of the group partook in the discussion and actively developed understanding. This approach is a result of the POGIL method where carefully designed worksheets guided learners through a series of activities that helped them to develop their own understanding using reason. The teacher facilitates and guides learners when they get stuck but don't provide them with the answers. Instead, they provide guiding questions that lead learners to the answers so that they own the knowledge they develop. This was evident during the intervention, which was far removed from the traditional teacher-centred approach as the teacher was rarely involved in the activities done by the learners except for those few moments mentioned previously.

On one occasion, I noticed that the teacher's presence as they came to check on the group, seemed to in fact disturb the learners. After the teacher was gone, the learners remained unfocused for a while before going back to their work. In this regard, I suggest teachers should only intervene when they have been called by the learners.

I also noticed that some learners never called the teacher, even when they were stuck, and that they eventually got the answer to the problem. They possibly got help from the other groups or members of the same group. It is acceptable either way because it is the same group and the whole class is a group as well. This is also good in the sense that it develops inquiry skills in the learners for them to find answers wherever they can find them. That is the final aim of all research.

I noticed one limitation concerning the filming of the intervention. It was a particularly good idea to capture video footage of what learners were doing in the class. This worked very well except for the fact that some learners did their discussions off-camera and re-joined the group to give their answers on camera. There were also moments when things were done off-camera and I had to classify them as 'disengaged' because I did not see or hear what learners were doing. I suggest that in addition to the camera recording the groupwork, another camera watching the general movements, gestures and activities of the group should be provided for in future. That camera would record any movement to and from the group and activities such as the group assigning specific members to do a certain question on the group's behalf. The extra camera could also record the gestures of the learners during the class, as well as the movements of the teacher.

4.6 Results from interview of the teachers

The POGIL teachers were initially trained to teach using POGIL during a three-day workshop prior to the commencement of the study. They went to their respective high schools and practiced using POGIL in their classes. Among those who managed to use POGIL are the two teachers who participated in the current study with one of their POGIL classes. The researcher visited their schools to support them during the training of their learners and to observe these teachers use POGIL during their teaching. This was done to ensure that the teachers were indeed able to use POGIL and their learners were ready to learn using POGIL in the intervention. Each teacher was interviewed for about 10 minutes in their respective offices soon after the intervention following the interview schedule in appendix 13. The interviews were subsequently transcribed by the researcher (see appendix 16 for teacher A and appendix 15 for teacher B).

In the following paragraphs, I present the results in the discussion format without distinguishing between the two teachers to enhance interpretation. I saw it fit to discuss the results from the interview of the teachers this way because their responses concurred in all questions except for one. Presenting the results for each teacher separately may have sounded like repetition.

The first question for the interview was *"How can you explain to someone what is POGIL?"*

The teachers seemed to be aware of POGIL since they explained during the interview that POGIL is a method where we *"use group work and learners are grouped in groups of four, sometimes six, whereby they have different roles"*. Another teacher said POGIL is a method where *"learners do teamwork and help each other"*. This appears to indicate that the teachers understood POGIL and, they explained what they did to implement POGIL in training their learners. It appears the teachers were also interested in teaching using POGIL since they said *"POGIL is a wonderful and easy method".*

The second question was "During POGIL, how can you explain the actions done by the learners?"

Both teachers acknowledged that the learners are "*active and each one of them participate actively"* during POGIL. The learners, however, can *"help each other in the process and solve even the difficult questions."* According to the teachers, their learners are actively engaged in their activities and helped each other. This a good practice for cooperative learning of which POGIL is one such method.

The next question was "*Okay can you briefly explain how you implemented POGIL in your classes?"*

The teachers suggest that grouping learners according to performance "*is the best method*" because it *"gives time to attend to the slow learners"* and that the *"fast learners will do a lot of work and go from one activity to another".* They felt that there would be fewer disturbances if the fast learners are grouped together. One of the teachers, however, indicated that they will not be teaching only the slow learners because the fast learners also asked questions in sections where they did not reach agreement. They indicated that the slow learners are less noisy but also give sound reasons for their ideas and that the *"slow learners also participated actively".* One of the teachers arranged her learners "according to their friends and work very well". It seems there is no best way of arranging learners in groups. Whichever method works for a particular group can be used in that group.

Both teachers followed the POGIL guidelines for being a facilitator of the learning process. They provided the worksheets at the front of their respective classrooms and allowed learners to manage the whole process. The teachers signalled the start and end of each activity, while the learners collected the worksheets and went through them as required in the POGIL method. The teachers moved around their respective classes guiding learners in terms of time management, challenges. and roles. In the process, they asked probing questions to particular groups and the class as a whole. In some instances, the teachers sent the spokesperson of one group to assist another group that may have been struggling. At the end of each activity, the teachers allowed learners to report their answers by writing them on provided charts. The teachers then conducted a class discussion to correct any errors and strengthen the learners' understanding of concepts.

The next question was *"How did your learners respond to POGIL?"*

Both teachers noted that their learners *"are very excited to use POGIL"* and that they sometimes request the teacher to teach them using POGIL. The reasons behind this were that *"POGIL makes them to be free and active"*. The learners are free to talk and *"everyone is alert and participating actively."* This was in contrast to the lecture method, where learners are supposed to be quiet, and some end up sleeping during the lesson. Both teachers noted that their Grade 10 learners are more excited about POGIL than their Grade 11s. They suggested that *"Grade 10s are energetic and want to be all over the place"* while Grades 11 or 12 *"are like, this is for kids"*. This suggests that the Grades 11s and 12s were not exposed to POGIL in Grade 10 and are now faced with a lot of work to cover. They therefore perceive POGIL activities as child's play. The learners' excitement during POGIL suggest that they paid attention to what they were learning. A method which draws learners' excitement and attention is likely to yield good results because they will remain focussed on the work.

The next question was "*During the POGIL lessons, what can you comment about the activities done by the learners? Were the activities giving the learners attention or were they too easy?"*

The teachers noted that learners participated actively during easy activities. The teachers know that the first activities used in POGIL are supposed to be *"simple real-life experiences".* This helps learners to understand the concept before they apply it to the subject content. When learners do *"difficult topics, they are passive and need a lot of help there"*. This suggests that the worksheet must not be too hard because the learners will disengage. Conversely, when doing easy topics "*each learner will be working quietly on their own."* Activities that are too easy do not support POGIL because each learner will be working individually. POGIL worksheets should aim for a balance between the two. The teacher ultimately understands the needs of their learners and acknowledged that the POGIL worksheets used during the intervention were neither too easy nor too hard. This kept the learners engaged throughout the intervention.

The next question was "*So, as a teacher, what is your role during POGIL lessons?*

The teachers understood that their role in the POGIL lesson is that of facilitators since they *"just making sure that learning is going on … provide the worksheets and monitor the time … observe that there is order"*. On rare occasions, the teachers assisted learners when they faced difficulties by directing them to the right path. The teachers acknowledged that they monitored the progress of the learners and sometimes asked the *"spokesperson of one group to go and assist another group"* or to get assistance from another group. The teachers, therefore, were *"checking if the learners had* *problems and if they were working in groups"*. The teacher provided advice, direction and motivation to the groups when they moved around the class. This view is in line with the POGIL philosophy that the approach must be learner-centred and not teacher-centred.

The following question was *"When you implemented POGIL how did the learners perform in that topic?"*

Both teachers acknowledged that when they teach using POGIL their *"learners perform much better than when they use lecture method"*. They wished to *"use POGIL in the whole syllabus"* if they had all the worksheets because *"POGIL encourages teamwork and more participation".* The teachers also noted that during POGIL the learners *"cannot go outside of what they are learning, and they are kept busy."* This suggests that the teachers appear to be happy with POGIL as a teaching method in their classes.

The next question was *"Do you think your learners, if given a choice, would prefer POGIL teaching over other teaching approaches?"*

One of the teachers mentioned that some learners asked their science teacher to tell the mathematics teacher *"to teach them using POGIL"*. This suggests that the learners are *"already motivated to learn using POGIL in other subjects".* All that is missing are the POGIL worksheets and the training for the teachers of the other subjects as the learners are already trained and are motivated and willing to use POGIL in other subjects.

The next question was *"When using POGIL do you think the learners are easier to control than when using direct teaching method?"*

The teachers acknowledge that it is a challenge to control learners during POGIL activities. They noted that *"strict control is needed during POGIL than during lecture method"* because the learners can be noisy and that *"the learners make so much noise which disturbs other groups and other classes"*. This is partly because learners expressing their ideas to the group during POGIL sessions, *"cannot just bring the answer without reason".* They must support their answers with reasons. They argue to support their answer until they are proven wrong or otherwise. If they do not agree, they ask other groups or the teacher.

The next interview question was "*What about the time management?"*

One of the teachers suggested that they *"initially thought POGIL was time-consuming"* but with experience discovered that what *"my learners do with POGIL will be permanent"*. So, they will not repeat that part. The teacher noted that *"with the lecture method I will repeat it like another three or four times"* and still the learners will not perform as they do when they learn using POGIL. This teacher seems to have analysed the time consumed per topic and not per lesson. The other teacher noted that POGIL is *"very time-consuming but at the end of the day you are able to do a lot."* The second teacher might not have viewed POGIL in the same way the first teacher did.

The last question was *"Do you think you will continue using POGIL in your lessons?"*

One teacher commented that she thinks *"POGIL is the way to go in all subjects"*. She mentioned that her school "*principal came to visit my class … and was very excited".* She explained that the principal worked with the learners in one of the groups and "*also understood science"*. This teacher was given permission to continue using POGIL in her school regardless of the noise associated with it, possibly because the principal saw the benefit and understood that the method requires learners to talk and argue.

The results from the interview with the two POGIL-trained teachers suggest that they both know POGIL, and they had trained their learners and used POGIL before the intervention. They both noted that their learners participated actively and were not disengaged during the intervention. The learners also worked interactively doing cooperative learning as opposed to individual learning and came up with one set of answers for the group, as opposed to individual answers. The teachers noted that the POGIL worksheets were neither too easy nor too hard and this allowed learners to remain focused on the activities because the work was challenging, but not excessively so. Both teachers played the role of facilitator during the intervention allowing for a learner-centred approach rather than a teacher-centred one. They sent spokespeople to other groups to assist them or to get assistance, while in some cases the teachers directed learners by asking guiding questions and not simply telling them answers like in the lecture method. Both teachers noted that POGIL resulted in noisy classes since learners argue to justify their answers. The teachers did not agree about the time management aspect. One teacher felt that it was time-consuming because the topic that had already been taught using the lecture method would have to be repeated. The other argued that POGIL is not time-consuming because what you teach will be permanent.

In the end, both teachers felt that POGIL is a good teaching approach that leads to improved understanding, reasoning, and performance. They both promised to continue teaching using POGIL because they witnessed better results in their classes. They both wished to have POGIL worksheets to use in all the science topics. The teachers also recommended for POGIL worksheets to be available for other subjects as well because their learners were excited to learn using POGIL as opposed to the lecture method.

4.7 Results from the focus group interview of learners

The learners who participated in the POGIL intervention group were initially trained by their teachers at their respective schools. They had already used POGIL to learn other science topics in the same year.

The first question was: "*You have been taught using POGIL, what can you comment about the method?”*

Learners acknowledged that they were familiar with POGIL because they defined it as a method where learners *“work in groups discussing classwork”.* Others identified POGIL as a method where learners *“read together and answer together”.* Yet other learners noted that POGIL uses *“examples which give clues on how to approach particular questions”* which makes science *“easier”* by using *“real life”* examples. Some learners recognised that one of POGIL’s advantages was that it guided them and gave them clues on how to approach problems. The learners indicated that POGIL is an *“interesting and funny”* method used to *“learn difficult topics”.* The learners observed that POGIL was used when teaching abstract topics. So, they associate it with difficult topics.

A follow-up question to this was "*So, is it a good method that you work in groups during POGIL?"*

To this question, the learners commented that with POGIL they can "*solve difficult questions without the help of the teacher".* Some commented that "*the method shows the steps to answer the questions*". The learners also commented that in POGIL they *"are free to talk many things and help each other."* And that *"no one hears"* their *"wrong answers"* except the people in their own group. This suggests that some learners may be afraid of participating in class because of fear of being laughed at. With POGIL they will be free to speak out, express their views and participate in arguments with other learners. They commended POGIL as it allowed them to *"help each other without laughing at one another."* Some experienced POGIL as *"good because we understand"* and that it made them *"think of why this answer is correct … to say the reason".* The learners are aware that they must reason before they write down an answer and not just give one without justification. Arguments develop when learners are debating and giving reasons for their responses, often resulting in the noisy classes that are typical for a POGIL session.

The next question was "*Do you think you understand science better or less? Explain."*

The learners commented that the POGIL *"method makes science to be easy"* showing a change in perception from initially finding science difficult, to viewing it as easy. The learners felt that they could now *"answer hard questions"* and indicated that the *"POGIL method is easy because we start with easy activities".* It appears as if learners who are taught using POGIL develop metacognition since they were able to describe the methodology of how they are taught and the difficulty level of questions they can answer. The learners acknowledged that *"in the past science was difficult to understand"* but now *"it is easy because of the POGIL method*." They also indicated that because of POGIL they learnt *"to be clever"* and can now think before writing the answer *"instead of guessing*". POGIL helped the learners *"to understand science better"* and improved their *"reasoning capacity*". The learners observed the available information and used the data to choose the appropriate formula or method to use.

This means they were aware of their thought processes. The learners were able to see what they had, how they were thinking and how much they had improved in reasoning because of the POGIL method.

Another follow-up question was "*You spoke about that there are easy examples in POGIL activities. How do examples help you to understand science better*?"

The learners responded that "*The examples show me how science is related to the car parts … and to the clothes that we wear*". The learners explained that *"wearing two shoes, two socks, one pants, one shirt"* are *"ratios like two moles of hydrogen react with 1 moles of oxygen"* to produce two moles of water. They could reason and assess that one *"cannot put on three shoes at the same time"*. This means that the learners have developed reasoning and understanding because of exposure to POGIL methodology. The learners seemed to be thinking critically which is necessary for problem-solving.

The following question was "*Do you think you shall perform better in the second test than in the first test? Remember you wrote 2 tests?"*

The learners expected better marks after being taught using POGIL because they felt they knew more and *"understand and think about the answer"* before writing it down. The learners mentioned that they *"can now reason and know how to find the limiting reactant"* and attributed this to the POGIL method. The learners commented confidently that with *"POGIL lessons we understand all things"* and said that they expected to pass the post-intervention test. The learners appreciated the *"step-by-step"* teaching as they felt it helped them *"understand better"* when taught that way. They believed that the POGIL method develops their understanding by gradually moving from the easy concepts to the harder concepts.

The next question was *"Do you expect to do further studies in science because of the use of POGIL?"*

The students believed that their marks were high enough for them to enrol in *"engineering because by using POGIL we will pass"* or *"do medicine … or become a dentist because POGIL will give us high passes"*. The POGIL method seemingly developed confidence in the learners as they demonstrated metacognition and were even considering long-term goals such as specific fields and careers they might pursue.

The last question was “What about using POGIL in other subjects? Do you think it will be a good idea?”

The learners wished to *“use POGIL in mathematics”* so that their *“marks will go up”*. They noticed that *“mathematics has a lot of measurements and objects”* and it is possible to use POGIL in mathematics. The learners acknowledged that currently *“the mathematics marks are the lowest”*. They believed that their marks could improve by using POGIL. This also showed that the learners had confidence that the method could be used in mathematics.

The results from the interview suggest that the learners were already familiar with POGIL as a learner-centred approach. The learners acknowledged that during POGIL they work in groups, discussing and solving questions as teams, without feeling embarrassed. They noticed that POGIL activities were structured to progress from easy, familiar concepts to more difficult concepts. The learners commended POGIL for making science easy, interesting, funny, and using real-life examples which made them understand science better. In POGIL, learners should support their answers with sound reasoning. They acknowledged that POGIL increased their reasoning capacity and improved their argumentation abilities as they had to reason with their peers. They noticed that they had to think about their answer before presenting it to the group. This suggests that learners develop metacognition through the use of POGIL. The learners also noticed that POGIL is helpful in abstract topics where in-depth critical thinking and reasoning are important for understanding the concepts. The use of real-life examples suggests that science is not isolated from daily experiences, thereby making it more attainable.

The learners detected an increase in their performance and understanding of science. They attributed the improvement to the step-by-step procedures used in POGIL that develops their understanding. This suggests that the learners improved their critical thinking skills in arguments and develop other process skills such as communication, management, teamwork and problem-solving, information processing, and assessment. The learners further assessed that they would qualify for tertiary studies in medicine and engineering because of their improved performance and understanding of science. They wished to be taught mathematics using POGIL because they recognised that they had low marks in that subject. The learners developed metacognition and their process skills improved. They attribute this development to the use of POGIL in their science classes.

4.8 Results from the observation of POGIL lessons

The POGIL lessons were observed by the researcher using the observation schedule in appendix 21. The observations were aimed at identifying how both teachers managed their respective classes and how the learners engaged during the lessons. In this section I discussed the results from the observation of both teachers, starting with how they arranged their learners to the actual intervention. I then discussed the results of the observation of both classes without distinguishing between them. I saw this as the best approach to avoid repetition since most of the observations were quite similar.

Results from observation of teachers

The teacher at school A grouped learners according to their abilities and considering gender balance. The teacher created 4 groups composed of four learners and one group with six learners. The total participants at school A were 22, though the class had around 36 learners in total. The rest of the learners did not give consent to participate in the study and as such, they were separately grouped, and their data was not used for this study. Each of the groups of four had two boys and two girls. The third group was made up of four girls and two boys.

The teacher at school B grouped the learners according to abilities, behaviour, and gender. There were about 40 learners in this class but the participants for this study were 26. There were six groups in total; five of which were composed of four learners and one group composed of six learners. The group with six learners had three boys and three girls, and as with school A the other 3 groups of four had two boys and two girls. There were two unique groups in this class, one was made of four girls and the other of four boys. The teacher explained that the girls were the most hardworking and fastest learners in the class and were all among the class' top ten. The teacher explained that if any of these learners were put in another group, that they would likely do all the work by themselves. The girls were said to be friends and understood each other well as they worked at almost the same pace. They were competing for better grades amongst each other, and they also studied together. Their friendship meant that they would communicate well and quickly do their class activities. This group indeed completed the activities earlier than the rest of the groups. The boys group had one high performing boy who was the best in the class. The teacher said the other three boys were among the lowest performers in the class. The teacher commented that all four learners in the group were naughty boys who would harass or bully any other learners or group members if they were grouped with others. The teacher considered that this was the best way to group them because at least results would come out, though most of the work would be done by the brightest learner. The teacher did not separate the naughty learners, which may be inconsistent with the POGIL way of grouping learners.

The teachers provided a table at the front of the classroom where the worksheets were piled up according to the relevant activities. The teacher would ask the document controller to collect worksheets for each member of the group. Each of the worksheets had time allocation and the learners made sure to keep up. The teacher made sure that the learners kept up to the allocated time by checking on them now and then. The teacher would remind the group managers to check the clock, which was placed in the front of the classroom. The teacher provided a stand for each group and instructed the learners to place their cell phone on it and to record videos of each activity they did. After each activity, the learners would transfer the video onto the laptop provided by the researcher. Figure 4.85 shows the stand used during video recording.

Figure 4:85

Diagram of the stand used by learners to record videos.

The teacher moved around checking the group activities and helping learners to discover the hidden concepts. At times, the teacher asked leading questions and then the learners figured out where they went off track. If the teacher saw that the learners were going astray, they asked key questions that would make learners reflect on the way they were doing the work. The learners spontaneously developed concepts and therefore owned the knowledge because they discovered it for themselves. The probing questions acted as a guide so that the learners re-directed their thoughts properly.

After each activity, the teacher asked the recorders to bring and put up the poster which represented the work done by the group. The teacher would then look at each question and do revision of the task. When there were wrong answers from any group, the teacher asked a learner from another group to explain the appropriate answer to the class. Sometimes the teacher sent a member of the groups that had finished earlier to help members of other groups who may have been struggling. There were no instances where the teachers explained the answer to the learners because the teachers maintained the role of facilitator of the learning process. The activities were easy to understand and carefully designed to effect concept development, understanding, and developing reasoning skills in the minds of the learners.

The teachers made sure that each group was working on the activity by checking their progress regularly while moving around the classroom. During that process, the teachers questioned the learners on their progress or asked guiding questions where learners needed help. In some instances, the teachers assigned a learner from one group to assist another group for a short while. The teachers always reminded learners of time-keeping by saying "*please 'managers' check your time*", because the manager is the time-keeper during POGIL activities. They asked regular probing questions to direct the learner, such as, *"how many atoms of hydrogen make up one molecule of water?"* In other instances, they asked, *"how many oxygen atoms are needed to make one water molecule?"* Sometimes the teachers asked, *"if you have 2 atoms of hydrogen, how many water molecules can you make?"* Such questions were directed to specific groups, or to the class depending on the needs of the learners as assessed by the teachers. The learners were familiar with the POGIL approach and understood that they were not expected to answer those questions, only in their respective groups. Both teachers followed the guidelines of the POGIL method, by guiding learners as facilitators and not telling them answers.

At the end of each activity, the teachers asked the groups, "*let us have the 'reporters' of each group come to the front to write the answers of their groups on the charts*". Each group had their chart put up in front of the class, identified with their group number. Sometimes the teachers allowed the learners to write on their chart while still in their respective groups and paste the chart afterwards. The teachers timed the learners as they wrote on the chart just like during a class activity. When all the charts were on the walls, the teachers went through all the questions one at a time, comparing the answers on all the charts. Where the answers were all correct, the teachers complimented the learners and moved on to the next question. Where one or more groups had a wrong answer, the teacher asked questions such as, *"what data is given for this question?".* Sometimes they asked*, "which formula can best be used for this calculation?".* This time, the learners answered. The teacher targeted the groups who got the correct answers so that they could explain to the other groups. After asking several probing questions, the teacher directed the question to the groups that got an inappropriate answer, *"so which method is the correct one form what we see on the charts?"* At this stage, most of the learners identified their mistakes and choose a correct answer among the displayed answers. Sometimes the teachers asked the groups to identify where mistakes had occurred on the wrong answers.

When starting a new activity, the teachers encouraged learners to change roles. This was uncomfortable for some learners and the teacher respected this. Such learners feared the roles of manager, spokesperson, or reader. Noise was a challenge in both classes, but the teachers tried to minimize it saying, "*there is too much noise, 'managers' control your groups*". This helped reduce the noise, but it persisted as the learners discussed the activities. Time management was a challenge since the learners were of mixed abilities. Some groups finished earlier than others and the teacher occupied them by sending them to assist the slower groups.

Both teachers appropriately facilitated their respective classes as recommended by the guidelines of the POGIL method. They both guided their learners well and managed their classes according to the expectations of the method.

Results from observation of learners

The two POGIL classes were overly excited when the teachers announced that they should go into groups and be ready to learn using POGIL. They started choosing the roles of their choices and identified their favourite group members, based on previous sessions where they had worked together. The teacher made sure that the learners were in the right groups and they were reminded of their roles through a five-minute question and answer session. The learners were then assigned their roles in the first activity.

The 'document controllers' collected worksheets for their group and distributed them among the group members at the instruction of the teacher. There was one 'document controller´ per group. The manager or the reader read the questions while the rest of the group paid attention in the 'passive' mode. After reading, the learners engaged in the 'constructive' mode where they individually constructed their own understanding of the question. They presented their answers to the group, one at a time. They supported their answers with reasoning and explained the justification for their answer.

The other learners in the group asked questions to the one answering the question, so that he/she could explain and clarify the reasoning behind the answer. The manager asked questions such as, “do we agree?”. The manager would not accept the answer until all group members agreed. When they were convinced that the answer was correct based on reasoning, they agreed with the answer. At this stage, the ‘spokesperson’ then wrote the answer that will represent the group. This stage in the ‘interactive’ stage where learners collectively construct knowledge through discussion.

Under the control of the ‘manager’, each group went through the activities writing on their worksheets, with the ‘reader’ also writing on the poster for display at a later stage. All the learners came to agree on the answers before writing them down. Learners who needed clarification asked and got assistance from the members of the group. The learners were seen concentrating and reading through things a second or third time when they came across a challenging question. In instances when one of the learners discovered the solution and shared it with the group, they would all shout out the “Aha” moment. Sometimes the learners in some group would remain stuck until the teacher noticed them, or they would ask for assistance from the teacher, who would just ask a leading question whereafter excited tended to fill the group. After each activity, the learners pasted their posters on the wall and the teacher revised the work via the worksheet, comparing all the answers on the posters.

The learners in both classes actively worked through the POGIL worksheets assisting each other eagerly. They played their respective POGIL roles well and helped each other to understand the topic.

4.9 Chapter summary

Chapter 4 was the discussion of results. I started by presenting and discussing the results from the pre-intervention test. This was followed by the presentation and discussion of the post-intervention test results. I discussed the ratio questions in the pre-intervention test and the post-intervention test. Thereafter, a presentation of the comparison of the pre-intervention test and post-intervention test results of all tests followed by a comparison of the ratio questions. The presentation and discussion of the intervention results was done. Finally, the discussion of the results from the interviews of the teachers and the learners, as well as the lesson observation, was presented. The chapter concluded with the chapter summary. The next chapter discusses the findings from the results presented in chapter four.

CHAPTER 5: CONCLUSION

5.1 Introduction

This chapter commences with the presentation of the overview of the study. The summary of the findings with respect to the research questions follows thereafter. The chapter then proceeds to the concluding remarks and limitations of the study. This is followed by the possible contributions of the study and the recommendations thereof.

5.2 Overview of the study

The purpose of this study was to explore how using the POGIL way of teaching in stoichiometry influences (or not) Grade 11 learners' reasoning. In the introduction of this study, I indicated the prevailing Grade 12 results for the past five years, which showed low pass rates in physical sciences. I also indicated that the Department of Education recommends the use of the inquiry approach for teaching science (Department of Basic Education (DoBE NCS-CAPS), 2016). Previous research has revealed that the use of inquiry methods led to the improvement of learners' achievement and understanding (Dudu & Vhurumuku, 2012; Mamombe, Mathabathe, & Gaigher, 2020; Moog & Spencer, 2008). Problem-solving techniques have been identified to yield a better understanding of science (Sunday, Ibemenji, & Alamina, 2019), and those who taught mathematical skills improved achievement in stoichiometry (Adigwe, 2013).

There seems to be no study undertaken to find out the influence of POGIL on learners' reasoning in the topic of stoichiometry. It is against this background that the current study wanted to determine to what extent the POGIL way of teaching influenced (or not) learners' reasoning. Investigation of learners' reasoning in stoichiometry was achieved by answering the secondary research questions of this pre-intervention test post-intervention test case study done at two township schools in a district in Pretoria. The assumption was that if learners' reasoning while solving stoichiometric calculations is identified, it might be possible to find ways to assist them in that topic. The following sub-research questions were answered:

- How do Grade 11 physical sciences learners engage and reason before exposure to POGIL?
- How do POGIL-trained physical sciences teachers engage learners during POGIL activities?
- How do Grade 11 physical sciences learners engage and reason during stoichiometric POGIL activities?
- How do Grade 11 physical sciences learners engage and reason after exposure to POGIL?
- What are the learners' perceptions of POGIL as a teaching and learning strategy?
- What are the teachers' perceptions of POGIL as a teaching and learning strategy?

The answers to these sub-research questions were used to answer the main research question of the study which is:

How does POGIL influence (or not) learners' reasoning about stoichiometry?

The learners' initial reasoning was observed by analysing their pre-intervention test scripts. This was followed by observing the learners' engagement and reasoning during the POGIL intervention. The teachers' approach was also assessed during the intervention to ascertain to what extent the POGIL approach was implemented during the intervention. The learners' reasoning after the intervention was observed in the analysis of their post-intervention test scripts. The interviews of the teachers and that of the learners revealed their respective perceptions of the POGIL way of teaching.

The findings are presented and discussed according to the following themes:

- Learners' reasoning before and after the intervention.
- Teachers' engagement during POGIL intervention.
- Learners' engagement and reasoning during the intervention.
- Learners' and teacher's perceptions of the POGIL way of teaching.

5.3 Description of the findings

The previous paragraphs were a presentation of the overview of the study. The following discussion focuses on the results obtained as well as how these results were used to answer the secondary research questions, thereby providing an answer to the primary research question.

5.3.1 Learners' engagement and reasoning in the pre-intervention test

The pre-intervention test was analysed based on how learners responded to the tests regarding concept development and demonstration of their understanding, as well as the level of critical thinking and reasoning involved. Because the pre-intervention test was written individually, the analysis of the learners' scripts examined the extent of the Constructive component of the ICAP framework (Chi, 2011; Chi, et al., 2018). At the constructive stage, the learners individually generate information beyond what is on the worksheet by providing justification, forming hypotheses, and comparing ideas. At this stage, learners engage in critical questions which do not have obvious answers. This is what the Department of Basic Education calls the cognitive levels which reveal the extent to which the learner has reasoned in solving the problem (Department of Basic Education [DoBE] Report, 2016). See Table 3.2 for a detailed description of the cognitive levels according to the DoBE.

In the pre-intervention test, the learners showed that they used mechanical memorized responses without understanding and reasoning. During this test, a few learners were able to complete easy single-step calculations, but most learners failed to fully answer the more complex multi-step level 4 questions. The level 4 questions require a lot of analysis, application, evaluation, and creation, which form the foundation of critical thinking and hence, the reasoning of the learner. The learners did not show any considerable reasoning skills in the pre-intervention test. Instead, most learners showed that they had novice ideas or elementary knowledge and, therefore, a limited understanding of most questions. A few of the learners had sufficient intermediate knowledge to answer the questions in the pre-intervention test. The failure to answer multi-step complex questions means that they lacked the necessary reasoning skills and understanding of how to solve such questions. As such, most of the learners' responses in the pre-intervention test were mainly level 1 which is the lowest cognitive level of reasoning (Department of Basic Education [DoBE] Report, 2016) (see section 3.6.2). The low cognitive levels revealed by learners in the pre-intervention test are in agreement with the previous pre-intervention test post-intervention test studies where learners initially demonstrated a low level of understanding (Koopman, 2017; Mamombe, Mathabathe, & Gaigher, 2020).

Where the learners demonstrated possession of some idea, they wrote down ideas which they had memorized and sometimes they inappropriately did so. Moreover, the learners failed basic tasks such as identifying the appropriate formula and constants which we provided on the datasheet. In instances where they identified the correct formula, they failed to use it appropriately. An example of such an instance is when learners interchanged the mass of a substance with the molecular mass of the same, indicating that their knowledge was not properly grounded. The haphazard use of the formulae and its constituent constants served as a sign that this was memorized knowledge and not based on conceptual understanding and reasoning. They failed to write down the molecular formula of some basic chemical substances like sodium hydroxide.

The pre-intervention test results show that the learners in the sample failed to successfully solve tasks assessing low-level cognitive skills to such an extent that even their recall was exceptionally low. This is shown by their failure to appropriately substitute in a calculation equation. It means that the learners did not remember what the symbols in the formula stood for. Such learners lacked basic knowledge and understanding such that it may be naïve to talk about their level of conceptual reasoning because it was simply not demonstrated.

The overall finding is that most of the learners' responses on the pre-intervention test showed that they did not have any idea of the topic which they were taught in the previous grade. This was evidenced by the blank spaces which most learners left in most of the questions. The fact that most learners had novice ideas of the topic was also shown by the number of inappropriate calculations done. The learners also picked wrong formulae from the formula sheet provided. This means that they did not have enough knowledge of how to answer the questions.

The learners also failed to define the concept of ‘limiting reactant’, a critical concept in stoichiometry, and left blanks while a few of them wrote completely inappropriate definitions. They also failed to balance the equation of the chemical reaction provided. That basic requirement of balancing a chemical reaction equation needs basic mathematical analysis of the number of atoms for each element on each side of the equation of the reaction. This seemed to be a challenge for most of the learners in the sample. Some learners wrote an inappropriate formula of sodium sulphate and this contributed to their failure to balance the equation of reaction. Though the national senior certificate examination provides balanced chemical equations in most of the questions, there are still one or two questions where learners need to write the chemical formula of the substances and balance equations of reactions. There are certain basic or common chemical substances, like sodium sulphate, where learners are expected to know the chemical formula or name.

In the pre-intervention test, the learners also showed that they had novice ideas when using the ratio technique. This fundamental mathematical operation is useful when it comes to multi-step complex calculations that link one formula to the next until finding the appropriate answer (see Section 3.6.2). All learners struggled to use the ratio technique in solving the multi-step calculations. Their results, therefore, showed that the learners performed poorly in the multi-step complex calculations.

In summary, in the pre-intervention test, the learners in the sample showed that their ability to respond to questions assessing low-level cognitive skills was exceptionally poor. The learners lacked the lowest cognitive skills of recall and understanding. Therefore, in the pre-intervention test, the learners demonstrated no understanding of basic concepts except in exceedingly rare cases. This was evidenced by a lot of blank spaces or incomplete responses to questions. They failed to choose suitable formulae from the formula sheet. And if they managed to choose the formula appropriately, they would fail to appropriately substitute in the formula. In rare cases, they would fail to do the appropriate mathematical operation to find the answer even if they had substituted appropriately. It appears all the learners failed to use the ratio technique in the pre-intervention test. They seemed to lack knowledge of the ratio techniques. The ratio technique is a fundamental mathematical reasoning skill which is essential in solving stoichiometry calculations. This shows that they were not equipped to solve stoichiometry problems. The learners lacked basic reasoning required to solve calculations. The findings indicate that the learners lacked understanding of the topic and hence it was naive to talk about the extent of their reasoning in the pre-intervention test. This deficiency in basic understanding or recall identified in the pre-intervention test is a possible indication that the learners lacked a grounded understanding of the concepts. Such a state of mind may lead learners to perceive science as difficult and unreachable which may lead to misconceptions (Areepattamannil, 2012).

More details about how learners engaged and reasoned during the pre-intervention test have been provided in section 4.11. The results include the pictures of the learners' responses as classified according to the levels of cognition, which are novice, elementary, intermediate, competent, or advanced.

5.3.2 How the learners engaged and reasoned in the post-intervention test

The post-intervention test was examined similarly to the pre-intervention test data based on the constructive component of the ICAP framework (Chi, et al., 2018; Chi, 2011). The constructive component of ICAP revealed the cognitive level of each learner as they completed the post-intervention test. The learners in both classes showed an improvement in understanding and reasoning in the post-intervention test compared to their reasoning and understanding in the pre-intervention test. The learners demonstrated more reasoning skills and understanding in all levels of the questions from the simplest to the most complex. The higher reasoning was shown by a higher number of learners with advanced and competent knowledge to answer level 3 and level 4 questions. There were a higher number of learners who demonstrated competent and intermediate knowledge in the level 3 and level 2 questions, respectively. And there was a decrease in novice ideas in each question in the post-intervention test as compared to the pre-intervention test.

In the post-intervention test, the learners did multi-step calculations using many formulae as required by the question. The minds of these learners were open to such an extent that they could easily solve complicated multi-step calculations. It should be noted that the POGIL activities did not directly teach similar questions. However, the activities were carefully designed in a way that learners developed their reasoning and understanding of concepts to enable successful problem-solving. The learners were equipped to tackle any question related to the topic.

The results show a large increase in the number of learners with intermediate, competent, and advanced, knowledge in level 2, level 3, and level 4 questions, respectively. There was a clear decrease in the number of learners with elementary knowledge and those with novice approaches to solving the questions.

The multi-step advanced questions that were appropriately solved are typical examination questions. This implies that after the POGIL intervention the learners are likely to successfully tackle such questions in the final examination. The learners solved the advanced questions very well except for a few who had minor errors.

The learners also solved the intermediate questions with ease. The number of learners who could appropriately describe the concept of a limiting reactant in their own words increased. It should be noted that the definition of limiting reactant was not recited during the intervention (see annexure 11 the POGIL worksheet). The learners did activities where they identified the limiting reactant. So, the learners developed the concept by themselves (concept invention) and the activity stated that the substance that is finished first is the limiting reactant. This was one of the 'aha' moments where learners developed the concepts by direct interaction with the content at their own pace and in their own language.

It should be noted that in as much as the teacher may enforce the use of the official language for instruction during the POGIL activities, some groups of learners held group discussions in the language of their choice. They then translated their responses back to the language of instruction. Furthermore, engaging learners when it comes to the use of home language in the teaching of any subject may yield results, because learners know the ways they can communicate with each other in their home language. Their communication, however, may need re-tailoring because it sometimes is a mixture of different home languages or sometimes it is mixed with street language.

Another possible advantage of POGIL may therefore be the flexibility in the language of communication within groups. During POGIL, learners can quickly switch to any language in their group to explain complex issues without shouting it out loud to the whole class. More details about the post-intervention test results are in chapter 4, Sections 4.1.4 and 4.1.5.

5.3.3 How the learners engaged and reasoned during POGIL activities?

The learners' engagement during the POGIL intervention was underpinned by the ICAP (Chi, et al., 2018) frameworks. The ICAP framework examined the learners' actions with regards to their discussions as they solved the POGIL worksheets.

During the POGIL activities, the learners worked through activities taking them from simple day-to-day examples, depending on the learners' contexts, to more complex tasks. This resulted in the development and use of low-level cognitive skills up to high levels of cognition. As the activities got tougher, there was a lot of critical thinking needed and the learners were prompted to apply their understanding and reasoning skills to be able to answer the activities fully. During the activities, there was also concept development which entailed the learners discovering conceptual links by themselves. The learners were not given definitions, but they arrived at the definitions, laws, or rules by going through activities on their own. As a result, the learners got to know definitions, laws, rules and so forth without memorizing, but with understanding. The learners are therefore able to apply their understanding to new situations. They are also able to do analysis, synthesis, and evaluation of their learning thereby creating new methods to solve problems.

The learners worked under the interactive stage of the ICAP framework most of the time. They discussed their ideas about each question sharing ideas based on suitable reasoning. During discussions, each learner gave answers based on justification and the rest of the team analysed the ideas objectively, based on the information they had. Each learner's ideas were either accepted or rejected based on the evidence that supported the ideas. This was the interactive stage of ICAP where learners benefitted from cooperatively working with each other. They solved their problems by themselves while the teacher acted as facilitator of the learning process. Details of the learners' engagement and reasoning during the POGIL intervention including some of their quotations during their discussions and pictures of their work are in section 4.1.9.

5.3.4 How the POGIL-trained Physical Sciences teachers engaged learners during POGIL activities

The POGIL lessons were guided by the Interactive-Constructive-Active-Passive framework (ICAP). The framework is based on the constructivist philosophy that learners develop their own mental constructs during learning. The role of the teacher is identified as a facilitator of the cooperative learning process giving guidance to the learners as they tackle POGIL worksheets. The role of the learners is cooperative work assisting one another to solve problems (Moog & Spencer, 2008; Simonson, 2019). One of the teachers' roles is to carefully group and train them the different roles they play during the POGIL activities in groups of four. This was essential to ascertain the cooperative component of the POGIL way of teaching.

The ICAP framework differentiates the observable behaviours of learners as levels of their cognitive engagement (Chi, et al., 2018; Chi, 2011). The ICAP framework is the muscle behind the POGIL classroom's powerful learning environment that leads to understanding, reasoning, and critical thinking. The assumption is that the behaviour of learners during an activity is related to the underlying cognitive processes. The ICAP framework was used in the current study to observe the learners' activities during the POGIL intervention. This was essential to identify the extent of the POGIL intervention which emphasizes the interactive and constructive levels of engagement of learners in the group. More details on the ICAP framework are found in section 2.7.

The way the teachers conducted their POGIL lessons showed that they knew how to implement POGIL in their classes. They had also previously trained their classes well and all the learners and teachers participated appropriately. The teachers successfully facilitated their classes. The participant learners were, therefore, previously trained to use POGIL by their respective teachers and were previously taught using POGIL in the other science topics. The researcher had also previously visited and informally observed the two teachers using POGIL in their classes. As a result, the learners were aware of their roles in the POGIL activities.

5.3.5 The learners' perceptions of POGIL as a teaching and learning strategy

The learners perceived POGIL as an interesting and playful method that makes scientific knowledge accessible to them. They acknowledged that POGIL made the hard and abstract topics easier to understand. The step-by-step and scaffolded procedures used during POGIL activities certainly helped in this regard. POGIL also improved the performance and understanding of the learners and developed their reasoning skills because the learners were prompted to justify their answers during the discussions. As a result, the learners developed critical thinking skills and other process skills like problem-solving, communication, teamwork, and information processing. The learners developed self-regulatory skills as they assessed their own answers before sharing with the group and assessed their peers' responses during discussions. The learners associated these skills with their use of POGIL as a teaching and learning approach. The learners speculated about their future careers in science and engineering because they anticipated achieving passes because of POGIL. They also wished to be taught mathematics using POGIL because they had noticed their low marks in mathematics. Their metacognitive awareness developed because of POGIL as they could identify the method as a possible solution to remedy their poor performance in mathematics.

Overall, the learners were interested in using POGIL in all their activities as they noticed the benefits of cooperative learning and that teamwork helps them to achieve more than individual work, as well as helping them in reasoning and understanding. POGIL allows learners the freedom to have discussions and allows all the learners to participate actively during the lessons. The learners preferred POGIL because they worked in small groups and were free to contribute to discussions without worrying that other learners would laugh at their ideas. The results suggest that the learners had developed confidence in working through stoichiometry calculations. This agrees with previous findings (De Gale & Boisselle, 2015). More details about learners' perceptions of the POGIL way of teaching is contained in chapter 4 Section 4.1.10.

5.3.6 The teachers' perceptions of POGIL as a teaching and learning strategy

Both teachers were interested in using POGIL and seemed pleased with the good results they obtained from using POGIL. Both participating teachers acknowledged that their learners understood and performed better when they were taught using POGIL. They both acknowledged that POGIL allowed all their learners to participate actively, including those who were usually passive. The teachers commended POGIL for producing good results even for the typically low-performing learners. They both acknowledged that POGIL classes are noisy and that the noise may be reduced by grouping learners according to their abilities. One of the teachers noted that POGIL is time-wasting while the other differed and viewed POGIL as saving time in the long run. Both teachers promised to continue using POGIL in their classes if they get worksheets for the rest of the topics. One of the teachers indicated that she wanted to use POGIL in all her lessons. This indicates that the teachers were happy with the POGIL teaching approach. They even suggested that it to be used in other subjects like mathematics because their learners had shown interest.

Overall, the teachers who participated in the current study were happy to use POGIL and had witnessed the benefits of using it in their classes. The teachers demonstrated confidence in using POGIL and promised to continue using POGIL provided they continued getting support. They only had worksheets for a few topics even though they may download for free from the POGIL website. More details about the teachers' perceptions of the POGIL way of teaching are provided in chapter 4 sections 4.1.10.

5.4 Summary of the findings

The learners demonstrated mostly novice and elementary knowledge and understanding during the pre-intervention test. There was very little evidence of conceptual understanding. Most of the learners had challenges in selecting the formulae or appropriately substituting in the formulae. During the POGIL intervention, the teachers facilitated the POGIL lessons in line with POGIL requirements (Moog & Spencer, 2008; Process Oriented Guided Inquiry Learning, 2010; Simonson, 2019). Both teachers allowed learner-centred learning to occur as learners worked through the POGIL worksheets. The teachers did not take on the role of knowledge transmitters but that of facilitators who provided direction for the learners to follow. The learners were familiar with the POGIL method of learning and collectively worked through the worksheets, assisting one another and producing common answers for the group. They displayed sound reasoning and justified their thinking about answers effectively.

The post-intervention test results suggest an improvement in the reasoning ability and understanding of learners. The learners demonstrated that they could select the correct formulae, substitute appropriately, perform multi-step calculations, and use the ratio technique appropriately to link one step to the next. The results show that the learners demonstrated higher-order thinking skills in their responses to questions requiring advanced and competent knowledge levels. It appears that POGIL was effective in improving understanding and reasoning skills and eliciting interest and participation of learners in classes.

The improvement in learners' cognitive levels in the post-intervention test following the POGIL intervention suggests improved critical thinking skills (analysing, evaluating, synthesizing, problem solving skills such as identification, planning and executing a strategy (Moog & Spencer, 2008). This improved critical thinking entails the improvement of learners' reasoning, which translates into improved performance and achievement in the topic. This is in line with previous research where inquiry learning resulted in improved academic performance and achievement (Hanson, 2006; Hein, 2012; Koopman, 2017; Moog & Spencer, 2008; Nadelson, 2009; Villagonzalo, 2014) . The learners in the current study worked well through the POGIL worksheets, manifesting process skills such as communication, teamwork, management, information processing and assessment (Simonson, 2019). This outcome is peculiar to inquiry and POGIL.

Previous studies observed that high school learners improved their achievement (chemistry knowledge, science process skills, and scientific attitude) and problem-solving competency when using guided inquiry learning (Tornee, Bunterm, Lee, & Muchimapura, 2019). The current results, where learners improved reasoning which translates into improved problem-solving competency, supports previous results. The unique feature for the current study is that it shows that learners improved their problem-solving skills and improved performance and understanding because their reasoning had improved.

Previous studies have identified that scientific inquiry improved learners’ curiosity in addition to improving their problem-solving skills (Wilujeng & Hastuti, 2020). This agrees with the observations done in the current study where learners showed excitement towards the POGIL way of teaching. The learners concentrated during the intervention and this resulted in the active participation of the usually passive learners. The participating teachers demonstrated interest in using POGIL in their future lessons. They witnessed excitement and active participation of their learners, improved understanding and reasoning of their learners and wished to proceed using POGIL if they get continuous support.

5.5 Concluding remarks

As an experienced physical sciences teacher, I have been concerned with the approaches used in the teaching of abstract and difficult topics such as stoichiometry. The study revealed that POGIL produces learners who are multifaceted in terms of process skills. These skills, such as teamwork, communication, problem-solving skills, information processing skills and critical thinking, were observed in the manner the learners related to one another. The learners displayed a high level of teamwork, communication, and critical thinking skills. These skills are not only useful during the early learning stages but also for their future careers and social life in general. The critical thinking skills form the background of the reasoning that learners develop and use to solve higher-order complex multi-step calculations.

It appears that POGIL may be effective in developing higher levels of cognition and reasoning. The available results suggest that POGIL may be effective in eliciting learner reasoning in the topic of stoichiometry. The findings suggest that if POGIL is effectively used, it may develop learners who are more critical thinkers who use reasoning rather than relying on rote learning. The use of POGIL seems to be effective in reducing the reliance on elementary knowledge to respond to advanced questions as well as improving the conceptual understanding of learners. It may be of benefit for high school teachers to use POGIL in their teaching since learners would develop higher-order cognitive skills. Such cognitive skills are especially useful for the learners' future careers as they develop application and creation which are necessary for scientific research. The excitement of the teachers who tried POGIL also indicates that this approach may be a solution to some challenges in our education system. If more teachers are trained in using POGIL, perhaps the achievement of the South African learners may increase. That achievement will in this case be linked to understanding.

5.5.1 Limitations of the study

The current study used a qualitative approach and a pre-intervention test post-intervention test case study design as well as lesson observations and face to face interviews for teachers and focus group interviews for learners. During lesson observations, direct observation of teachers was done while learners' group work was video recorded. There were challenges related to the research approach and the research design used in this study. Case studies are limited in that they are focused on a small sample, meaning that their findings cannot be generalized (Nieuwenhuis, 2011). The current study was carried out at only two schools and the participating learners were only two classes with a total of 48 learners, and the respective teachers of those classes. As such, the sample was too small, and the findings cannot be used as a representation for the whole of South Africa. But they can be used to guide the influence of POGIL on learners' reasoning in stoichiometry and other science topics.

Another limitation was the video recording used in this study. It was very important to record the learners' groupwork during the POGIL intervention. As such, video recordings were successfully made using cell phone cameras which focused on learners' work. However, it was observed during analysis that some learners did part of their discussions and calculations off-camera and only brought the finished answer to the camera afterwards. In such cases, there was no chance during analysis to determine the learners' actions based on the ICAP framework (Section 2.7). It was not clear whether the ideas provided by the group came from the group or one or two individuals. An extra video recorder was necessary to capture learners' activities and gestures as they participated in the groupwork. Such recordings could have been useful to reveal the active participation of all learners during the discussions, and the possible consultations of members of other groups.

Another limitation was the manner in which the pre-intervention test and post-intervention test were administered. After completing each test, the learners submitted their scripts for analysis. During analysis, some learners had left blank spaces, especially in the pre-intervention test. It was assumed that the learners had no suitable answer for those questions. However, more information could have been collected by an interview of each learner. Another limitation during the tests was related to the anonymity of the learners. The learners did not write their names on the scripts and this was good practice to protect the privacy of the learners. However, the learners should have been given fixed pseudonyms. The names could have been used to assess the personal progress of each learner. Such analysis could have been beneficial to the subject teachers who could have provided individual personalised attention to a learner based on the findings. Such analysis could have been essential to give in-depth data analysis and provide richer information about the influence of POGIL on learners' reasoning.

5.5.2 Possible contributions of the study

The study showed that the POGIL strategy is useful in the development of learners' cognitive skills and understanding of a complex topic like stoichiometry. This was achieved using the POGIL worksheets whereby learners worked in groups with activities starting from simple and familiar concepts to more complex scientific concepts. Besides assisting one another by giving justification to their ideas, the learners were guided by the teacher on how to think critically. The teacher acted as facilitator of the learning process without telling the learners the answers to questions and instead guiding them towards the answers. Each learner ended up with better understanding than they would have done if they worked individually.

The findings in the current study contribute to the body of knowledge by developing a tool for assessing the pre-intervention test and the post-intervention test. The tools used in the current study may be used to assess learners' reasoning and understanding. These instruments were successfully used in the pilot study and in the two schools as both pre-intervention test and post-intervention test. The tools were adapted from the previous examination questions in the same grade and were framed according to the requirements of the examination guidelines of the DoBE. The consistency of these instruments during use in the current study may confirm their usefulness in future related studies. The instruments may be modified to accommodate the needs of any particular research. The study provided the tool for assessing learners' cognitive levels in the pre-intervention test and post-intervention test answers as either novice, elementary, intermediate, competent of advanced (see Section 3.6.2). Although the tool is similar to the tool used by the DoBE, the description and elaborated classification of questions is a possible contribution. The novice cognitive level was when learners lacked a basic understanding of the question.

The study noted that South African learners who participated in this study were interested in being taught using POGIL because the learners in the sample demonstrated excitement. The learners claimed that they understood science better and that their marks had improved when they used POGIL in the previous topics. They described understanding science better, unlike in the past when they tended to memorise without understanding. The learners improved their reasoning and use of the ratio technique. Both the learners and the teachers attributed this improvement in reasoning and understanding of the ratio technique to the POGIL way of teaching. The learners requested to be taught mathematics using POGIL with the hope of improving their marks. Their teachers testified that the performance and participation of the learners also increased, especially the usually passive learners. This implies that POGIL may have increased learners' interest and metacognition.

The current study used the ICAP framework as the theoretical framework to monitor the learners' activities during the POGIL intervention and to assess their pre-intervention test and post-intervention test responses as a measure of the learners' constructive engagement (Chi, 2011; Chi & Wylie, 2014). It was observed that at times the learners were in none of the four cognitive levels of engagements described in the ICAP framework. For that reason, and for the purposes of this study, I modified the ICAP framework to an ICAPD framework to measure the cognitive engagement of learners during the POGIL lessons. The lowest stage being disengagement. This was observed as different from the passive state where the learner will be attentive and focused on the given task (Chi, et al., 2018; Chi & Wylie, 2014). The disengaged state is when the learner is not attentive to the given task but doing other unrelated things.

Regarding language usage, the study observed that during the POGIL intervention learners sometimes used their home language or gestures which they all understood. Such communication between learners appeared to be fast and very efficient. The study identified that the learners feel more comfortable working in small groups than discussing as a class for fear of being laughed at by other learners if they give incorrect answers.

The video stand used in the current study can be used in future studies of this nature. The stand can be used to capture learners' work as video and audio without focusing on their faces. The benefits of this particular stand (Figure 4.85) include accurately capturing the progress of the learners during the activities and ensuring the anonymity of the participants.

5.5.3 Recommendations

I recommend that high school science teachers use POGIL in teaching stoichiometry. This method may reduce the learners' elementary levels of cognition and improve their advanced and competent levels of cognition. I also suggest the use of POGIL in all the abstract topics in chemistry. I hope that the learners' cognition will improve as it did in stoichiometry. I also suggest that more science teachers undergo POGIL training, as a greater number of trained teachers will produce better results. This will lead to more networking in order to help each other to help learners learn better.

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Appendices

Appendix 1: Pre- intervention test

Pre-intervention test   Stoichiometry grade 11

Time: 1 hour   Total = 50 marks

Answer ALL the following questions showing ALL the calculations as clearly as possible. DO NOT write answers only. Write all final answers to 2 decimal places.

1. There are 0,2 moles of pure Na in a crucible. Calculate the mass of the Na in the crucible. (3)

2. How many O atoms are present in 245g sample of CO2? (5)

3. $CuO_{(s)} + H_{2(g)} \rightarrow Cu_{(s)} + H_2O_{(g)}$

Consider the balanced reaction above.

3(a) If 25g of CuO reacts completely in the reaction, calculate the mass of Cu produced in the reaction. (5)

3(b) Calculate the volume of H_2 used. (5)

4. Given the balanced chemical reaction:

$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$

Define the term limiting reagent. (2)

4(b) Calculate the mass of nitrogen dioxide that can be made when 20g of NO react with 20g of O_2 in the gaseous phase. (8)

5. Which of the following solutions has the highest concentration of chloride ions? (8)

- 10g of NaCl dissolved in $50cm^3$ of solution.
- 15g of $CaCl_2$ dissolved in 100 cm^3 of solution.
- 20g of $CrCl_3$ dissolved in 125 cm^3 of solution.

6. $15cm^3$ of $0,4moldm^{-3}$ solution of H_2SO_4 reacted with $20cm^3$ of NaOH of concentration 0,5 $moldm^{-3}$.

6(a) Write a balanced equation of this reaction (2)

6(b)	Calculate the number of moles of H_2SO_4	(3)
6(c)	Calculate the number of moles of NaOH	(3)
6(d)	Which of the two, H_2SO_4 or NaOH was in excess?	(2)
6(e)	How many grams of H_2O was produced in this reaction?	(4)

Appendix 2: Memorandum for pre-intervention test

1. $n = \frac{m}{M}$ √

$0{,}2 = \frac{m}{23}$ √ (3)

$m = 4{,}6$ g √

2. $n = \frac{m}{M}$ √ $M(CO_2) = 12+16+16 =$ (7)

44g/mol

$n = \frac{245}{44}$ √

m = 5.57 moles √

1 mole CO_2 = 2 moles O atoms

5,57 moles CO_2 = x √

x = 5.57 x 2 √ x= 11,14 moles

$n = \frac{N}{NA}$

$11{,}14 = \frac{N}{6.02 \text{ x } 1023}$ √

n = 6.7 x10^{24} O atoms √

3(a) If $n = \frac{m}{M}$ √ M(CuO) = 63.5+16 = 79.5g/mol √ (7)

$n = \frac{25}{79.5}$ √

n = 0,31 moles √

1 mole CuO produce 1 mole Cu √

0,31 moles CuO produce 0,31 moles Cu

Mass of Cu

$n = \frac{m}{M}$

$0{,}31 = \frac{m}{63{,}5}$ √

n = 19,69 g of Cu √

3(b) CuO(s) + H_2(g) → Cu(s) + H_2O(g) (3)

1 mole : 1 mole √

0,31 moles CuO: x

x = 0,31 moles H_2

$n = \frac{V}{Vm}$ $0{,}31 = \frac{V}{22.4}$ √ V of H_2 = 6,94 dm3 √

4(a) A limiting reagent is a substance that is used up first in a chemical reaction and it determines the amount of product formed. √√ (2)

4(b) Moles of NO moles of O_2

$n = \frac{m}{M}$ $n = \frac{m}{M}$ √

$n = \frac{20}{30}$ √ $n = \frac{20}{32}$

n = 0,67 moles √ n = 0,625 moles (7)

√

2NO(g) + O_2(g) → $2NO_2$(g)

2 moles : 1 mole

0,67 moles : x
x = 0, 335 moles √
0,67 moles NO react with 0,335 moles O_2
We have 0,625 moles O_2
Therefore, NO is limiting
$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$
2 moles 2 moles
0,67 moles x
x = 0,67 moles NO_2 √
$0{,}67 = \frac{m}{46}$ m = 30,82 g √

Question 5

NaCl	$CaCl_2$	$CrCl_3$	

Molar masses of each compound

23+35.45 = 58,45g/mol	40+35.45+35.45 = 110,9 g/mol	52+35,45+35,45+35,45 = 158,35 g/mol √	(1)
50/1000 = 0,05 dm^3	100/1000 = 0,1 dm^3	125/1000 = 0,125 dm^3 √	(1)

Calculate concentration of each salt

$c = \frac{m}{MV}$	$c = \frac{m}{MV}$	$c = \frac{m}{MV}$	
$c = \frac{10}{58{,}45\ x\ 0{,}05}$	$c = \frac{15}{110.9\ x\ 0{,}1}$	$c = \frac{20}{158{,}35\ x\ 0{,}1250}$	
c = 3,42 mol/dm^3 √	c = 1,35 mol/dm^3 √	c = 1.01 mol/dm^3 √	(3)

Calculate concentration of chloride ions

1 mole of NaCl produces 1 mole of Cl^- 3.42 mole of NaCl produces 3.42 mol/dm^3 Cl^- ions	1 mole of $CaCl_2$ produces 2 mole of Cl^- 1.35 moles of NaCl produces 2.7 mol/dm^3 Cl^- ions	1 mole of NaCl produces 3 mole of Cl^- √ 1.01 moles of NaCl produces 3.03 mol/dm^3 Cl^- ions √√	(1) (2)

NaCl has the highest concentration of Cl^- ions √ **(1)**

6a) $H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$ √√ (2)

6b) $c = \frac{n}{V}$ √ $0.4 = \frac{n}{15x10-3}$ √ n = 0.006 mole √ (3)

6c) $c = \frac{n}{V}$ √ $0.5 = \frac{n}{20x10-3}$ √ n = 0.01 moles √ (3)

6d) (2)

H_2SO_4 : NaOH
1 : 2
0.006 : x √
X = 0.012 moles NaOH needed
H_2SO_4 is in excess√

6e) (4)

NaOH : H_2O
2 : 2
0.01 : x √
X = 0.01 moles H_2O produced
$n = \frac{m}{M}$ √ $0.01 = \frac{m}{18}$ √ m = 0.18g H_2O √

Appendix 3: Post-intervention test

Post-intervention test Stoichiometry grade 11

Time: 1 hour Total = 50 marks

Answer ALL the following questions showing ALL the calculations as clearly as possible. DO NOT write answers only. Write all final answers to 2 decimal places.

1. There are 0,5 moles of pure Mg in a crucible. (3)

   Calculate the mass of the Mg in the crucible.

2. How many moles of O atoms are present in 25g sample of N_2O_4? (7)

3. $CaO_{(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)}$

   Consider the balanced reaction above.

3(a) If 25g of CaO reacts completely in the reaction, calculate the volume of CO_2 used. (5)

3(b) Calculate the mass of $CaCO_3$ produced. (5)

4(a) Given the balanced chemical reaction: $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$ (2)

Define the term limiting reagent.

4(b) Calculate the mass of water that can be made from 20g of H_2 and 40g of O_2 in the gaseous phase. (8)

5. Which of the following solutions has the highest concentration of HYDROGEN IONS? (7)

   - 10g of H_2SO_4 dissolved in 250cm^3 of solution.
   - 15g of HCl dissolved in 100 cm^3 of solution.

6. There are 20cm^3 of HCl with concentration 0,3moldm^{-3} which react with 23cm^3 of NaOH of concentration 0,25 moldm^{-3}.

   a) Write a balanced equation of this reaction (2)

   b) Which of the two, HCl or NaOH was in excess? (7)

   c) How many grams of H_2O was produced in this reaction? (4)

Appendix 4: Memorandum for post-intervention test

1. $n = \frac{m}{M}$ √

$0{,}5 = \frac{m}{24}$ √ (3)

$m = 12$ g √

2. $n = \frac{m}{M}$ √ $M(N_2O_4) = 14X2+16X4 = 92$g/mol

$n = \frac{25}{92}$ √

$m = 0{,}27$ moles √

1 mole N_2O_4 = 4 moles O atoms

0,27 moles N_2O_4 = x √

x = 0,27 x 4 √

x= 1,08 moles O atoms √√ (7)

3.

c) If $n = \frac{m}{M}$ √ $M(CaO) = 40+16 = 56$g/mol

$n = \frac{25}{56}$ √

$n = 0{,}45$ moles √

1 mole CaO reacts with 1 mole CO_2 √

0,45 moles CuO reacts with 0,45 moles CO_2

Volume of CO2

$n = \frac{V}{Vm}$ (6)

$0{,}45 = \frac{V}{22{,}4}$ √ (4)

$n = 10{,}08$ dm^3 of CO_2 √

d) Mass of $CaCO_3$ produced

1 mole CaO produce 1 mole $CaCO_3$ √

0,45 moles CuO produce 0,45 moles $CaCO_3$

n = $\frac{m}{M}$ √

0,45 = $\frac{m}{(40+12+48)}$ √

m = 45 g of $CaCO_3$ √

4.

(2)

a) A limiting reagent is a reactant which get used up first during a reaction and it determines the amount of product formed. √√

b) Number of moles of H_2

n = $\frac{m}{M}$

n = $\frac{20}{2}$ √

n = 10 moles of H_2 √

Number of moles of O_2

n = $\frac{m}{M}$

n = $\frac{40}{32}$ √

n = 1,25 moles of O_2 √

From equation of reaction

2 moles H_2 reacts with 1 mole O_2

So 1,25 moles O_2 reacts with 1,25x2 = 2,5 moles H_2 √

We have 10 moles H_2, therefore

(6)

The H_2 is in excess and O_2 is limiting reactant.

From the equation, 1 mole of O_2 produces 2 moles of H_2O

Therefore 1,25 moles O_2 will produce 1,25 x 2 moles = 2,5 moles H_2O √

Mass of H_2O produced

n = $\frac{m}{M}$

2,5 = $\frac{m}{18}$ √

n = 45 g of H_2O √

5 a)	b)	
H_2SO_4	HCl	
Molar masses of each compound		
2x1+32x1+16x4 = 98g/mol	1x1+35.5x1 = 36.5 g/mol	(1)
Calculate concentration of each		
$c = \frac{m}{MV}$	$c = \frac{m}{MV}$	(3)
$c = \frac{10}{98\ x\ 0{,}25}$ c = 0.41 mol/dm^3	$c = \frac{15}{36.5\ x\ 0{,}1}$ c = 4.1 mol/dm^3	
Calculate concentration of hydrogen ions		(1)
1 mole of H_2SO_4 produces 2 moles of H^+ Therefore	1 mole of HCl produces 1 moles of H^+ Therefore	(2)
0.41 moles H_2SO_4 produce **0.82 moles** H^+	4.1 moles HCl produce **4.1 moles** H^+	(1)
HCl has the highest concentration of H^+ ions		(2)

(7)

6. a) HCl + NaOH $\longrightarrow$ NaCl + H_2O

b) $c = \frac{n}{V}$ $0{,}3 = \frac{n}{20x10-3}$ $c = \frac{n}{V}$ $0{,}25 = \frac{n}{23x10-3}$

n = 0,006 mole HCl n = 0,00575 mole

1 mole HCl reacts with 1 mole NaOH HCl is in excess

(4)

c) NaOH : H_2O
1 moles : 1 moles
0,00575 moles: *x* moles *x* = 0,00575 moles H_2O

$n = \frac{m}{M}$ $0{,}00575 = \frac{m}{18}$ $m = 0{,}1035$ g H_2O

Appendix 5: Marking guidelines.

The work done by learners in the pre-intervention test and post-intervention test was coded with the assistance of marking guidelines on table as well as the memoranda on the appendices section.

Marking guidelines for pre-intervention test and post-intervention test

Question	**Codes**	**Expected learner activity**	
1	Intermediate	Correct **formula** Correct **substitution** Appropriate answer	
	Elementary	Correct formula Wrong substitution Wrong answer	
	Novice	Wrong formula Wrong answer	No response written
2	Advanced	Correct formula for number of moles $n = \frac{m}{M}$ Correct substitution Correct number of moles = 5.57 moles Correct ratio of 1:2 Correct calculation of number of moles = 11.14 moles Correct formula for number of moles $n = \frac{N}{NA}$ Correct substitution Correct number of atoms = 6.7 $\times 10^{24}$ O atoms {all steps well done}	
	Competent	Correct formula for number of moles $n = \frac{m}{M}$ Correct substitution Correct number of moles = 5.57 moles Wrong ratio of 1:2 or no ratio at all Calculation of number of moles Correct formula for number of moles $n = \frac{N}{NA}$ Correct substitution Incorrect number of atoms {only 1 step not done appropriately}	
	Intermediate	Correct formula for number of moles $n = \frac{m}{M}$ Incorrect substitution Incorrect number of moles No ratio used	

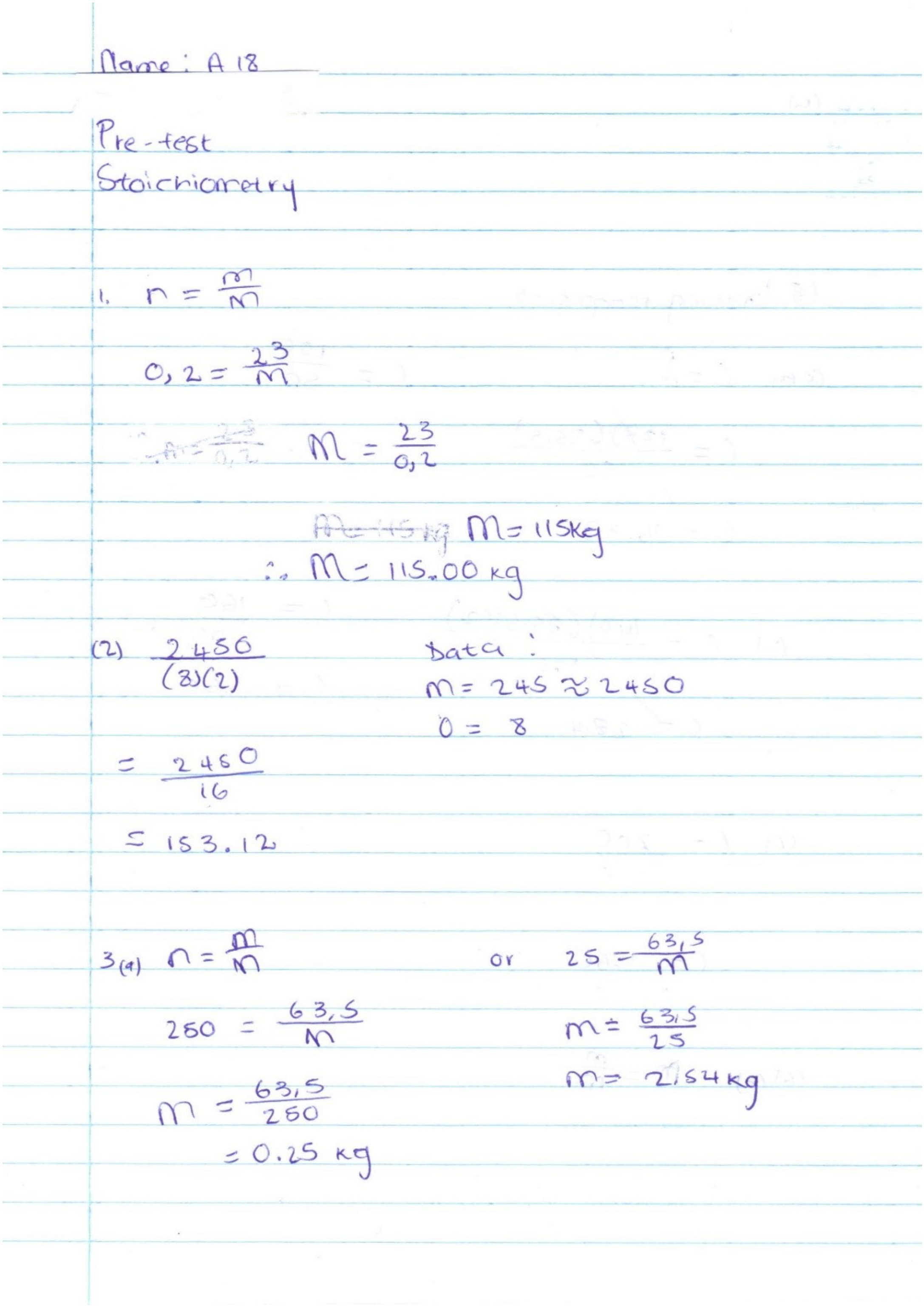
		Correct formula for number of moles n = $\frac{N}{NA}$ Correct substitution of wrong number of moles Incorrect number of atoms {only 2 steps appropriately done}	
	Elementary	Correct formula for number of moles n = $\frac{m}{M}$ Correct substitution Correct number of moles No ratio used {only one step appropriately done}	
	Novice	Wrong formula used Wrong substitution Wrong answer	No response
3a	Advanced	Correct formula n = $\frac{m}{M}$ Correct substitution Appropriate answer Correct ratio of 1:1 Correct number of moles of Cu Correct formula n = $\frac{m}{M}$ Correct mass of Cu	
	Competent	Correct formula n = $\frac{m}{M}$ Correct substitution Appropriate answer No ratio used Correct number of moles of Cu Correct formula n = $\frac{m}{M}$ Correct mass of Cu	
	Intermediate	Correct formula n = $\frac{m}{M}$ Correct substitution Appropriate answer Correct ratio of 1:1 Correct number of moles of Cu Correct formula n = $\frac{m}{M}$ Correct mass of Cu	
	Elementary	Correct formula n = $\frac{m}{M}$ Correct substitution Appropriate answer	
	Novice	Correct formula Wrong substitution Wrong answer	
3b	Intermediate	Correct ratio 1:1 Correct formula n = $\frac{V}{Vm}$ Correct substitution Correct volume of H_2 = 6,94 dm^3	

	Elementary	Correct formula n = $\frac{V}{Vm}$ Incorrect substitution Incorrect volume of H_2	
	Novice	Nothing written	Wrong formula Wrong substitution Wrong answer
4a	Intermediate	Complete definition of limiting reactant	
	Elementary	Partially correct definition	
	Novice	No definition given	Wrong definition
4b	Advanced	Correct formula n = $\frac{m}{M}$ Correct substitution Correct numbers of moles of NO = 0,67 moles and O_2 = 0,625 moles Correct mole ratio of 2:1 Correct number of equivalent moles of O_2 or NO Correct identification of NO as the limiting reactant Correct ratio of 2:2 Correct number of moles of NO_2 = 0,67 moles Correct formula n = $\frac{m}{M}$ Correct substitution Correct mass of NO_2 = 30,82 grams	
	Competent	Correct formula n = $\frac{m}{M}$ Incorrect substitution incorrect numbers of moles of NO and O_2 Correct mole ratio of 2:1 Correct number of equivalent moles of O_2 or NO Correct identification of NO as the limiting reactant Incorrect ratio of 2:2 Incorrect number of moles of NO_2	
	Intermediate	Correct formula n = $\frac{m}{M}$ Incorrect substitution incorrect numbers of moles of NO and O_2 Incorrect number of equivalent moles of O_2 or NO Incorrect identification of NO as the limiting reactant Incorrect ratio of 2:2 Incorrect number of moles of NO_2	
	Elementary	Correct formula n = $\frac{m}{M}$ Incorrect substitution Incorrect number of equivalent moles of O_2 or NO Incorrect identification of NO as the limiting reactant Incorrect ratio of 2:2 Incorrect number of moles of NO_2	
	Novice	Nothing written	Correct formula n = $\frac{m}{M}$ Incorrect substitution Incorrect ratio of 2:2 Incorrect number of moles of NO_2

5	Advanced	Correct conversion of units to $0,05dm^3$; $0,1dm^3$ and $0,125dm^3$ Correct calculation of concentration of each of the three salts of $3,42dm^3$; $1,35dm^3$; and $1,01dm^3$ respectively Use of correct ratio Correct calculation of number of concentrations of chloride ions in each salt Correct comparison of the of the concentration of the chloride ions Correct final answer	
	Competent	Correct conversion of units to $0,05dm^3$; $0,1dm^3$ and $0,125dm^3$ Correct calculation of concentration of each of the three salts of $3,42dm^3$; $1,35dm^3$; and $1,01dm^3$ respectively No comparison of the of the concentration of the chloride ions	
	Intermediate	Correct conversion of units to $0,05dm^3$; $0,1dm^3$ and $0,125dm^3$ Correct calculation of concentration of each of the three salts with minor errors. No comparison of the of the concentration of the chloride ions	
	Elementary	Incorrect conversion of units Incorrect calculation of concentration of salts No comparison of the of the concentration of the chloride ions	
	Novice	No response	Wrong formula Wrong substitution Wrong answer
6a	Intermediate	Correct **formula** Correct **substitution** Appropriate answer	
	Elementary	Correct formula Wrong substitution Wrong answer	
	Novice	Wrong formula Wrong answer	No response written
6b	Intermediate	Correct **formula** Correct **substitution** Appropriate answer	
	Elementary	Correct formula Wrong substitution Wrong answer	
	Novice	Wrong formula Wrong answer	No response written
6c	Intermediate	Correct **formula** Correct **substitution** Appropriate answer	
	Elementary	Correct formula Wrong substitution	

		Wrong answer	
	Novice	Wrong formula Wrong answer	No response written
6d	Intermediate	Correct **formula** Correct **substitution** Appropriate answer	
	Elementary	Correct formula Wrong substitution Wrong answer	
	Novice	Wrong formula Wrong answer	No response written
6e	Intermediate	Correct **formula** Correct **substitution** Appropriate answer	
	Elementary	Correct formula Wrong substitution Wrong answer	
	Novice	Wrong formula Wrong answer	No response written

Appendix 6: Sample pre-intervention test script



Name : A 18

Pre-test

Stoichiometry

1. $n = \frac{m}{M}$

$0,2 = \frac{23}{M}$

~~$\therefore M = \frac{23}{0,2}$~~ $M = \frac{23}{0,2}$

~~$M = 115$ kg~~ $M = 115$kg

$\therefore M = 115.00$ kg

(2) $\frac{2450}{(8)(2)}$

Data :

$m = 245 \approx 2450$

$0 = 8$

$= \frac{2460}{16}$

$= 153.12$

3(a) $n = \frac{m}{M}$

$250 = \frac{63,5}{M}$

$m = \frac{63,5}{250}$

$= 0.25$ kg

or $25 = \frac{63,5}{M}$

$m = \frac{63,5}{25}$

$m = 2,54$ kg

(b)

(4) limiting reagent -▷

(5 (a) $C = \frac{n}{m}$

~~$C = \frac{(23)(35;5)}{50}$~~

~~$C = 16.33$~~

$C = \frac{100}{50}$

$C = 2.00$

(b) ~~$C = \frac{(40)(35,5)(2)}{100}$~~

~~$C = 28.4$~~

$C = \frac{150}{100}$

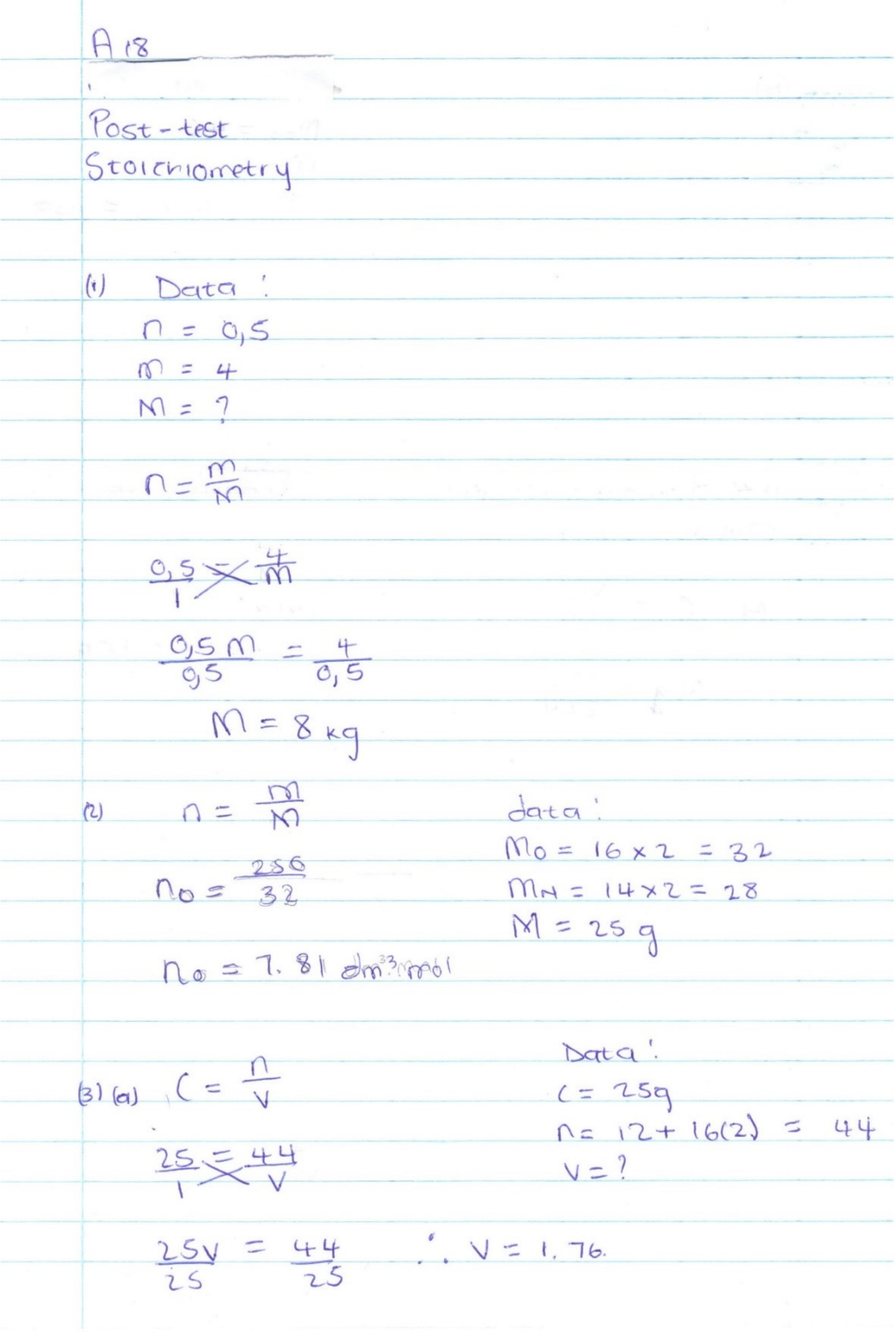
$C = 1,50$

(c) $C = \frac{200}{125}$

$C = 1.60$

(6) (b) $M = \frac{m}{M}$

Appendix 7: Sample Post-intervention test script



A 18

Post - test
Stoichiometry

(1) Data :

$n = 0,5$
$m = 4$
$M = ?$

$n = \frac{m}{M}$

$\frac{0,5}{1} \overset{\times}{=} \frac{4}{m}$

$\frac{0,5\ m}{0,5} = \frac{4}{0,5}$

$M = 8\ kg$

(2) $n = \frac{m}{M}$

$n_o = \frac{256}{32}$

$n_o = 7.\ 81\ dm^{3}\ mol$

data :
$M_O = 16 \times 2 = 32$
$M_N = 14 \times 2 = 28$
$M = 25\ g$

(3) (a) $C = \frac{n}{V}$

$\frac{25}{1} \overset{\times}{=} \frac{44}{V}$

$\frac{25V}{25} = \frac{44}{25}$ $\therefore V = 1.76.$

Data :
$C = 25g$
$n = 12 + 16(2) = 44$
$V = ?$

(b) $n = \frac{m}{M}$

Data!

$M_{Ca} = 40$

$M_C = 12$

$M_O = 16 \times 3 = 48$

$\frac{1.76}{224}$

=

$CO_2 =$

$C = \frac{V_A}{V_m}$

$C =$

4 (a) ∴Limiting reagent is a ~~electron~~ ~~reagent~~ ~~that~~ proton donor

(b) $C = \frac{VA}{Vm}$

Data!

20g + 40g = 60g

$60g = \frac{VA}{224}$

Appendix 8: Letter of informed consent for principals

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Date:
23/04/2019

Dear Principal.

RE: <u>REQUEST FOR PERMISSION TO CONDUCT A RESEARCH AT YOUR SCHOOL.</u>

I am a student in the Department of Science, Mathematics and Technology Education at the University of Pretoria, studying for a Doctoral degree (PhD). To fulfil the requirements of the course, I must conduct a research study entitled “Exploring how Process-Oriented Guided Inquiry Learning on high school chemistry learners elicit understanding of stoichiometry.” I request your permission to collect data at your school.

The aim of the study is to identify how physical science learners develop understanding as they engage in process-oriented guided inquiry learning (POGIL) activities. The study analysed the learners’ reasoning during problem-solving as they developed understanding. In this study a grade 11 physical science teacher was trained to teach using POGIL outside normal working hours. That teacher shall teach three lessons his or her grade 11 physical science class (30 learners) during normal teaching time under observation by the researcher using POGIL. The three lessons were video, and audio recorded and soon after the lesson the learners was interviewed after school hours. This study is very important for both teachers and learners because it will reveal to the teacher how learners’ reason and how they solve stoichiometry questions. This will help the teachers to find ways of assisting their learners to improve their understanding.

All information related to the study will be treated anonymously when reporting results. The identity of participating schools, teachers and learners will be strictly confidential. Your positive consideration of my request will be highly appreciated.

Should you agree to have the study conducted at your school, we request you to kindly read and sign the attached consent form. Thank you very much for spending time to consider this request.

Kind regards.

Mr. Charles Mamombe Signature: Date: 23/04/2019

(Doctoral Student, University of Pretoria)

Student Number: 12293581

Supervisor: Dr. K.C. Mathabathe Signature Date: 23/04/2019

Informed consent form for data collection

Please read the conditions below and sign if you agree that your school may participate.

I understand and agree that:

1. The physical science educator will be trained to teach using POGIL for two hours.
2. The physical science teacher will be observed three lessons by the researcher while teaching his/her class using POGIL during normal teaching time at my school.
3. The learners will be interviewed by the researcher after normal teaching time at the school in the presence of their usual teacher.

4. The identity of the school, the teacher and the learners will be held in the strictest confidence.
5. This school's participation in the study is voluntary, and the school can withdraw at any stage of the research.
6. I am not waiving any human or legal rights by agreeing to participate in this study.
7. I verify by signing below that I have read and understood the conditions listed above.

Principal Signature: …………………………………..

School's stamp:

Appendix 9: Letter of informed consent for educators

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Date: 23/04/2019

Dear Teacher

RE: <u>REQUEST TO PARTICIPATE IN A RESEARCH STUDY.</u>

You may be aware that the performance of South African high school learners in physical science has been declining for almost a decade now. We are conducting a research study in an attempt to find a way of finding the possible cause of such low performance. The purpose of this study is to investigate the thinking patterns of the learners, their reasoning and problem-solving skills as they engage in stoichiometric activities. We have identified that stoichiometry is a challenging topic which constitutes a considerable percentage of the chemistry section in physical science.

To achieve this, we intend to train you to teach using process-oriented guided inquiry learning (POGIL) in the topic stoichiometry. This teaching method has been identified to yield good results with regards to the understanding of learners. After training for about two hours you will be asked to teach stoichiometry to your grade 11 physical sciences class under observation by the researchers. You will be having full support from the researchers with regards to POGIL teaching and class activities. You may seek assistance before, during and after the lessons. We will provide with the lesson plans and all the materials needed, and you may request any extra materials you may need for the lessons. In this study you have the opportunity to share your views towards the use of POGIL. You are therefore invited to participate in the study.

If you are interested in participating in the research, your role will be to teach three lessons to your grade 11 physical science class for about three hours in total on the topic stoichiometry. The decision to participate in this study is entirely yours. You have the right to decline participation now or afterward you initially agreed. This means that if you agree now you still have the right to change your mind at a later stage. Your participation or no participation in the study and the outcomes of the study will have NO consequences on your profession as a teacher, or on your personal reputation. Your identity and that of the school will be strictly confidential. You are free to withdraw from the study anytime.

If you are willing to participate in this research, please kindly sign on the attached declaration form.

Kind regards.

Mrs Charles Mamombe Signature Date: 23/04/2019

(Doctoral Student, University of Pretoria)

Student Number: 12293581

Supervisor: Dr. K.C. Mathabathe Signature Date: 23/04/2019

Declaration of informed consent

I have read, and I understand the above information. I voluntarily agree to participate in the research study described above.

I DO AGREE to be trained to teach using POGIL ☐

I DO NOT agree for my child to participate ☐

I DO AGREE to teach using POGIL ☐

I DO NOT agree teach using POGIL ☐

I DO AGREE to be VIDEO recorded ☐

I DO NOT AGREE to be VIDEO recorded ☐

I DO AGREE to be AUDIO recorded ☐

I DO NOT AGREE to be AUDIO recorded ☐

I DO AGREE to be interviewed by POGIL experts ☐

I DO NOT agree to be interviewed by POGIL experts ☐

Teacher’s signature: .... Date: ....

Appendix 10: Letter of informed consent for parent or guardian

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Date: 23/04/2019

Dear Parent/Guardian

RE: <u>REQUEST FOR YOUR CHILD TO PARTICIPATE IN A RESEARCH STUDY</u>

You may be aware that the performance of South African high school learners in physical science has been declining for almost a decade now. We are conducting a research study in an attempt to find a way of finding the possible cause of such low performance. The purpose of this study is to investigate the thinking patterns of the learners, their reasoning and problem-solving skills as they engage in stoichiometric activities. We have identified that stoichiometry is a challenging topic which constitutes a considerable percentage of the chemistry section in physical science.

To achieve this, we intend to train your child's physical science teacher to teach using process-oriented guided inquiry learning (POGIL) in the topic stoichiometry. This teaching method has been identified to yield good results with regards to the understanding of learners. We ask permission for your child to participate in the POGIL lessons taught by their usual teacher under observation by the researchers. Your child will participate in group activities with classmates, will be video recorded during the lessons and audio also recorded during interviews. In this study your child may have the opportunity to participate in this modern teaching approach which may help better understanding of difficult topics. You are asked whether you wish your child to participate in the study or not.

If you are interested in allowing your child to participate during the three lessons for about three hours in total on the topic stoichiometry. The decision for your child to participate in this study is entirely yours as the parent of guardian. You have the right to decline participation of your child now or at a later stage. The participation or no participation by your child in the study and the outcomes of the study will have NO consequences on your child or yourself. You are free to withdraw your child from the study anytime. The identity of your child school will be strictly confidential.

If you are willing to that your child participates in this research, please kindly sign on the attached declaration form.

Kind regards.

Mrs Charles Mamombe Signature Date: 23/04/2019

(Doctoral Student, University of Pretoria)

Student Number: 12293581

Supervisor: Dr. K.C. Mathabathe Signature Date: 23/04/2019

Declaration of informed consent

I have read, and I understand the above information. I voluntarily agree for my child to participate in the research study described above.

I DO AGREE for my child to be taught using POGIL ☐

I DO NOT AGREE for my child to be taught using POGIL ☐

I DO AGREE for my child to be VIDEO recorded ☐

I DO NOT AGREE for my child to be VIDEO recorded ☐

I DO AGREE for my child to be AUDIO recorded ☐

I DO NOT AGREE for my child to be AUDIO recorded ☐

Parent’s or guardian’s signature: .... Date: ....

Appendix 11: Letter of informed assent of the learner

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

Date: 23/04/2019

Dear Learner

RE: <u>REQUEST FOR YOU TO PARTICIPATE IN A RESEARCH STUDY.</u>

You may be aware that the performance of South African high school learners in physical science has been declining for almost a decade now. We are conducting a research study in an attempt to find a way of finding the possible cause of such low performance. The purpose of this study is to investigate the thinking patterns of the learners, their reasoning and problem-solving skills as they engage in stoichiometric activities. We have identified that stoichiometry is a challenging topic which constitutes a considerable percentage of the chemistry section in physical science.

To achieve this, we intend to train your physical science teacher to teach using process-oriented guided inquiry learning (POGIL) in the topic stoichiometry. This teaching method has been identified to yield good results with regards to the understanding of learners. We ask you to participate in the POGIL lessons taught by your usual teacher under observation by the researchers. You will participate in group activities with classmates, will be video recorded during the lessons and audio also recorded during interviews. In this study you may have the opportunity to participate in this modern teaching approach which may help you better understand difficult topics. We ask you whether you wish to participate in the study or not.

If you are interested in participating in this research project, you will be taught for three lessons, a total of three hours on the topic stoichiometry. The decision to participate in this study is entirely yours. You have the right to decline participation now or at a later stage. Your participation or no participation in the study and the outcomes of the study will have NO consequences on you. You are free to withdraw from the study anytime. Your identity will be strictly confidential.

If you are willing to participate in this research, please kindly sign on the attached declaration form.

Kind regards.

Mrs Charles Mamombe Signature Date: 23/04/2019

(Doctoral Student, University of Pretoria)

Student Number: 12293581

Supervisor: Dr. K.C. Mathabathe Signature Date: 23/04/2019

Declaration of informed consent

I have read, and I understand the above information. I voluntarily agree to participate in the research study described above.

I DO AGREE to be taught using POGIL ☐

I DO NOT AGREE to be taught using POGIL ☐

I DO AGREE to be VIDEO recorded ☐

I DO NOT AGREE to be VIDEO recorded ☐

I DO AGREE to be AUDIO recorded ☐

I DO NOT AGREE to be AUDIO recorded ☐

Learner’s signature: .... Date: ....

Appendix 12: POGIL worksheet

Limiting and Excess Reactants

Is there enough of each chemical reactant to make a desired amount of product?

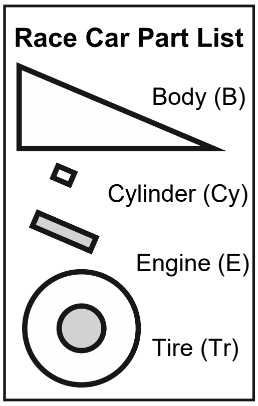
Why?

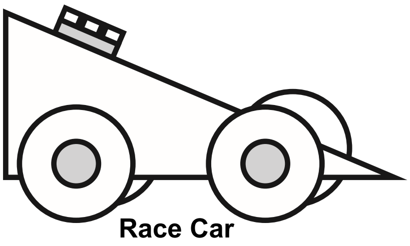
If a factory runs out of tyres while manufacturing cars, production stops. No more cars can be fully built without ordering more tires.

A similar thing happens in a chemical reaction. If there are fixed amounts of reactants to work with in a chemical reaction, one of the reactants may be used up first. This prevents the production of more products.

In this activity, you will look at several situations where the process or reaction is stopped because one of the required components has been used up.

Model 1 – Assembling a Race Car (10 minutes)





1. How many of each part are needed to construct 1 complete race car?

   Body (B)　Cylinder (Cy)　Engine (E)　Tyre (Tr)

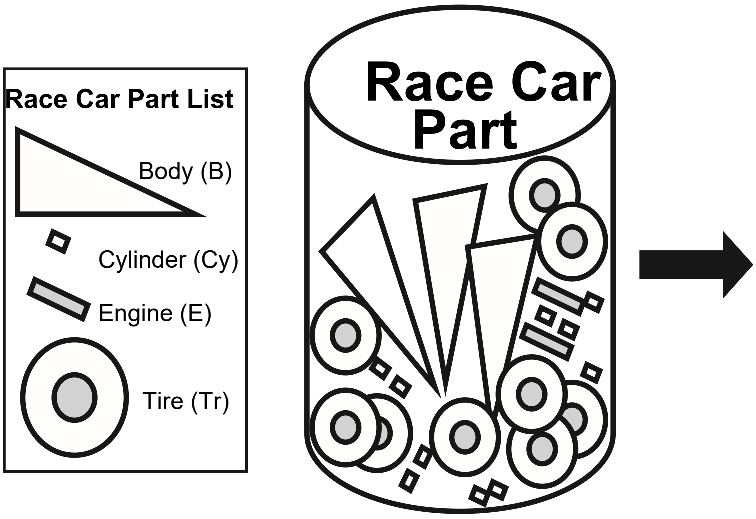
2. How many of each part would be needed to construct 3 complete race cars? Show your work.

   Body (B)　Cylinder (Cy)　Engine (E)　Tire (Tr)

3. Assuming that you have 15 cylinders and an unlimited supply of the remaining parts:
   a. How many complete race cars can you make? Show your work.
   b. How many of each remaining part would be needed to make this number of cars? Show your work.

STOP

Model 2 – Manufacturing Race Cars (20 minutes)



Container A

4. Count the number of each Race Car Part present in Container A of Model 2.

Body (B) Cylinder (Cy) Engine (E) Tire (Tr)

5. Complete Model 2 by drawing the maximum number of cars that can be made from the parts in Container A. Show any excess parts remaining also.
6. A student says “I can see that we have three car bodies in Container A, so we should be able to build three complete race cars.” Explain why this student is incorrect in this case.

7. Suppose you have a very large number (dozens or hundreds) of tyres and bodies, but you only have 5 engines and 12 cylinders.

   a. How many complete cars can you build? Show your work.
   b. Which part (engines or cylinders) limits (stops you from making) the number of cars that you can make?

7. Fill in the table below with the maximum number of complete race cars that can be built from each container of parts (A–E), and indicate which part limits the number of cars that can be built.

Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of complete cars for their container. Container A from Model 2 is already completed as an example.

1 B + 3 Cy + 4 Tr + 1 E = 1 car

Container	**Bodies**	**Cylinders**	**Tires**	**Engines**	**Max. Number of Completed Cars**	**Limiting Part**
A	3	10	9	2	2	Engines
	Used = 2 Left = 1	Used = 6 Left = 4	Used = 8 Left = 1	Used = 2 Left = 0		
B	50	12	50	5		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		
C	16	16	16	16		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		
D	4	9	16	6		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		
E	20	36	40	24		
	Used = Left =	Used = Left =	Used = Left =	Used = Left =		

9. The Zippy Race Car Company builds toy race cars by the thousands. They do not count individual car parts. Instead they measure their parts in “oodles” (a large number of things).

b. Assuming the inventory (list) in their warehouse below, how many race cars could the Zippy Race Car Company build? Show your work.

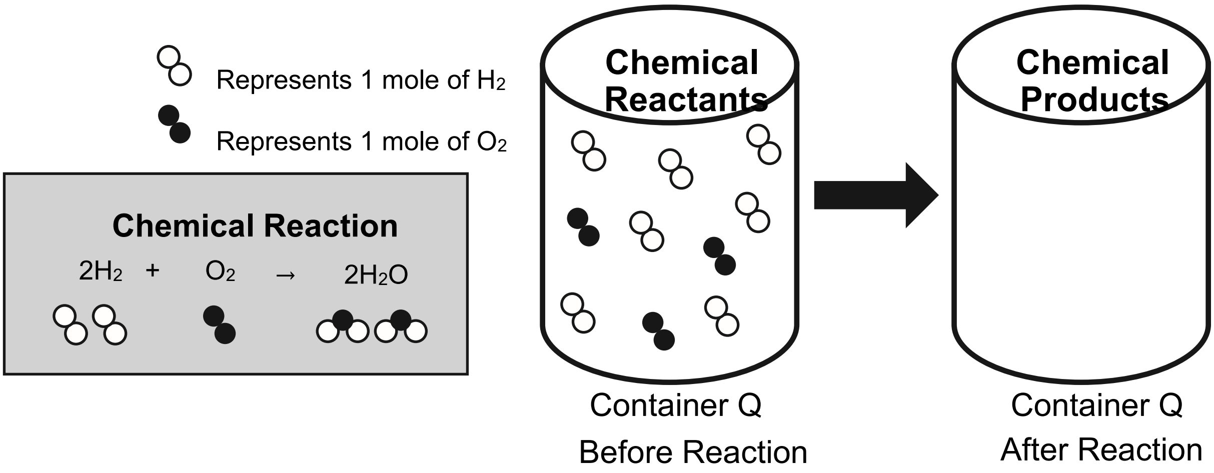
Body (B)	Cylinder (Cy)	Engine (E)	Tire (Tr)
4 oodles	5 oodles	8 oodles	8 oodles

c. Explain why it is not necessary to know the number of parts in an “oodle” to solve the problem in part *a*.

10. Look back at the answers to Questions 8 and 9. Is the component with the smallest number of parts always the one that limits production? Explain your group’s reasoning.

STOP

Model 3 – Assembling Water Molecules (20 minutes)



11. Refer to the chemical reaction in Model 3.

    a. How many moles of water molecules are produced if one mole of oxygen molecules completely reacts?

    b. How many moles of hydrogen molecules are needed to react with one mole of oxygen molecules?

12. Complete Model 3 by drawing the maximum moles of water molecules that could be produced from the reactants shown and draw any remaining moles of reactants in the container after reaction as well.

    a. Which reactant (oxygen or hydrogen) limited the production of water in Container Q?

    b. Which reactant (oxygen or hydrogen) was present in excess and remained after the production of water was complete?

13. Fill in the table below with the maximum number of moles of water that can be produced in each container (Q–U). Indicate which reactant limits the quantity of water produced—this is the **limiting reactant**. Also show how much of the other reactant—the **reactant in excess**—will be left over. Divide the work evenly among group members. Space is provided below the table for each group member to show their work. Have each group member describe to the group how they determined the maximum number of moles of water produced and the moles of reactant in excess. Container Q from Model 3 is already completed as an example.

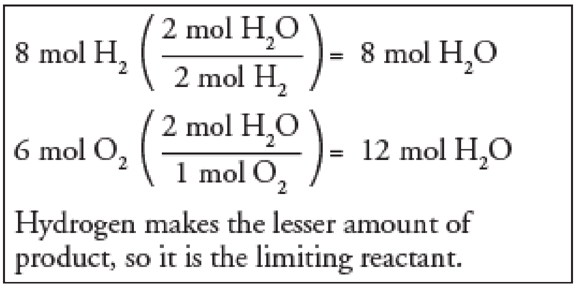
$$2H_2 \quad + \quad O_2 \quad \rightarrow \quad 2H_2O$$

Container	**Moles of Hydrogen**	**Moles of Oxygen**	**Max. Moles of Water Produced**	**Limiting Reactant**	**Reactant in Excess**
Q	7	3	6	O_2	1 mole H_2
	Used = 6 Left = 1	Used = 3 Left = 0			
R	8	3			
	Used = Left =	Used = Left =			
S	10	5			
	Used = Left =	Used = Left =			
Teacher:	5	5			
	Used = Left =	Used = Left =			
U	8	6			
	Used = Left =	Used = Left =			

14. Look back at Questions 12 and 13. Is the reactant with the smaller number of moles always the limiting reactant? Explain your group's reasoning.

Model 4 – Extension Questions (8 minutes)

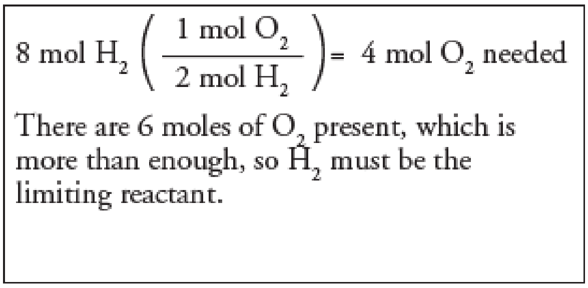
15. Below are two examples of mathematical calculations that could be performed to find the limiting reactant for Container U in Question 13.



$$8 \text{ mol } H_2 \left(\frac{2 \text{ mol } H_2O}{2 \text{ mol } H_2}\right) = 8 \text{ mol } H_2O$$

$$6 \text{ mol } O_2 \left(\frac{2 \text{ mol } H_2O}{1 \text{ mol } O_2}\right) = 12 \text{ mol } H_2O$$

Hydrogen makes the lesser amount of product, so it is the limiting reactant.



$$8 \text{ mol } H_2 \left(\frac{1 \text{ mol } O_2}{2 \text{ mol } H_2}\right) = 4 \text{ mol } O_2 \text{ needed}$$

There are 6 moles of O_2 present, which is more than enough, so H_2 must be the limiting reactant.

a. Do both calculations give the same answer to the problem?

b. Which method was used most by your group members in Question 13?

c. Which method seems "easier," and why?

d. Did your group use any other method(s) of solving this problem that were scientifically and mathematically correct? If so, explain the method.

Extension Questions (8 minutes)

16. Consider the synthesis of water as shown in Model 3. A container is filled with 10.0 g of H_2 and 5.0 g of O_2.

a. Which reactant (hydrogen or oxygen) is the limiting reactant in this case? Show your work. *Hint:* Notice that you are given reactant quantities in mass units here, not moles.

What mass of water can be produced? Show your work.

b. Which reactant is present in excess, and what mass of that reactant remains after the reaction is complete? Show your work.

Extension Questions (12 minutes)

18cm3 of 0,25moldm-3 solution of H_2SO_4 reacted with 23cm3 of NaOH of concentration 0,35 moldm-3.

a. Write a balanced equation of this reaction.

b. Calculate the number of moles of H_2SO_4 .

c. Calculate the number of moles of NaOH.

d. Which of the two, H_2SO_4 or NaOH was in excess?

e. How many grams of H_2O was produced in this reaction?

Appendix 13: Interview schedule for teachers

1. You have been workshopped to teach using POGIL and you have done so practically in your class, how was the experience?
2. Do you think POGIL is an effective teaching approach as compared to lecture method?
3. With your experience what are the advantages of using POGIL?
4. What are the disadvantages of using POGIL?
5. What was the experience of your learners as compared to the usual lessons?
6. During your POGIL lessons what can you comment about the activities done by the learners?
7. Do you expect your learners to have understood you better than during your usual lessons? Explain.
8. Do you intend to use POGIL in your future lessons?

Appendix 14: Interview schedule for learner

1. You have been taught using POGIL, what can you comment about the method?
2. Do you think you understand science better or less? Explain
3. Has the POGIL method made you to reason better in science?
4. Did the POGIL method make you to love science? Explain.
5. Do you think you shall perform better in the post test than the first test? Explain
6. Would you like to be taught using POGIL in the other science topics? Explain.
7. Do you expect to pursue your further studies in science related field?

Appendix 15: Teacher interview transcription school B

Interviewer: Okay. Good morning ma'am.

Teacher: Good morning sir. How are you?

Interviewer: I am fine, how are you?

Teacher: Good

Interviewer: You have been trained to use POGIL and you have taught your learners using POGIL

Teacher: Yes

Interviewer: How can you explain to someone what is POGIL?

Teacher: POGIL is a teaching strategy whereby we use group work and learners are grouped in groups of four sometimes six whereby they have different roles that they play, and they interchange. At the end of the day all the learners are able to become managers and able to become document controllers and all the other roles.

Interviewer: Okay can you briefly explain how you implemented POGIL in your classes?

Teacher: Okay. What I did I had six learners per group, but the groups were fixed. So, there was no need for me to change them because anyways the roles are rotated. So, all the learners were able to participate and play every role in the POGIL strategy.

Interviewer: okay, how did your learners respond to POGIL?

Teacher: My learners we very happy with POGIL. Reason being that they are exposed to different things at a time. They are not fixed to 1 role. They are able to share and discuss, and every learner was able to participate.

Interviewer: Okay and just an additional question there. How did you see the participation of the usually slow learners? Did they participate more during the POGIL activities or they just remained passive?

Teacher: I think it depends on the topic. Sometimes if they are not well versed with the topic, they end up being passive and allow others to talk. But at the end of the day they went back and became a team. It gives pressure if the other group is participating more, they will be motivated to go with the flow.

Interviewer: During your POGIL lessons what can you comment about the activities done by the learners?

Teacher: The learners helped each other. The slow learners also participated actively. Learners gave their many different opinions. The learners argued their answers with reasoning. Sometimes they requested my opinion when they fail to reach agreement.

Interviewer: Okay. Which of the grades accepted POGIL the most?

Teacher: Grade 10s more than grade 11.

Interviewer: Can you explain. What do you think the grade 10 accepted POGIL more? Is it because of their age or what?

Teacher: I think it's because of the age. Grade 10s are very playful. So, if they are in a group and given the role cards, they are so into the role cards than anything. They all want to be managers or sometimes refuse. They participate more than grade 11s. grade 11s are like this is for kids.

Interviewer: When you implemented POGIL how did the learners perform in that topic?

Teacher: I would say the overall performance or participation was much better unlike if I was the one presenting the lesson. Only a selected few will respond but if it's a POGIL almost 50% of the learners are participating. So POGIL encourages teamwork and more participation.

Interviewer: during the POGIL lessons what can you comment about the activities done by the learners? Were the activities giving the learners attention or were they too easy?

Teacher: If I refer to stoichiometry the activities were challenging. But the topic was more of relating to real life than the lesson. So, it was an eye opener that physical science is not all about chemistry or the physics part. So, the learners pay attention more into the topic. It gets them interested and thinking more.

Interviewer: Initially, how was the performance of your learners in stoichiometry?

Teacher: Uhm, very bad.

Interviewer: and how do you expect your learners to perform in stoichiometry after POGIL?

Teacher: I would say much better than the way they started.

Interviewer: Do you think you learners if given a choice would prefer POGIL teaching over other teaching approaches?

Teacher: I think they learners will prefer POGIL teaching because all members in the group are participating whether they like it or not. So, they are kept in the content. They cannot go outside of it and they are kept busy.

Interviewer: if POGIL is used in other subjects like mathematics do you think it is going to be beneficial for the learners?

Teacher: I believe so. Reason being when you are working in a group you are sharing information. Whatever little data that you have you also feel the need to voice it out so at the end of the day everyone is able to give their suggestion and in turn they are getting immediate response. Unlike it's just a learner working in isolation unlike in a group.

Interviewer: When using POGIL do you think the learners are easy to control than when using direct teaching method?

Teacher: Unfortunately, with POGIL you have to be firm. Because sometimes they become very noisy and disturb the other classes and some will just take advantage of that the teacher is on that other group and sneak out or something. POGIL needs more thorough control unlike in the lecture method.

Interviewer: what about the time?

Teacher: Its very time consuming but at the end of the day you are able to do a lot. Because sometimes you can give them not just 1 activity. That is what I did when I was doing revision of paper 2, I gave them different questions. I gave different questions to different groups. So that when revising we know that we done with the question paper in one goal. Instead of focusing on 1 question. POGIL is very good and very helpful

Interviewer: So, you think you will continue using POGIL in your lessons?

Teacher: Exactly. To improve POGIL I would ask the spokesperson from one group to go around to the other group and explain their experience.

Appendix 16: Teacher interview transcription school A

Interviewer: Okay. Good morning ma'am.

Teacher: Good morning sir.

Interview: How are you?

Teacher: I am fine, how are you?

Interview: I am fine, thank you.

Interviewer: You have been trained to use POGIL and you have taught your learners using POGIL

Teacher: Yes

Interviewer: How was your experience during POGIL training?

Teacher: POGIL is a wonderful and easy method. Initially I thought it was just a joke and nothing special which they were training. But I saw the examples which were used were of other subjects but still I understood them easily.

Interviewer: Yea, they used the example of a business question and everyone got it right in their groups, right?

Teacher: Yes, that was when I started to see that there could be some magic with this POGIL method.

Teacher: So, how can you tell someone what is POGIL?

Teacher: POGIL is a method where learners work in groups of two, four or six working together. The learners do teamwork and help each other to work through the provided worksheet. The learners have roles like manager, spokesperson and the like and they rotate the roles after some time.

Interviewer: So, during POGIL how can you explain the actions done by the learners?

Teacher: Yoh, the learners are so active and each one of them participate actively. They end up producing a noise that can disturb other groups and other classes. But the learners finally help each other in the process and solve even the difficult questions. Each learner has to support their ideas before the group. They cannot just bring the answer without reason. So, the learner explain why that is the appropriate answer.

Interviewer: Okay can you briefly explain how you implemented POGIL in your classes?

Teacher: Okay. It depends with the class. In one of my grades 10 classes I asked them to make the groups of their own choice. So, the learners sat there according to their friends and work very well. In one class of the grades 11 I arranged them according to performance in science. The brightest alone and the lowest alone.

Interviewer: So, arranging brightest learners alone, what was your experience?

Teacher: That’s the best method to do. It gives me time to attend to the slow learners and I will attend to them in a group. The fast learners will do a lot of work and go from one activity to another without asking for my help. So, the fast learners learn more.

Interviewer: So, you are basically teaching the slow learners?

Teacher: Not as such. The slow learners themselves go quite fast. It appears that they are slow when they see the fast learners. But on their own they work very well and solve difficult questions like number 5 of the second test. They give reasons and discuss. They are just more quiet than the fast learners.

Interviewer: How long have used POGIL? And in what grades have used it?

Teacher: It’s now about a year since I was trained. I use it in all my grades 10 and 11 classes.

Interviewer: okay, how did your learners respond to POGIL?

Teacher: My learners are very excited to use POGIL. They even ask me to use POGIL at sometimes. The reason is that they will talking to each other and sometimes they can talk about their personal things without the teacher stopping them. So POGIL makes them to be free and active. Even those learners who usually sleep in the class, during POGIL everyone is alert and participating actively.

Interviewer: All the learners participate actively during POGIL?

Teacher: Ooh let me say most learners participate actively. When they are doing a difficult topic, they are passive and need a lot of help there. If they don't get it the start doing other things. They can play or just talk other things. If the topic is too easy, they will be very quiet. Each learner will be working quietly on their own.

Interviewer: If the learners are working individually and quietly as you just said, will that be POGIL method?

Teacher: Oh, I see what you say. According to the definition of POGIL that won't be POGIL. The learners won't be following their POGIL roles. So yes, it won't be POGIL. So, easy topics don't work with POGIL.

Interviewer: Okay. Which of the grades accepted POGIL the most?

Teacher: Grade 10s like it more than grade 11.

Interviewer: Can you explain. What do you think the grade 10 accepted POGIL more?

Teacher: I think it is because of the age. Grade 10s are energetic and want to be all over the place. So, when they are learning using POGIL its their chance to be active and play as they solve the problem. They will freely talk as they so wish, and their ideas are quickly heard.

Interviewer: So, as a teacher what is your role during POGIL lessons?

Teacher: during POGIL I will be just making sure that learning is going on. I provide the worksheets and monitor the time. I observe that there is order, and answer some of the learners' questions.

Interviewer: During the POGIL lessons what were you doing? I just saw you walking up and down.

Teacher: Oh, it's not just walking up and down. I was checking learners' work. Checking how far they are. Checking if they have problems, and if they are working in groups, because they can leave one learner to do all the work. I was answering some questions from the groups. I told the spokesperson of one group to go and assist another group, or to go and get assistance from another group.

Interviewer: When you implemented POGIL how did the learners perform in that topic?

Teacher: My learners perform much better than when I use lecture method. If I have all the POGIL worksheets I think I will just use POGIL in the whole syllabus.

Interviewer: During the POGIL lessons what can you comment about the activities done by the learners? Were the activities giving the learners attention or were they too easy?

Teacher: The first activities were easy because they were about simple real-life experiences. But when they started stoichiometry the activities were more difficult. The learners however, followed through the worksheet and solved the problems quite well.

Interviewer: Initially, how was the performance of your learners in stoichiometry?

Teacher: My learners have always found limiting reactant very difficult to understand.

Interviewer: And how do you expect your learners to perform in stoichiometry after POGIL?

Teacher: They will definitely perform well in the second test because I saw how well they were doing in the lesson.

Interviewer: Do you think your learners if given a choice, would prefer POGIL teaching over other teaching approaches?

Teacher: My learners already asked me to tell their mathematics teacher to teach them using POGIL. My learners like POGIL so much that if a tell them that tomorrow we shall have a POGIL lesson no one will be absent. They enjoy POGIL lessons.

Interviewer: If POGIL is used in other subjects like mathematics do you think it is going to be beneficial for the learners?

Teacher: Exactly. My learners already asked for POGIL in mathematics. It means they are already motivated to learn using POGIL in other subjects. I don't know if there are worksheets for mathematics. But because mathematics is difficult for them, they will perform better when they use POGIL.

Interviewer: When using POGIL do you think the learners are easy to control than when using direct teaching method?

Teacher: Unfortunately, that's a challenge. They can disturb other classes because of their noise and excitement. Strict control is needed during POGIL than during lecture method. But its better because learners benefit more in POGIL than sleeping in the lecture method.

Interviewer: What about the time management?

Teacher: Initially I thought its time consuming. But I see that it's not time consuming at all. Because if I have done a topic once then its already done. I don't have to come back to it again. What my learners do with POGIL will be permanent. But what they do with lecture method I will repeat it like another three or four times but still they will not understand as they understand with POGIL.

Interviewer: So, you think you will continue using POGIL in your lessons?

Teacher: Exactly. I think POGIL is the way to go in all subjects. My principal came to visit my class and sat at some of the groups. She was very excited. She also understood science and this method is the best. So, for me now I don't have problem even if my learners are making noise. She knows they are doing POGIL.

Interviewer: Thank very much for your contributions. Keeping on working with POGIL.

Teacher: Thank you sir. Thank you for your support

Appendix 17: Learners' focus group interview school A

Interviewer: Okay good afternoon learners

Learners: Morning sir

Interviewer: Yes, how are you?

Learners: We are fine, thank you sir

Interviewer: I am fine. Yes, today I want to interview you about the POGIL lessons that we had last week. What is POGIL?

Learner 1: POGIL is a method of working in groups discussing classwork.

Learner 2: POGIL... is when we do the work in groups. When we read together and answer together.

Learner 3: The method we use to do difficult topics

Interviewer: Okay, how do you like POGIL?

Learner 3: Its very interesting. Its funny but we learn.

Learner 4: We are free to talk many things. We help each other.

Learner 5: No one hears your wrong answers…. yea, only the people in your group hear and not the whole class.

Interviewer: So, is it a good method that you work in groups during POGIL?

Learner 1: Yes, sir. In the groups we help each other without laughing at one another.

Learner 2: The method was good because we understand. We think of why this answer is correct because at the group they want you to say the reason. You must show the working.

Interviewer: Okay

LEARNER 3: That method it can help me to solve difficult questions without the help of the teacher. The method shows the steps to answer the questions.

INTERVIEWER: Okay, and you?

LEARNER 5: POGIL method makes science to be easy. Science used to be difficult but now we understand a lot. We can answer hard questions.

INTERVIEWER: Okay

LEARNER 3: POGIL method is easy because we start with easy activities which make us understand the real science better.

INTERVIEWER: Okay. Alright. Can you say why you say you understand science better? You said you understand better?

Learner1: Yes. Because in the past science was difficult to understand. Everyone, or let's say most people failed science and mathematics. But now we pass science better than some subjects. So, it's because POGIL because …, yea, that's when we started to pass. Because POGIL uses easy examples.

Learner 3: POGIL made me to be clever. In the past I used to guess especially multiple choice, aah. Now I think before I say the answer.

Learner 4: Yea, multiple choice I was just guessing. I never read the question most of the times. Yea, true. Even some long questions if I see many words, eish, I pick any formula I see and start substituting. But with POGIL I must ask myself why I pick that formula.

Interviewer: So POGIL make you increase your reasoning?

Learner 4: Yea, that is what I wanted to say. I can now reason. I am now thinking and clever.

INTERVIEWER: I think you spoke about that there are easy examples in POGIL activities. How do examples help you to understand science better?

LEARNER 2: The examples show me how science is related to the car parts and I can now give another example that science is related to the clothes that we wear.

Interviewer: To the clothes? How so? Can you explain please?

Learner 2: I am wearing two shoes, two socks, one pants, one shirt. So that is the same with science because two moles of hydrogen react with one mole of oxygen. It’s the same ratio.

Interviewer: Ooh I see what you mean. So how does that help you understand science?

Learner 3: When balancing the equations, you look at the ratio in the same way. You can’t put on three shoes at the same time, yea.

INTERVIEWER: Okay I think you already answered this question. How has the POGIL method made you to reason better? In what sense has it made you to reason better?

LEARNER 2: By using easy examples and many examples. Yea we answered this, sir.

INTERVIEWER: Did the POGII method help you to love science?

LEARNER 3: Yes, because it helps to look at the question in a clever way. I will see what I am given and what I must find. It helps me to see obvious things and use correct method. Because the other learners will ask you why you used that formula? So, you must explain.

INTERVIEWER: Do you think you shall perform better in the second test than in the first test? Remember you wrote 2 tests?

LEARNER 2: I shall do better in the second test. The first one, eish I didn’t do well. Now I know many things and I will do better.

Learner 4: The second test because I now understand and think about the answer because of POGIL.

Learner 1: I will do better in test two because I know that I wrote well. In test one I left many blanks because I didn't know. But now I know because we did the topic using POGIL.

INTERVIEWER: So, you mean the POGIL method helped you to understand?

LEARNER 2: Yes, I can now reason and know how to find the limiting reactant.

INTERVIEWER: would you like to be taught using POGIL in the other science topics.

LEARNER 4: I think I like to be taught using POGIL only. Because after POGIL lessons I understand all things. But if we don't use POGIL I don't understand when the teacher is teaching.

INTERVIEWER: Okay can you explain that.

LEARNER 4: If they teach me using POGIL I will know how to approach things because they have to have to teach me step-by-step like how POGIL explains. If they teach me step by step, I will be able to understand other topics

INTERVIEWER: Do you expect to do further studies in science because of the use of POGIL?

Learner 1: Yea I think I will be able to do engineering because by using POGIL I will pass

Learner 3: I will pass and do medicine. Because POGIL will give me high passes.

Learner 5: I will become a dentist. My marks will be high because of POGIL.

INTERVIEWER: What about using POGIL in other subjects? Do you think it will be a good idea?

LEARNER 1: I think it is good because POGIL. Mathematics has a lot of measurements and objects. If we use POGIL I think it will be the easiest.

Learner 4: I think if we use POGIL in mathematics our marks will go up. At the moment, the mathematics marks are the lowest. Many people pass all the other subjects. But mathematics…. Eish.

Interviewer: Okay boys and girls. Thank you for your time.

Appendix 18: Learners' focus group interview school B

INTERVIEWER: Okay good morning

Learners: Morning sir

INTERVIEWER: Yes, how are you?

Learners: Fine thanks, and, how are you?

INTERVIEWER: I am fine. Yes, today I want to interview you about the POGIL lessons that we had last time I came here. Eh, you have been taught using POGIL. What can you comment about the method? OK

LEARNER 1: The method was good.

INTERVIEWER: Okay

LEARNER 1: That method it can help me to approach things in a different way. The method was useful because it shows you how to solve a problem step-by-step, and we understand better when doing that.

INTERVIEWER: Okay, and you?

LEARNER 2: POGIL method I think it's the simplest method because you understand better. Because it has many examples so you will understand.2

INTERVIEWER: Okay

LEARNER 3: POGIL method was phenomenal because I did manage to analyse which method do the cars need.

INTERVIEWER: Okay. Alright. Can you say why you say you understand science better? You said you understand better?

L1: Yes. Because before that POGIL method I was not aware of how to approach things. But when using that method, (POGIL) I am aware of how to approach things and how to solve problems that leads me to understand science better, and also improves my reasoning capacity.

INTERVIEWER: Alright, anyone else?

INTERVIEWER: I think you spoke about that there are many examples in POGIL activities. How do examples help you to understand science better?

LEARNER 2: The examples give me a clue on how to approach that particular question.

INTERVIEWER: okay our next question is how has the POGIL method made you to reason better? In what sense has it made you to reason better?

LEARNER 2: Because the method and the examples are more easier.

INTERVIEWER: they are more easier, so they help you to reason. Did the POGIL method help you to love science?

LEARNER 3: Yes, because it helps to analyse about the things of nature and it helps in future when I want to build something like a vehicle I will be having some knowledge about building a vehicle.

INTERVIEWER: Okay. Because you know about the parts and how many of each is needed. Now how about in science when you are balancing equation of reaction do you see the relationship between building a car and building a chemical product?

LEARNER 1: Yes. You realize that there are also reactants and limiting reactants also. So it also applies in real life where you have to build a car. Because you may find that you have a certain number of engines. Let's say the number of engines it the reactant and the bodies of the car are the limiting reactant.

INTERVIEWER: Okay. So, you have understood about the cars. Where do you think you can now work comfortably? As a job after school. Where can you apply it?

LEARNER 1: As an aircraft engineer, mechanical engineer.

INTERVIEWER: even also in also in consumer studies like at KFC they should know how many drumsticks or other parts of chicken

INTERVIEWER: do you think you shall perform better in the second test than in the first test? Remember you wrote 2 tests?

LEARNER 2 We will perform better in the second test. Because in the first test we didn’t have knowledge but in the second test we did have knowledge about what is going to happen.

INTERVIEWER: So, you mean the POGIL method helped you to understand?

LEARNER 2: yes

INTERVIEWER: would you like to be taught using POGIL in the other science topics.

LEARNER 3: Yes

INTERVIEWER: Okay can you explain that.

LEARNER 3: If they teach me using POGIL next time I will know how to approach things because they have to have to teach me step-by-step like how POGIl explains. If they teach me step by step, I will be able to understand other topics

INTERVIEWER: Yah, than to just rush through?

LEARNER 3: yes

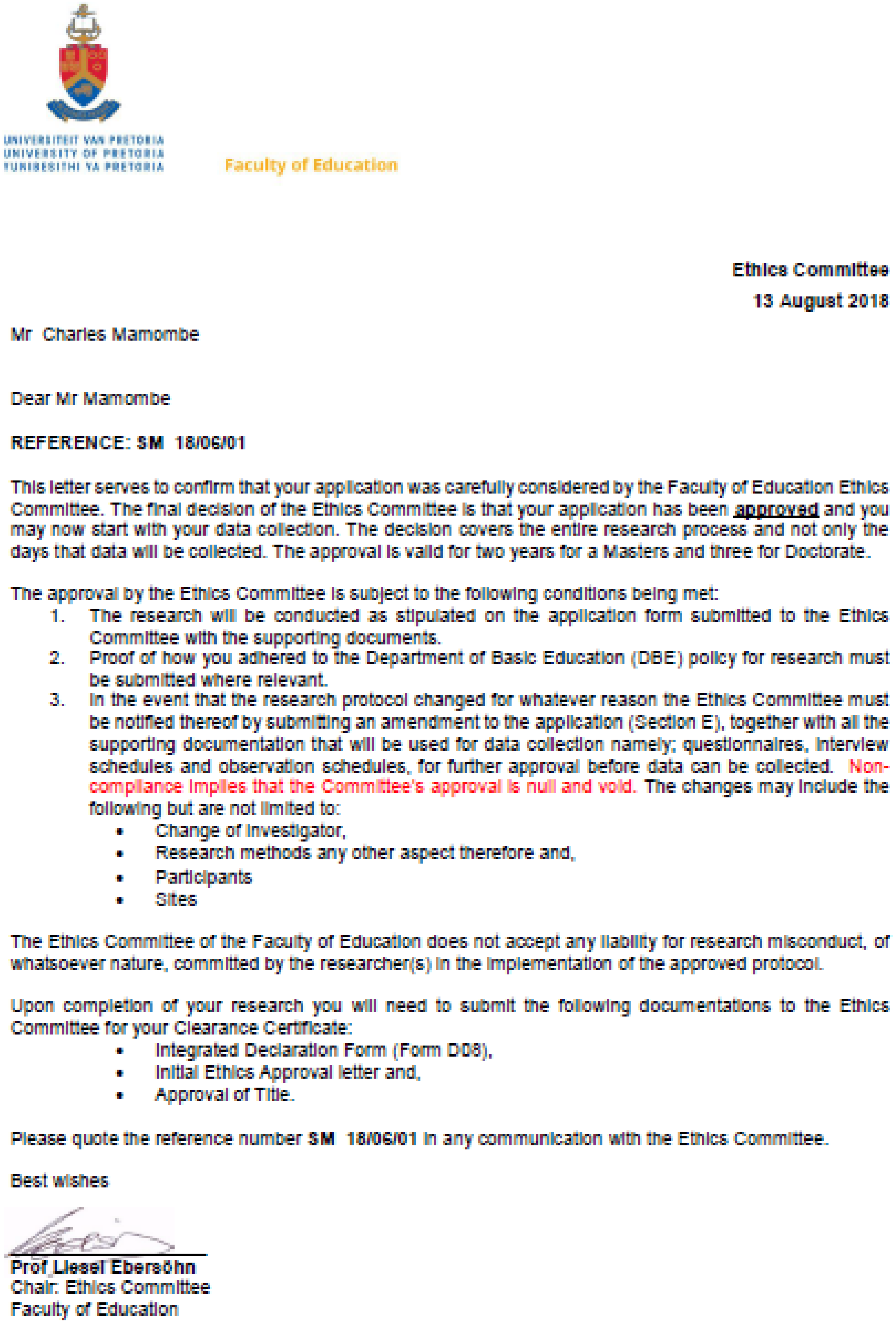
INTERVIEWER: do you expect to do further studies in science because of the use of POGIl?

INTERVIEWER: Yes, you already spoke about mechanical engineering

INTERVIEWER: what about using POGIL in other subjects? Do you think it will be a good idea?

LEARNER 1: I think it is good because POGIL. The things that we need in mathematics we need to measure some materials of a vehicle like for the car to be suitable and stable.

Appendix 19: Ethics approval letter for data collection



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YUNIBESITHI YA PRETORIA

Faculty of Education

Ethics Committee
13 August 2018

Mr Charles Mamombe

Dear Mr Mamombe

REFERENCE: SM 18/06/01

This letter serves to confirm that your application was carefully considered by the Faculty of Education Ethics Committee. The final decision of the Ethics Committee is that your application has been **approved** and you may now start with your data collection. The decision covers the entire research process and not only the days that data will be collected. The approval is valid for two years for a Masters and three for Doctorate.

The approval by the Ethics Committee is subject to the following conditions being met:

1. The research will be conducted as stipulated on the application form submitted to the Ethics Committee with the supporting documents.
2. Proof of how you adhered to the Department of Basic Education (DBE) policy for research must be submitted where relevant.
3. In the event that the research protocol changed for whatever reason the Ethics Committee must be notified thereof by submitting an amendment to the application (Section E), together with all the supporting documentation that will be used for data collection namely; questionnaires, interview schedules and observation schedules, for further approval before data can be collected. Non-compliance implies that the Committee's approval is null and void. The changes may include the following but are not limited to:
    - Change of investigator,
    - Research methods any other aspect therefore and,
    - Participants
    - Sites

The Ethics Committee of the Faculty of Education does not accept any liability for research misconduct, of whatsoever nature, committed by the researcher(s) in the implementation of the approved protocol.

Upon completion of your research you will need to submit the following documentations to the Ethics Committee for your Clearance Certificate:

- Integrated Declaration Form (Form D08),
- Initial Ethics Approval letter and,
- Approval of Title.

Please quote the reference number **SM 18/06/01** in any communication with the Ethics Committee.

Best wishes

Prof Liesel Ebersöhn
Chair: Ethics Committee
Faculty of Education

Appendix 20: GDE research approval letter for data collection

GAUTENG PROVINCE
Department: Education
REPUBLIC OF SOUTH AFRICA

8/4/4/1/2

GDE AMMENDED RESEARCH APPROVAL LETTER

Date:	25 April 2019
Validity of Research Approval:	04 February 2019 – 30 September 2019 2018/287AA
Name of Researcher:	Mamombe C
Address of Researcher:	302 Arniston, 2016 Ben Vilijoen Street
	Pretoria North
	Pretoria, 0182
Telephone Number:	074 299 6108
Email address:	mamoocm@gmail.com
Research Topic:	Exploring how Process- Oriented Guided Inquiry Learning elicit high school learners' reasoning about stoichiometry
Type of qualification	PhD (Science, Mathematics & Technology Education)
Number and type of schools:	Four Secondary Schools
District/s/HO	Tshwane North and Tshwane West

Re: Approval in Respect of Request to Conduct Research

This letter serves to indicate that approval is hereby granted to the above-mentioned researcher to proceed with research in respect of the study indicated above. The onus rests with the researcher to negotiate appropriate and relevant time schedules with the school/s and/or offices involved to conduct the research. A separate copy of this letter must be presented to both the School (both Principal and SGB) and the District/Head Office Senior Manager confirming that permission has been granted for the research to be conducted.

25/04/2019

The following conditions apply to GDE research. The researcher may proceed with the

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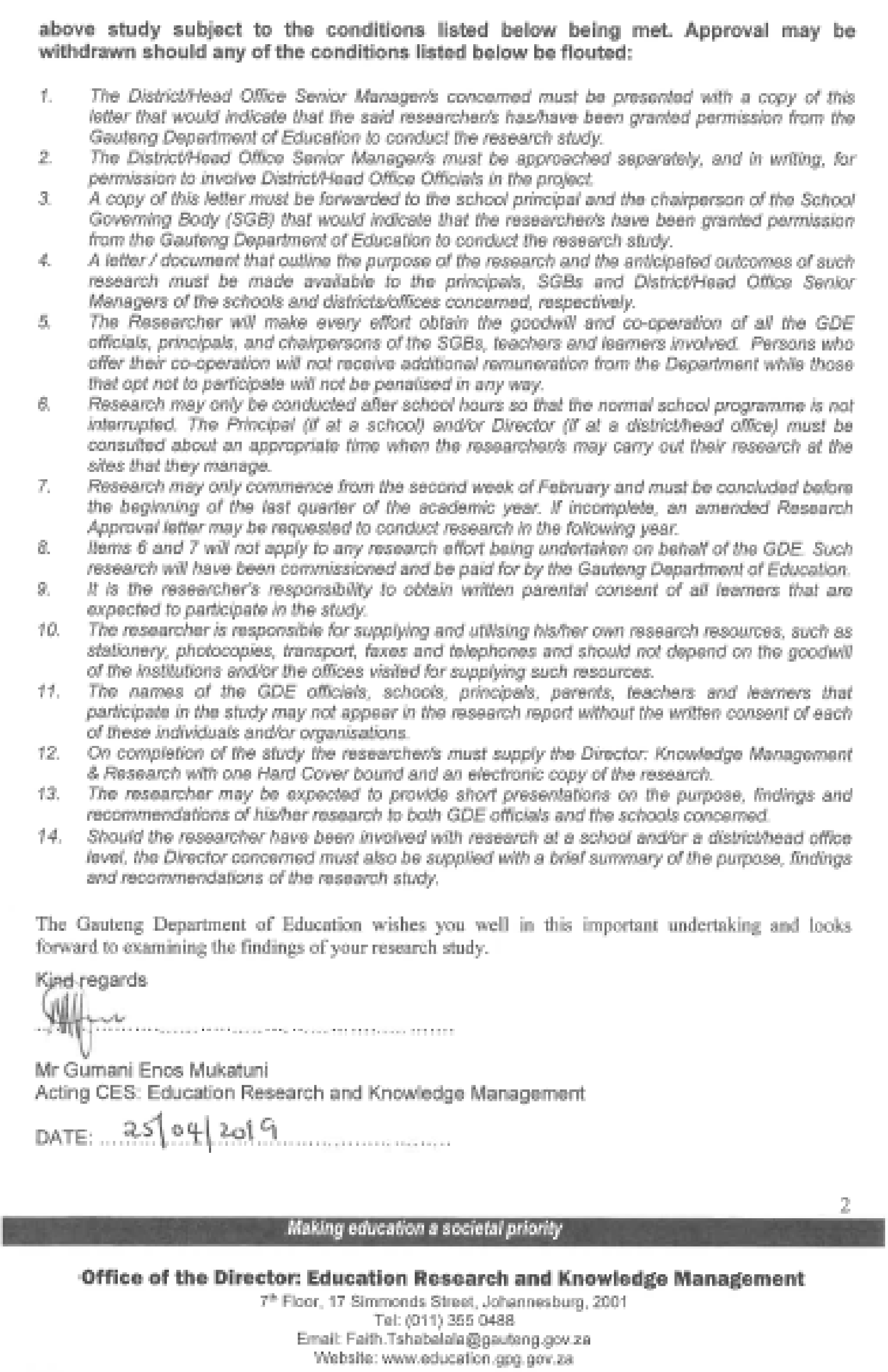
7th Floor, 17 Simmonds Street, Johannesburg, 2001
Tel: (011) 355 0488
Email: Faith.Tshabalala@gauteng.gov.za
Website: www.education.gpg.gov.za



above study subject to the conditions listed below being met. Approval may be withdrawn should any of the conditions listed below be flouted:

1. *The District/Head Office Senior Manager/s concerned must be presented with a copy of this letter that would indicate that the said researcher/s has/have been granted permission from the Gauteng Department of Education to conduct the research study.*
2. *The District/Head Office Senior Manager/s must be approached separately, and in writing, for permission to involve District/Head Office Officials in the project.*
3. *A copy of this letter must be forwarded to the school principal and the chairperson of the School Governing Body (SGB) that would indicate that the researcher/s have been granted permission from the Gauteng Department of Education to conduct the research study.*
4. *A letter / document that outline the purpose of the research and the anticipated outcomes of such research must be made available to the principals, SGBs and District/Head Office Senior Managers of the schools and districts/offices concerned, respectively.*
5. *The Researcher will make every effort obtain the goodwill and co-operation of all the GDE officials, principals, and chairpersons of the SGBs, teachers and learners involved. Persons who offer their co-operation will not receive additional remuneration from the Department while those that opt not to participate will not be penalised in any way.*
6. *Research may only be conducted after school hours so that the normal school programme is not interrupted. The Principal (if at a school) and/or Director (if at a district/head office) must be consulted about an appropriate time when the researcher/s may carry out their research at the sites that they manage.*
7. *Research may only commence from the second week of February and must be concluded before the beginning of the last quarter of the academic year. If incomplete, an amended Research Approval letter may be requested to conduct research in the following year.*
8. *Items 6 and 7 will not apply to any research effort being undertaken on behalf of the GDE. Such research will have been commissioned and be paid for by the Gauteng Department of Education.*
9. *It is the researcher's responsibility to obtain written parental consent of all learners that are expected to participate in the study.*
10. *The researcher is responsible for supplying and utilising his/her own research resources, such as stationery, photocopies, transport, faxes and telephones and should not depend on the goodwill of the institutions and/or the offices visited for supplying such resources.*
11. *The names of the GDE officials, schools, principals, parents, teachers and learners that participate in the study may not appear in the research report without the written consent of each of these individuals and/or organisations.*
12. *On completion of the study the researcher/s must supply the Director: Knowledge Management & Research with one Hard Cover bound and an electronic copy of the research.*
13. *The researcher may be expected to provide short presentations on the purpose, findings and recommendations of his/her research to both GDE officials and the schools concerned.*
14. *Should the researcher have been involved with research at a school and/or a district/head office level, the Director concerned must also be supplied with a brief summary of the purpose, findings and recommendations of the research study.*

The Gauteng Department of Education wishes you well in this important undertaking and looks forward to examining the findings of your research study.

Kind regards

....

Mr Gumani Enos Mukatuni
Acting CES: Education Research and Knowledge Management

DATE: ....25/04/2019..

2

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Office of the Director: Education Research and Knowledge Management
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Appendix 21: Lesson observation schedule

Activities of the teacher

1. Introduction of lesson
2. Guidance of learners
3. Control of class
4. Time management
5. Attention to groups in need of help.
6. Facilitation role
7. Subject knowledge

Learners' activities

3. Attention to the teacher.
4. Reading of worksheet
5. Working with the assigned group
6. Excitement
7. Participation
8. Asking for help